European Commission

Study on impacts of EU actions supporting the development of renewable energy technologies

PP-05441-2017

Onne Hoogland, Elske Veenstra, Liliana Guevara Opinska, Perla C. Torres Vega, Koen Rademaekers
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European Commission
Directorate-General for Research and Innovation
Directorate G - Energy
Unit G.3 – Renewable Energy Sources
Contact Irene Bonvissuto
E-mail *RTD-ENERGY-SR-IDRE@ec.europa.eu*
Irene.BONVISSUTO@ec.europa.eu
RTD-PUBLICATIONS@ec.europa.eu
European Commission
B-1049 Brussels

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ABSTRACT

This study assesses the impact that the EU Research & Innovation Framework Programmes funding has had on renewable energy technologies over the past twenty years (1995-2015). Eight renewable energy sectors are assessed: bioenergy, biofuels, geothermal, hydropower, ocean, solar PV, solar thermal and wind. The study consists of a quantitative assessment and a qualitative assessment based on interviews, case studies, a questionnaire and stakeholder workshops. The results show that the EU and its Member States play a leading role in R&D for most of the renewable energy technologies. EU funding has contributed to acquire a leading academic position that the EU holds for all renewable energy technologies. It has strongly supported pan-EU collaboration and continuity of research, which led to the introduction into the market of innovative solutions. Several technologies have already reached high levels of maturity, and renewable energy related jobs grew to 1 180 000 in 2016. EU industry turnover has constantly reached EUR 100 000 million over the past nine years, with growth in other sectors offsetting the decrease in solar PV industry turnover. The development of innovative renewable technologies has also contributed to a growing share of renewable energy consumption in the power, heating & cooling (H&C) and transport market sectors. However until today, technologies for power received significantly more R&D funding and progress in decarbonising the power sector has been faster than in the H&C and transport sectors.

RESUME

La présente étude évalue l'impact du financement des programmes-cadres de recherche et d'innovation de l'UE sur les technologies des énergies renouvelables au cours des vingt dernières années (1995-2015). Huit secteurs des énergies renouvelables sont évalués: la bioénergie, les biocarburants, la géothermie, l’hydroélectricité, l’énergie marine, le solaire photovoltaïque, le solaire thermique et l’éolien. L'étude se compose d’une évaluation quantitative et d’une évaluation qualitative fondée sur des entrevues, des études de cas, un questionnaire et des ateliers avec les parties prenantes. Les résultats montrent que l'UE et ses États membres jouent un rôle de premier plan en matière de R&D pour la plupart des technologies liées aux énergies renouvelables. Grâce au financement qu’elle a accordé, l'UE est à la pointe de la recherche universitaire pour toutes les technologies d'énergie renouvelable. Ce financement a fortement soutenu la coopération paneuropéenne et la continuité de la recherche, ce qui a conduit à la mise sur le marché de solutions innovantes. Plusieurs technologies ont déjà atteint un haut niveau de maturité et les énergies renouvelables représentaient 1.180.000 emplois en 2016. Le chiffre d'affaires du secteur au sein de l’UE a constamment atteint la barre des 100 milliards d'euros au cours des neuf dernières années, la baisse du chiffre d'affaires de l'industrie photovoltaïque solaire ayant été compensée par la croissance des autres énergies renouvelables. Le développement de technologies renouvelables innovantes a également contribué à l’augmentation de la part de la consommation d'énergies renouvelables dans les secteurs de l'électricité, du chauffage et du refroidissement ainsi que des transports. Mais jusqu'ici, les technologies de production d’électricité ont reçu beaucoup plus de financement en R&D et les progrès dans la décarbonisation du secteur de l'électricité ont été plus rapides que ceux des secteurs des transports ou du chauffage et du refroidissement.

EXECUTIVE SUMMARY

The main objective of the EU research and innovation policy is to support the development of low-carbon technologies and make them economically viable, with the aim to accelerate their uptake in the market. Research, innovation and competitiveness are a fundamental dimension of the Energy Union, as they can drive the decarbonisation of the energy system and at the same time supports the overall goal to ensure that Europe has secure, affordable and climate-friendly energy.

This study assesses the impact that the EU R&D funding support to renewable energy technologies has had over the past twenty years. It looks at the impacts on the development of the technological sectors themselves, the related market and industrial developments, and economic growth generated. Eight renewable energy sectors are assessed: bioenergy, biofuels, geothermal, hydropower, ocean, solar PV, solar thermal and wind energy. The study consists of a quantitative assessment on a selection of indicators, as well as a qualitative assessment, based on a series of interviews, case studies, a questionnaire and stakeholder workshops.

EU and Member State R&D funding

The EU and its Member States play a leading role in research and innovation of several renewable energy technologies. The EU and its Member States provided over 50 % of the R&D funding for bioenergy, solar thermal, ocean and wind energy in OECD countries, and over 20 % for the other technologies.

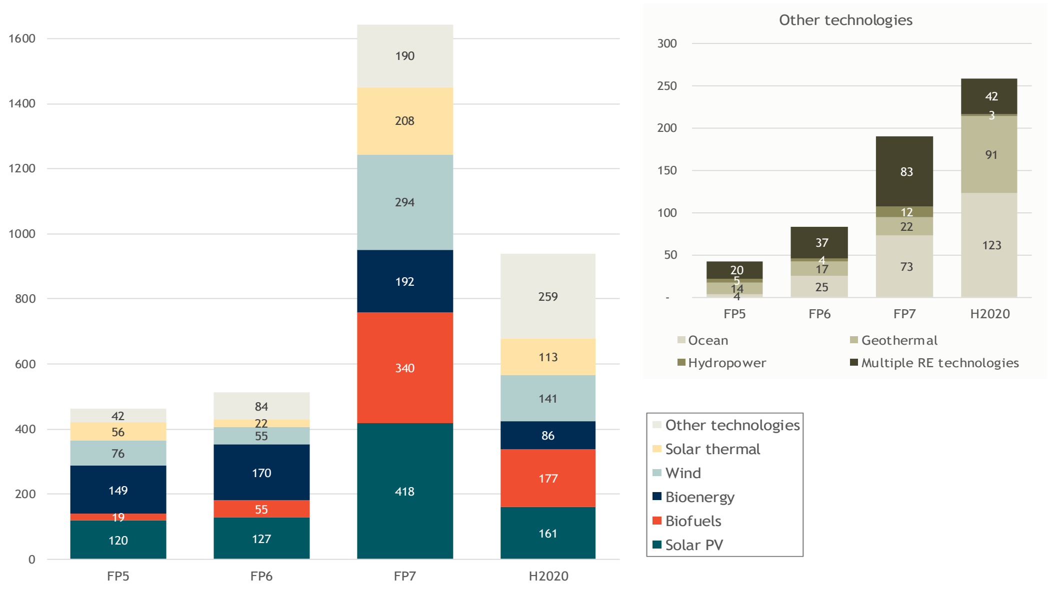

Figure 0-1 EU R&D funding for renewable energy technologies per FP (in EUR 2016 million)

The EU has provided considerable support for renewable energy technologies over the past 20 years. Through its Framework Programmes (FP5 – H2020), the EU spent EUR 3.6 billion on renewable energy technologies. Most funding (70 %) went to solar PV, bioenergy, biofuels and wind energy. While the EU budgets are significant, the national R&D budgets of EU Member States are three times as high: EUR 11.6 billion from 1995-2015. The impacts should therefore be viewed within this context. The distribution of Member State funding per technology is roughly similar to that of the EU FPs.

Impacts on the renewable energy technologies

In terms of publications, the EU holds a leading position for all renewable energy technologies, with more publications by EU authors than by authors from any other country. There is a strong correlation between the amount of R&D funding made available by the EU and its Member States and the number of publications from the EU. The combined efforts from the EU and its Member States have been effective in establishing a leading academic position. The EU share of global publications is particularly high for ocean energy (51 %), bioenergy (43 %) and wind energy (38 %).

Patenting activity does not show a strong correlation with public R&D funding. Patenting activity in the EU is declining, which is not favourable for EU leadership. This is due to reasons that are not linked to the amount of R&D funding. Furthermore, there are considerable limitations in the use of patents filed as an indicator for R&D success: the value of patents differs strongly for instance, the minimum requirements for filing patents differ significantly across the world, and their enforcing is country specific, which makes a global comparison difficult.

EU R&D funding has strongly supported pan-EU collaboration. Stakeholders in all eight sectors clearly recognise the added value of EU R&D funding for stimulating collaboration with organisations from other countries within the EU. Large projects that coordinate research activities and foster collaboration across the EU have been funded in virtually all sectors and have delivered clear benefits for the organisations involved, such as improved alignment of research topics, increased collaboration and knowledge exchange.

Several technologies have reached higher levels of maturity thanks to support through the EU Framework Programmes. Technologies such as solar CSP and fixed-bottom offshore wind benefited greatly from EU support to accelerate their development and market entry. Similar efforts have been made to accelerate the development of technologies such as tidal and wave energy, enhanced geothermal systems, advanced biofuels and floating offshore wind, but more time is needed to assess the full effects. The stakeholders in all of these sectors assign significant importance to the role of EU funding for bringing these technologies closer to the market. Continuity of research topics has allowed for high impact projects, with numerous examples of successful projects that benefit from the results of previous EU-funded projects.

The cost reductions are most pronounced for solar PV, wind energy and solar CSP. Each has experienced cost reductions over 20 % in the past 10 years, with particularly high cost reductions for solar PV (70 %). There are examples of EU-funded projects that contributed to cost reductions in each technology sector, but the overall impact of EU funding differs strongly and it is not realistic to expect steep cost reductions for all renewable energy technologies. For geothermal and hydropower, the most favourable sites had already been exploited before 1995, leading to less favourable circumstances and higher costs for new capacities installed between 1995 and 2015. Production of biofuels and bioenergy is highly dependent on feedstock costs, thus cost reductions by technological innovation have a smaller effect on the total production costs than for the other technologies. Diversity of technologies in the solar heating sector makes it hard to identify clear trends in production costs. Finally, ocean plants have not yet reached commercial scale, therefore it is too early to see cost reduction trends.

The biggest contributions in terms of energy generation come from hydropower, bioenergy and wind energy, followed by biofuels and solar PV. There is no clear correlation between public R&D funding and energy generation as R&D can either aim at developing new technologies, which take a long time to reach commercial scale, or at improving existing technologies that are already applied at scale. In the latter case, regulation and market incentives can also play a strong role in the growth of energy sectors, but they can also create barriers to market introduction of new technologies.

The five technologies that received the most R&D funding exhibited the strongest growth in energy generation over the past 5 years. In the 2011-2016 period, all renewable energy technologies experienced growth in energy generation. The largest growth was for solar CSP (185 %), solar PV (132 %) and wind energy (68 %). Solar CSP saw a quick rise followed by stagnation, and the future of the sector in the EU is unclear as there are insufficient market incentives from the Member States at the moment. Market incentives also played a big supportive role for the growth of wind and solar PV. Energy generation by biofuels and bioenergy grew by a third. The sectors receive a substantial amount of R&D funding, and regulation created a market for first generation technologies. However, the ability to push new bioenergy and biofuels technologies to the market is severely hindered by the lack of a supportive regulatory framework. The lack of a sufficiently supportive regulatory framework has a negative impact on the prospects for R&D to deliver innovations that reach the market.

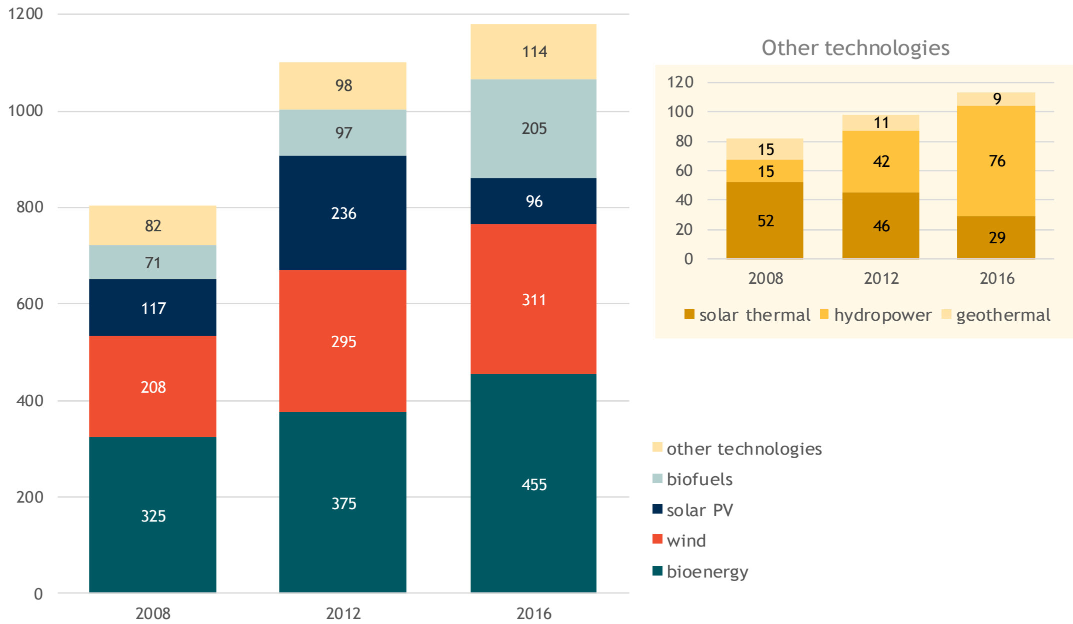

Figure 0-2 Number of jobs per technology sector (in thousands)

Jobs in the eight renewable energy sectors grew from 803 000 to 1 180 000 over the past 9 years.

The development of a leading industry has been most successful for bioenergy, wind energy and biofuels. These sectors now provide over 200 000 jobs to the EU economy each. Solar PV also has a significant number of jobs, but this number is declining due to the shrinking PV manufacturing industry in the EU.

The EU renewable energy industry has remained at a constant level of turnover of around EUR 120 000 million over the past 9 years, with the decrease in solar PV industry turnover offsetting the growth in other sectors. For technologies such as wind energy and bioenergy, the EU has been successful in establishing a leading and growing industry. For solar PV, the European industry did not maintain a leading industrial role and has seen a strong decline in industry turnover and jobs since 2011 due to a declining local market and a lack of competitiveness versus Chinese manufacturers who were leading in terms of economies of scale. The EU industries for solar thermal and geothermal are smaller but are competitive in the global context as illustrated by the trade surplus of these industries. For ocean energy there is no significant industry yet due to the lack of commercial capacities but based on the strong knowledge position and leading demonstration projects, the EU industry looks set to take a leading role in the market.

Impacts on the market sectors

Between FP5 and H2020, the majority of the EU R&D funding went to renewable energy technologies that produce electricity. In FP5 and FP6, heating & cooling (H&C) technologies received the second most funding. In FP7 and H2020 this attention shifted to technologies that produce transport fuels. The difference between funding for power production compared to the other two market sectors is significant.

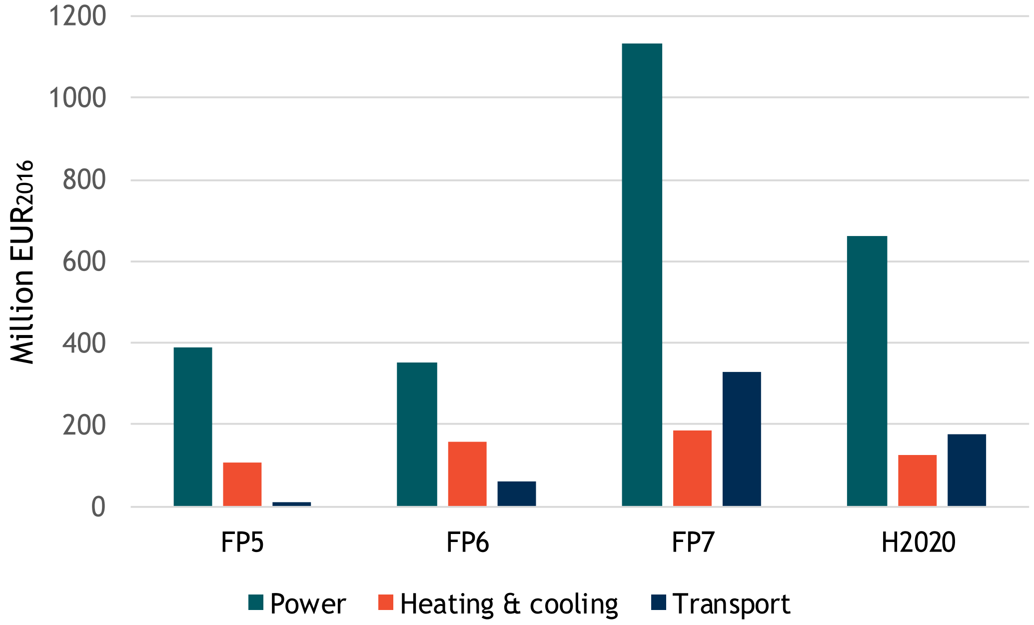

Figure 0-3 EU R&D funding per market sector

Source: Own elaboration based on CORDIS (2018) data
Note: The numbers for power and H&C are an aggregate of funding for each of the sectors plus the funding of projects in the 'Electricity, Heating & cooling' group. Funding for projects with no-end use is not shown thus the sum of the three columns does not correspond to the total amount of R&D funding per FP.

The eight renewable energy technologies have contributed to a growing share of renewable energy consumption in the power, heating & cooling (H&C) and transport market sectors. The power sector has the largest share of renewable energy consumption out of the three market sectors, reaching nearly 30 % in 2016. It also had the strongest growth; on average by 1.3 % per year from 2004 to 2016. Hydropower accounts for the largest amount of this share (37 % in 2016), followed by wind (32 %), bioenergy (18 %) and solar PV (11 %). The H&C sector reached 19 % renewable energy in 2016. It had an annual growth of 0.7 % per year. Bioenergy represents the largest amount of this share. The transport sector has the lowest penetration of renewables in the final energy consumption. The renewable energy share reached 7.1 % in 2016, with an annual growth of 0.5 % between 2004 and 2016.

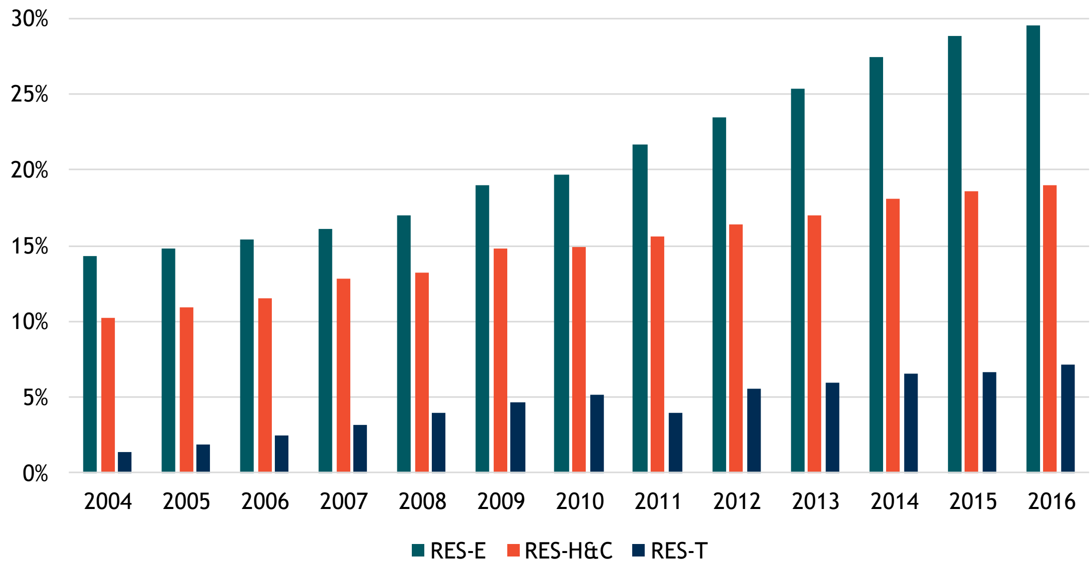

Figure 0-4 Shares of energy consumption from RES in the EU per market sector

Source: Eurostat (2018)

The link between the long-term plans and roadmaps to decarbonise the EU energy sector and the levels of funding for the different renewable energy technologies is not always clear. Less than 15 % of the EU R&D budget has been allocated to projects with relevance for the H&C sector, while H&C is responsible for approximately 50 % of EU energy consumption. Additionally, progress in decarbonising the H&C sector has been slow compared to the electricity sector. Renewables in the transport sector also show modest growth and will face challenges in bringing more sustainable options to the market. The link between the long-term plans and roadmaps to decarbonise the EU energy sector and the levels of funding for the different renewable energy technologies is not fully evident.

SYNTHESE

La politique de recherche et d'innovation de l'UE a pour principal objectif de soutenir le développement de technologies à faible intensité de carbone et de les rendre économiquement viables, en vue d'accélérer leur mise sur le marché. La recherche, l'innovation et la compétitivité constituent une dimension fondamentale de l'Union de l'énergie, car elles peuvent stimuler la décarbonisation du système énergétique tout en soutenant l'objectif global qui est de garantir que l'Europe dispose d'une énergie sûre, abordable et respectueuse du climat.

La présente étude évalue l'impact du soutien financier de l'UE à la R&D dans le domaine des technologies des énergies renouvelables au cours des vingt dernières années. Elle examine son impact sur le développement des secteurs technologiques proprement dits, sur l'évolution du marché et de l'industrie qui y sont liés et sur la croissance économique générée. Huit secteurs des énergies renouvelables sont évalués: la bioénergie, les biocarburants, la géothermie, l'hydroélectricité, l'énergie marine, le solaire photovoltaïque, le solaire thermique et l'éolien. L'étude se compose d'une évaluation quantitative basée sur une sélection d'indicateurs ainsi que d'une évaluation qualitative fondée sur des entrevues, des études de cas, un questionnaire et des ateliers avec les parties prenantes.

Financement R&D par l'Union européenne et les États membres

L'Union européenne et ses États membres jouent un rôle de premier plan dans le domaine de la recherche et de l'innovation pour plusieurs technologies liées aux énergies renouvelables. L'UE et ses États membres ont fourni plus de 50 % du financement de la R&D pour la bioénergie, le solaire thermique, l'énergie marine et l'éolien dans les pays de l'OCDE, et plus de 20 % pour les autres technologies.

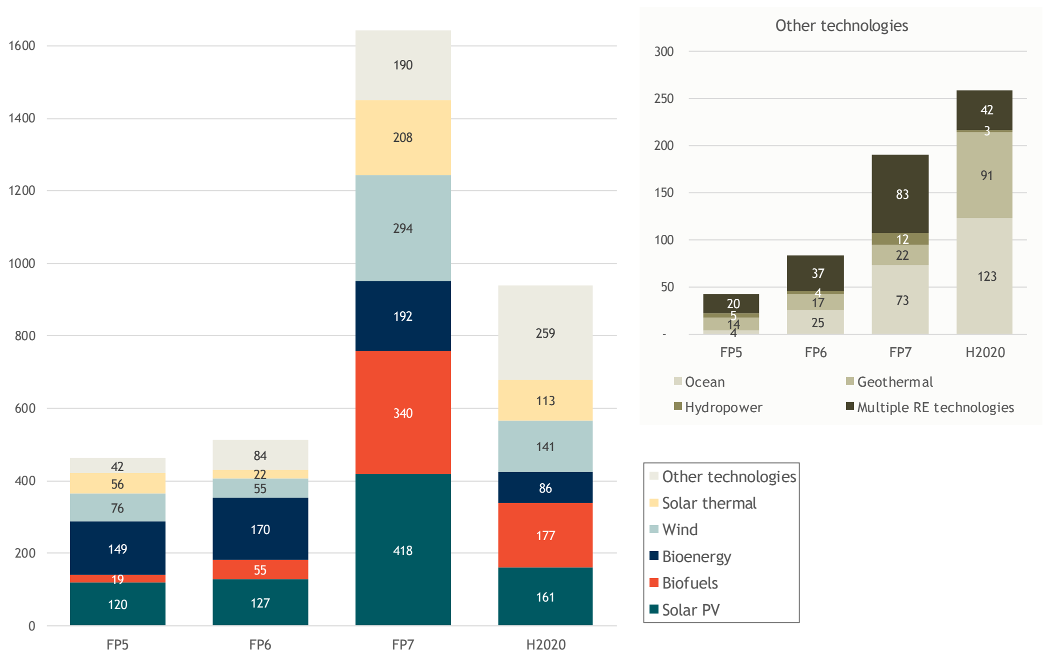

Tableau 0-1 Financement UE de la R&D dans le domaine des technologies des énergies renouvelables par PC (en millions d'euros 2016)

L'UE a apporté un soutien considérable aux technologies des énergies renouvelables ces 20 dernières années. Au travers de ses programmes-cadres (5e PC - H2020), l'UE a consacré 3,6 milliards d'euros aux technologies des énergies renouvelables. L'essentiel du financement (70 %) a été consacré à l'énergie solaire photovoltaïque, à la bioénergie, aux biocarburants et à l'énergie éolienne. Bien que les budgets de l'UE soient importants, les budgets R&D des États membres de l'UE sont encore trois fois plus élevés: 11,6 milliards d'euros de 1995 à 2015. C'est dans ce contexte que l'impact sur les différentes énergies renouvelables doit donc être envisagé. La répartition du financement des États membres entre les différentes technologies est à peu près similaire à celle des PC de l'UE.

Impacts sur les technologies des énergies renouvelables

En matière de publications, l'UE arrive en tête de classement pour toutes les technologies des énergies renouvelables, les auteurs de publications de l'UE se montrant plus prolifiques que ceux des autres pays. Il existe une forte corrélation entre le montant des fonds affectés à la R&D par l'UE et ses États membres et le nombre de publications européennes. Les efforts combinés de l'UE et de ses États membres leur ont permis d'atteindre une position de leader dans le monde universitaire. La part de l'UE dans les publications mondiales est particulièrement élevée pour l'énergie marine (51 %), la bioénergie (43 %) et l'énergie éolienne (38 %).

Le nombre de brevets déposés ne présente pas de corrélation étroite avec le financement public de la R&D. Le nombre de brevets déposés au sein de l'UE est en baisse, ce qui n'est pas favorable au leadership de l'UE. Les raisons de ce déclin sont sans rapport avec le montant du financement de la R&D. En outre, l'utilisation des brevets déposés comme indicateur du succès de la R&D présente des limites considérables: la valeur des brevets, par exemple, diffère considérablement d'un pays à l'autre, les exigences minimales pour le dépôt de brevets sont très variables dans les différentes parties du monde et leur application est spécifique à chaque pays, ce qui rend difficile d'établir une comparaison à l'échelle mondiale.

Le financement de la R&D par l'UE a fortement soutenu la collaboration paneuropéenne. Les parties prenantes des huit secteurs reconnaissent pleinement la valeur ajoutée du financement européen de la R&D en ce qu'il stimule la collaboration entre organisations de différents pays de l'UE. Des grands projets visant à coordonner les activités de recherche et à encourager la collaboration au sein de l'UE ont été financés dans presque tous les secteurs et ont clairement apporté des avantages aux organisations concernées, tels qu'une meilleure harmonisation des sujets de recherche, une collaboration accrue et un échange de connaissances.

Plusieurs technologies ont atteint des niveaux de maturité plus élevés grâce au soutien apporté par les programmes-cadres de l'UE. Des technologies telles que le solaire thermodynamique à concentration (CSP) et l'éolien offshore ancré ont largement bénéficié du soutien de l'UE, ce qui a permis d'accélérer leur développement et leur mise sur le marché. Des efforts similaires ont été déployés pour accélérer le développement de technologies telles que l'énergie marémotrice et houlomotrice, les systèmes géothermiques améliorés, les biocarburants avancés et les éoliennes offshore flottantes, mais il faudra plus de temps pour en évaluer pleinement les effets. Les parties prenantes de tous ces secteurs s'accordent à reconnaître le rôle essentiel du financement de l'UE pour rapprocher ces technologies du marché. La continuité des thèmes de recherche a permis la réalisation de projets à fort impact, avec de nombreux exemples de projets réussis qui bénéficient des résultats de projets antérieurs financés par l'UE.

Les réductions de coûts les plus prononcées sont enregistrées dans l'énergie solaire photovoltaïque, l'énergie éolienne et l'énergie solaire thermodynamique à concentration. Les coûts de production de chacune de ces énergies ont baissé de plus de 20 % au cours des 10 dernières années, avec des réductions de coûts particulièrement élevées pour le photovoltaïque (70 %). Il existe des exemples de projets financés par l'UE qui ont contribué à réduire les coûts dans chaque secteur technologique, mais l'impact du financement européen est très variable au niveau global et il n'est pas réaliste de s'attendre à des réductions importantes des coûts pour toutes les technologies des énergies renouvelables. Pour la géothermie et l'hydroélectricité, les sites les plus favorables avaient déjà été exploités avant 1995, de sorte que les nouvelles capacités installées entre 1995 et 2015 l'ont été dans des conditions moins favorables et avec des coûts plus élevés. La production de biocarburants et de bioénergie dépend fortement des coûts des matières premières, de sorte que les réductions de coûts dues à l'innovation technologique ont un effet moindre sur les coûts de production totaux que pour les autres technologies. La diversité des technologies dans le secteur du chauffage solaire rend difficile de discerner des tendances claires dans les coûts de production. Enfin, la production d'énergie marine n'ayant pas encore atteint l'échelle commerciale, il est trop tôt pour voir apparaître des tendances à la réduction des coûts.

Les principaux contributeurs en termes de production énergétique sont l'hydroélectricité, la bioénergie et l'énergie éolienne, suivies par les biocarburants et le photovoltaïque solaire. Il n'y a pas de corrélation claire entre le financement public de la R&D et la production d'énergie, car la R&D peut viser soit à mettre au point des technologies nouvelles, qui mettent beaucoup de temps à atteindre le stade de la commercialisation, soit à améliorer des technologies existantes qui sont déjà appliquées à grande échelle. Dans ce dernier cas, la réglementation et les incitants du marché peuvent également jouer un rôle important dans la croissance des secteurs énergétiques, mais ils peuvent aussi créer des obstacles à l'introduction de nouvelles technologies sur le marché.

Les cinq technologies qui ont reçu le plus de financement en R&D ont affiché la plus forte croissance en matière de production d'énergie ces 5 dernières années. Au cours de la période 2011-2016, toutes les technologies d'énergie renouvelable ont enregistré une croissance de leur production d'énergie. La plus forte croissance a été enregistrée par l'énergie solaire thermodynamique à concentration (185 %), le solaire photovoltaïque (132 %) et l'éolien (68 %). La production d'énergie solaire thermodynamique par concentration a connu une augmentation rapide suivie d'une stagnation, et l'avenir du secteur au sein de l'UE est incertain parce que les incitants sur le marché des États membres sont actuellement insuffisants. Les incitations du marché ont aussi fortement soutenu la croissance de l'éolien et du photovoltaïque solaire. La production d'énergie par les biocarburants et la bioénergie a augmenté d'un tiers. Les secteurs reçoivent un montant substantiel de financement pour la R&D et la réglementation a créé un marché pour les technologies de première génération. Mais l'absence d'un cadre réglementaire soutenant les nouvelles technologies de bioénergie et de biocarburants freine fortement leur commercialisation. L'absence d'un cadre réglementaire suffisamment incitatif a un impact négatif sur les perspectives de mise sur le marché des innovations issues de la R&D.

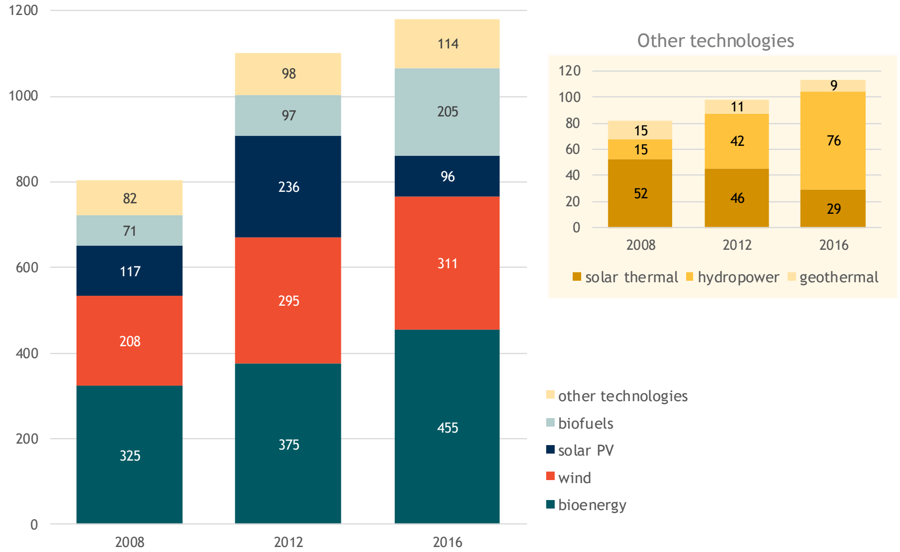

Tableau 0-2 Nombre d'emplois par secteur technologique (en milliers)

Le nombre d'emplois dans les huit secteurs des énergies renouvelables est passé de 803.000 à 1.180.000 au cours des neuf années écoulées.Le développement d'une industrie de pointe a été très fructueux pour la bioénergie, l'éolien et les biocarburants. Ces secteurs représentent aujourd'hui chacun plus de 200.000 emplois dans l'économie européenne. Le photovoltaïque solaire fournit également un nombre élevé d'emplois, mais ce nombre est en baisse en raison de la contraction de la fabrication de panneaux photovoltaïques au sein de l'UE.

Le chiffre d’affaires du secteur européen de l'énergie renouvelable est resté à un niveau constant d'environ 120 milliards d'euros au cours des neuf années écoulées, la baisse du chiffre d'affaires du secteur photovoltaïque solaire ayant été compensée par la croissance des autres secteurs. Pour des technologies comme l'éolien et la bioénergie, l'UE a réussi à se doter d’une industrie de pointe en pleine croissance. En ce qui concerne le photovoltaïque, l'industrie européenne n'a pas su conserver sa position dans le peloton de tête et a connu une forte baisse du chiffre d'affaires et des emplois depuis 2011 en raison d'un marché local en déclin et d'un manque de compétitivité par rapport aux fabricants chinois qui avaient plusieurs longueurs d’avance en matière d'économies d'échelle. Les industries européennes du solaire thermique et de la géothermie sont plus petites, mais elles sont compétitives dans le contexte mondial, comme le montre l'excédent commercial de ces industries. En ce qui concerne l'énergie marine, il n'existe pas encore d'industrie significative en raison du manque de capacités commerciales, mais, compte tenu de sa forte position en matière de connaissances et de ses projets de démonstration de pointe, l'industrie européenne semble prête à jouer un rôle de premier plan sur le marché.

Impacts sur les secteurs du marché

Entre le 5e PC et le H2020, la majeure partie du financement de la R&D de l'UE est allée aux technologies des énergies renouvelables qui produisent de l'électricité. Sous les 5e et 6e PC, les technologies de chauffage et de refroidissement ont obtenu la deuxième plus grande part de financement. Dans le 7e PC et le H2020, l’attention s'est portée sur les technologies qui produisent des carburants pour le transport. La différence entre le financement de la production d'électricité et celui des deux autres secteurs du marché est importante.

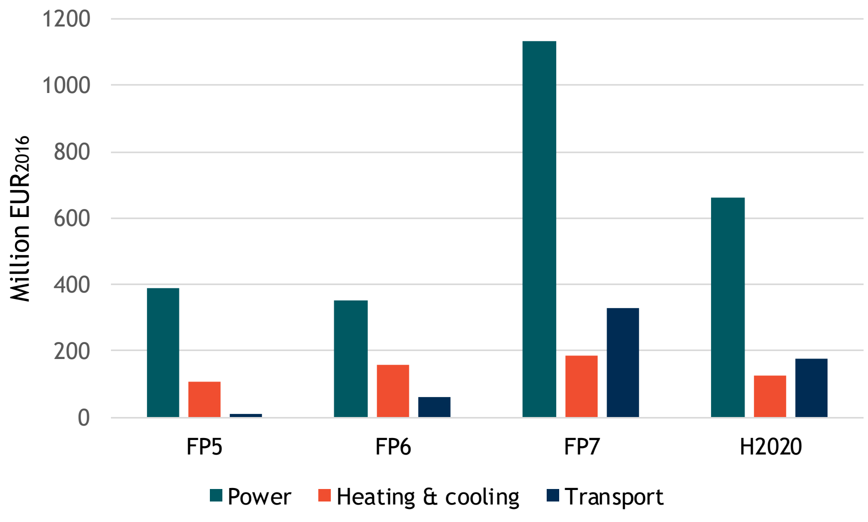

Tableau 0-3 Financement européen de la R&D par secteur du marché

Source: Analyse personnelle basée sur les données de CORDIS (2018)
Remarque: Les chiffres pour l'électricité ainsi que le chauffage et le refroidissement sont un agrégat du financement de chacun des secteurs auquel vient s’ajouter le financement des projets dans le groupe «Électricité, chauffage et refroidissement». Le financement des projets sans utilisation finale n'est pas repris, de sorte que la somme des trois colonnes ne correspond pas au montant total du financement de la R&D par PC.

Les huit technologies renouvelables ont également contribué à l’augmentation de la part de la consommation d'énergies renouvelables dans les secteurs de l'électricité, du chauffage et du refroidissement ainsi que des transports. Avec pas loin de 30 % en 2016, le secteur de l'électricité représente la plus grande quote-part de la consommation d'énergie renouvelable des trois secteurs du marché. Il a également connu la plus forte croissance, à savoir une moyenne de 1,3 % par an entre 2004 et 2016. L'hydroélectricité se taille la part du lion (37 % en 2016), suivie de l'éolien (32 %), de la bioénergie (18 %) et du photovoltaïque (11 %). Le secteur du chauffage et refroidissement a atteint 19 % d'énergie renouvelable en 2016. Il a connu une croissance de 0,7 % par an. La bioénergie représente la plus grande partie de cette quote-part. C'est dans le secteur des transports que la part des énergies renouvelables dans la consommation finale d'énergie est la plus faible. La part des énergies renouvelables a atteint 7,1 % en 2016, avec une croissance annuelle de 0,5 % entre 2004 et 2016.

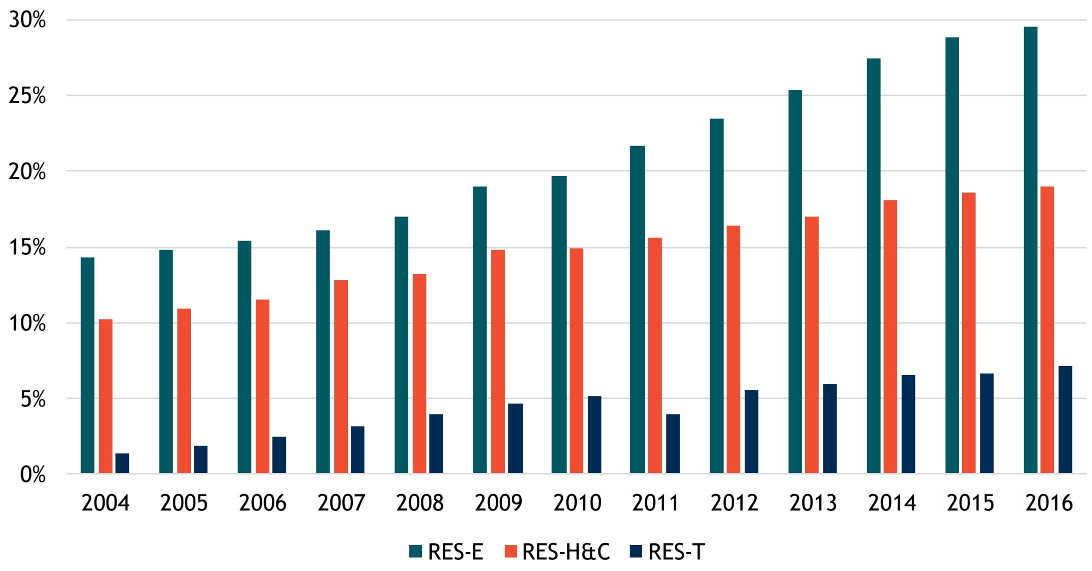

Tableau 0-4 Répartition de la consommation d'énergie provenant des SER dans l'UE par secteur du marché

Source: Eurostat (2018)

Le lien entre les plans à long terme et les feuilles de route pour la décarbonisation du secteur énergétique de l'UE et les niveaux de financement des différentes technologies des énergies renouvelables n'est pas toujours évident. Moins de 15 % du budget de R&D de l'UE a été alloué à des projets présentant un intérêt pour le secteur du chauffage et refroidissement, alors que ce dernier représente environ 50 % de la consommation énergétique de l'UE. De plus, les progrès dans la décarbonisation du secteur du chauffage et refroidissement ont été lents par rapport à ceux du secteur de l'électricité. Les énergies renouvelables dans le secteur des transports connaissent également une croissance modeste et devront relever des défis pour mettre sur le marché des options plus durables. Le lien entre les plans à long terme et les feuilles de route pour la décarbonisation du secteur énergétique de l'UE et les niveaux de financement des différentes technologies des énergies renouvelables n'est pas toujours d'une évidence manifeste.

1 Introduction

This report is the final report for the study *Impacts of EU actions supporting the development of renewable energy technologies,* prepared for the European Commission, DG RTD. The objective of this study was to assess the impact that EU support to research, development and innovation in the area of renewable energy technologies had had over the past 20 years, focusing on market-related aspects rather than technological advancements.

The scope of this study included eight renewable energy technologies: bioenergy, biofuels, geothermal, hydropower, ocean, solar PV, solar thermal and wind energy. Additionally, an assessment from the perspective of the three market sectors was included: power generation, heating & cooling (H&C) and transport.

The deliverables of this study included:

- a literature review to find empirical evidence on the impacts of R&D support, identify existing models and assumptions for assessing the impacts of R&D funding, and identify indicators for measuring the impacts of R&D funding;
- a methodology for assessing the impacts of EU R&D funding on the developments in the eight renewable energy sectors;
- eight technology sector reports, describing the impacts of EU R&D funding based on the above-mentioned methodology;
- eight conferences for disseminating the findings per technology sector and collecting feedback to improve the technology sector reports;
- eight leaflets for disseminating the findings for each technology sector to a wider audience;
- a report describing the impacts of EU R&D funding on the three market sectors (power, H&C and transport);
- three leaflets for disseminating the findings for each market sector to a wider audience;
- a database covering all datasets and analyses used for the reports.

In this final report, the following is provided:

- Chapter 2 contains a summary of the methodology that has been developed and applied in this study, outlining the selection of indicators, the main data sources and the qualitative assessment methods applied;
- Chapter 3 presents the key findings on impacts of EU R&D funding across the eight renewable energy technologies. First, it provides a high-level, quantitative overview on the key figures and trends across all eight technologies. Secondly, it provides an in-depth assessment on the impacts of EU R&D funding for each sector individually;
- Chapter 4 summarises the assessment on the impacts of EU R&D funding for each market sector, namely power, H&C and transport;
- Chapter 5 provides conclusions and recommendations based on the analyses performed as well as the inputs collected during the dissemination conferences.

More detailed information is available in the technology sector reports (annexed to this report), market sector report and methodology document.

2 Methodology

To properly address the scope and objectives of this study, it was necessary to develop a tailor-made methodology. Previous studies had applied methodologies to evaluate either the results of individual Framework Programmes in detail or to analyse the impacts of R&D funding on specific indicators such as patents and publications. As this study needed to provide a more holistic view on the developments of the renewable energy sectors while also pinpointing specific contributions of the EU Framework Programmes, a tailor-made methodology was required.

The methodology that we developed for this study is based on the findings of an extensive literature review and consists of a quantitative assessment and a qualitative assessment. The quantitative assessment is used to provide a view on the main trends and developments in the sector to which the R&D funding has contributed in conjunction with other factors. The qualitative assessment is used to pinpoint specific contributions of the projects funded through the EU FPs to the development of the sectors.

The literature review and the methodology are documented in a separate report.[1] In this section a brief summary of the methodology is presented.

2.1 Quantitative assessment

2.1.1 Selection of indicators

The first part of the methodology entails a quantitative assessment on a selection of indicators to analyse the R&D funding available to each sector and its impacts on the development of the sector (see Figure 2-1)

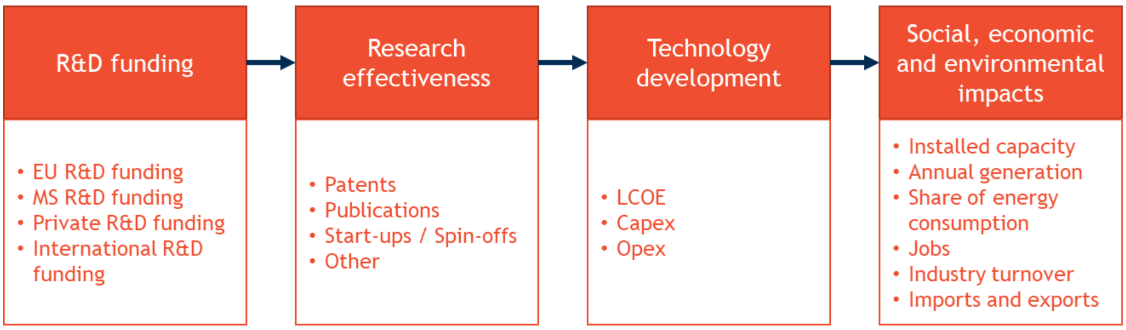

Figure 2-1 Selection of indicators for quantitative assessment of the impacts of EU R&D funding

The first set of indicators concern the amount of R&D funding made available by the EU, Member States, private parties and non-EU countries (international funding). EU R&D funding comprises all funding made available through the Framework Programmes for Research and Technological Development (FPs) over the past 20 years (FP5 up to the first half of Horizon 2020) and is the primary input variable for the assessment. R&D funding made available by EU Member States, private parties and non-EU countries is analysed to provide context to the EU funding volumes in terms of the size of funding and the corresponding scale of impacts that could be expected.

The second set of indicators concerns patents, publications, start-ups/spin-offs and other direct outputs of R&D projects. These indicators measure the most direct outputs of R&D funding and thereby provide the most direct measure of the effectiveness of the R&D that has been funded.

The third set of indicators concerns the development of the technology in terms of its cost competitiveness and includes capital expenditure (capex), operational expenditure (opex)

[1] Trinomics (2018) – Study on impacts of EU actions supporting the development of renewable energy technologies – Literature review and methodology

and levelised cost of energy (LCOE) as indicators. For these impacts several other factors such as market incentives and industry policy play a significant role, which makes it harder to establish a direct link between the R&D funding and its effect on cost reductions. Hence, the analysis of impacts in this part of the methodology builds more on qualitative inputs whereas the quantitative assessment is used to provide an understanding of the trends in the sector to which the R&D funding has contributed.

The fourth set of indicators covers the social, economic and environmental impacts. It includes three indicators related to the deployment of the technology (installed capacity, annual generation, share of energy consumption) and three indicators related to the development of the EU industry (jobs, industry turnover, imports/exports). For this category of impacts, the link between R&D funding and the trends on the indicators is even more indirect than for the technology development.

2.1.2 Data sources

The data used in this study is based on a mix of publicly available databases, a questionnaire among coordinators of EU funded projects and data from the literature.

To analyse the amount of EU R&D funding per RE technology data was collected from the European Commission's Community Research and Development Information Service (CORDIS). Excel data containing information on all projects under FP5-H2020 was downloaded directly from the EU Open Data Portal. The data downloaded is not classified in a way which would enable the direct selection of projects related to R&D in the area of RE technologies. To identify all projects in scope of this study a number of steps were taken. Projects were considered in scope if they related to research in one of the eight RE technologies per the definitions for each sector agreed at the start of this study. An initial pre-selection of projects was undertaken by performing a keyword search which targeted the titles of the projects as well as information describing the projects' objectives. All projects containing at least one of the keywords were considered as initial 'hits'. To determine whether or not the projects were in scope of the study a careful analysis of the projects' description was undertaken by the project team's technology experts. All projects in scope were classified under one of the eight renewable energy (RE) technologies or under the category 'multiple RE technologies' in case the project covered a combination of renewable energy technologies. Furthermore, projects were classified into technology sub-categories and into market sectors based on expert assessment.

Data on Member State and international public R&D funding was obtained from the International Energy Agency (IEA) R&D database. Data on private R&D investments was obtained from Bloomberg New Energy Finance's Global Trends in Renewable Energy Investments reports. Data on patents was collected from the IRENA INSPIRE database. A bibliometric analysis using keywords was undertaken via Web of Science to collect data related to publications. Information from a questionnaire sent out to project coordinators of FP projects was used to complement the information on patents and publications. In addition, the questionnaire was used to obtain data on spin-offs/start-ups resulting from FP projects as well as other relevant project outputs such as knowledge sharing, technological advances and improved market access.

Most data on capex and opex were collected from the following two sources: the National Renewable Energy Laboratory (NREL) and IRENA Cost Database. Further estimates were added based on a literature review. LCOE numbers were taken directly from these sources or calculated based on previously collected data on capex and opex. Data on installed capacity and annual generation was collected from Eurostat. The share of energy consumption for each of the three market sectors were calculated following the methodology described in the Eurostat's SHARES (Short assessment of Renewable Energy Sources) Tool Manual and using data from Eurostat.

Data on industry turnover and jobs was collected from EurObserv'ER reports (2008-2016). Import and export data was collected from Eurostat's Comext database. To isolate import and export data related to RE technologies a methodology was developed to establish which of the Harmonized System 6 (HS6) goods are used in the manufacture of these technologies, and how much of the trade in these goods can be attributed to them.

Time series were constructed for all indicators analysed. The length of these time series was based on data availability. Detailed information on indicators' definitions, data gaps, assumptions and exceptions are explained in detail in the Literature review and methodology report and repeated in the technology sector reports where relevant.

2.2 Qualitative assessment

The second part of the methodology consists of a qualitative assessment to identify the main impacts of EU R&D funding for the eight renewable energy technologies. For each technology, a series of ten interviews, three in-depth case studies and approximately ten high-level case studies (referred to as 'project spotlights' in the reports) have been delivered. Additionally, qualitative inputs were gathered through the questionnaire among project coordinators described in the previous section and through a literature review.

Based on the quantitative assessment and the qualitative inputs a storyline on the main impacts of EU R&D funding has been elaborated and documented in a separate report for each technology. These reports have been shared and discussed with the participants of the dissemination conferences that were organised as part of this study. Based on these discussions, the findings have been refined and finalised.

3 Technology sector assessment

The impacts of EU R&D funding on the development of renewable energy technologies have been assessed for eight main renewable energy technologies: bioenergy, biofuels, geothermal, hydropower, ocean, solar thermal, solar PV, and wind energy. In this chapter, we first provide a high-level overview on the key figures and trends for all technologies and a detailed overview of the impacts of EU R&D funding for each sector individually.

3.1 Key figures and trends

3.1.1 Table 3-1 Summary table

Table 3-1 provides a high-level summary on the quantitative assessment for the eight renewable energy technologies. The most remarkable figures are highlighted in the table and have been discussed in the previous section.

Table at the end of this section provides an overview of the key figures and trends for all eight renewable energy technologies in scope of this study. They cover the inputs (R&D funding) and the main categories of impacts: knowledge development, cost reduction, energy generation and industry development. For each, the main findings are summarised below.

3.1.2 R&D funding

Solar PV, bioenergy, biofuels and wind energy have been the main recipients of EU R&D funding through the Framework Programmes (FPs), each receiving more than 15 % of the budget (see Figure 3-1). Together, these technologies account for more than 70 % of the EUR 3.6 billion of R&D funding made available over the past 20 years. Solar thermal received slightly over 10 % of the funding, while ocean and geothermal received around 5 %. Hydropower received the least funding at 1 % of the overall budget. Furthermore, 5 % of the EU funding went to projects that cover a combination of these renewable energy technologies.

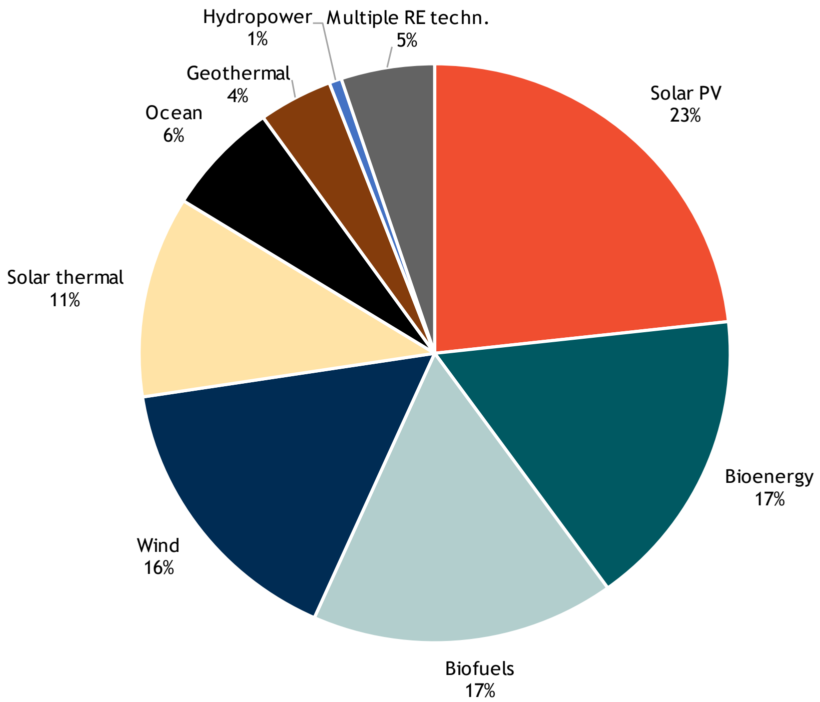

Figure 3-1 Share of EU R&D funding per technology (FP5 – mid-H2020)

Source: Own elaboration based on data from Cordis (2018)

The national funding made provided by EU Member States is more than 3 times the size of the funding through the EU FPs (EUR 11.6 billion from 1995 to 2015). The distribution of Member State funding per technology is roughly similar to that of the EU FPs (see Figure 3-2).

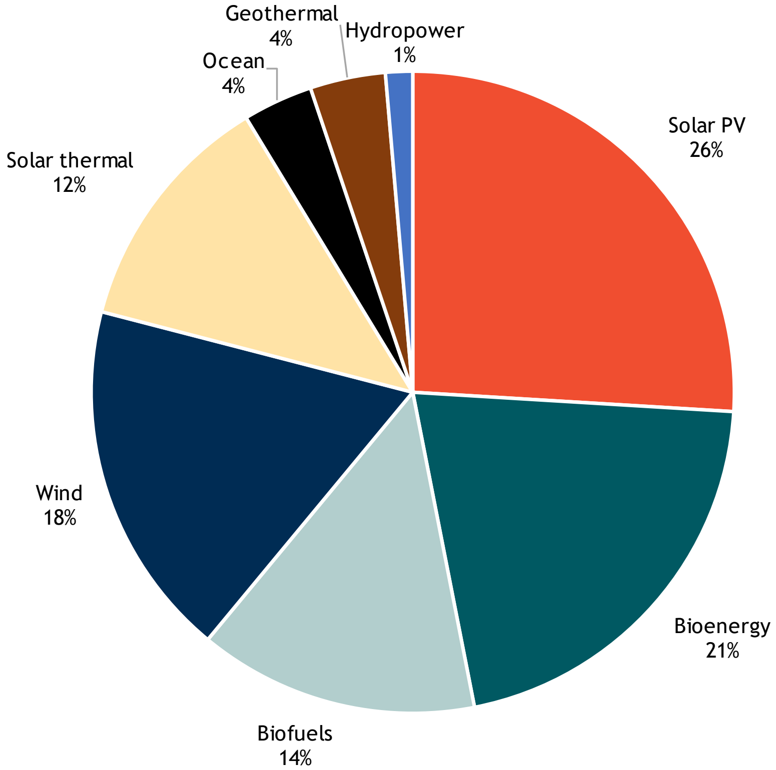

Figure 3-2 Share of Member State R&D funding per technology (1995-2015)

Source: Own elaboration based on data from OECD/IEA (2018)

In comparison to the funds made available by other OECD countries such as the US, Japan and Korea, the funding available in the EU (EU FPs + Member State budgets) is relatively high for bioenergy, solar thermal, ocean and wind energy (see Table 3-1). For each of these technologies EU funding is over 50 % of total OECD funding, indicating that the EU budgets for these technologies are large within the international context. For solar PV EU funding is 39 % of OECD funding and for biofuels, geothermal and hydropower the share is below 30 %. Important to note is that R&D budgets in China, which is one of the largest funders for some technologies, are not included in this analysis due to the lack of reliable data.

3.1.3 Knowledge development

In terms of publications, the EU holds a leading position for all renewable energy technologies (see Figure 3-2, with more publications by EU authors than by authors from any other country.[2] Moreover, our analyses for each technology show that there is a strong correlation between the amount of R&D funding made available by the EU and its Member States and the number of publications from the EU. Together, this leads us to conclude that the combined efforts from the EU and its Member States have been effective in establishing a leading academic position. The EU share of global publications is particularly high for ocean energy (51 %), bioenergy (43 %) and wind energy (38 %). These are all technologies for which the research budgets in the EU are relatively large compared to other OECD countries (see Table 3-1).

[2] See technology sector reports for details

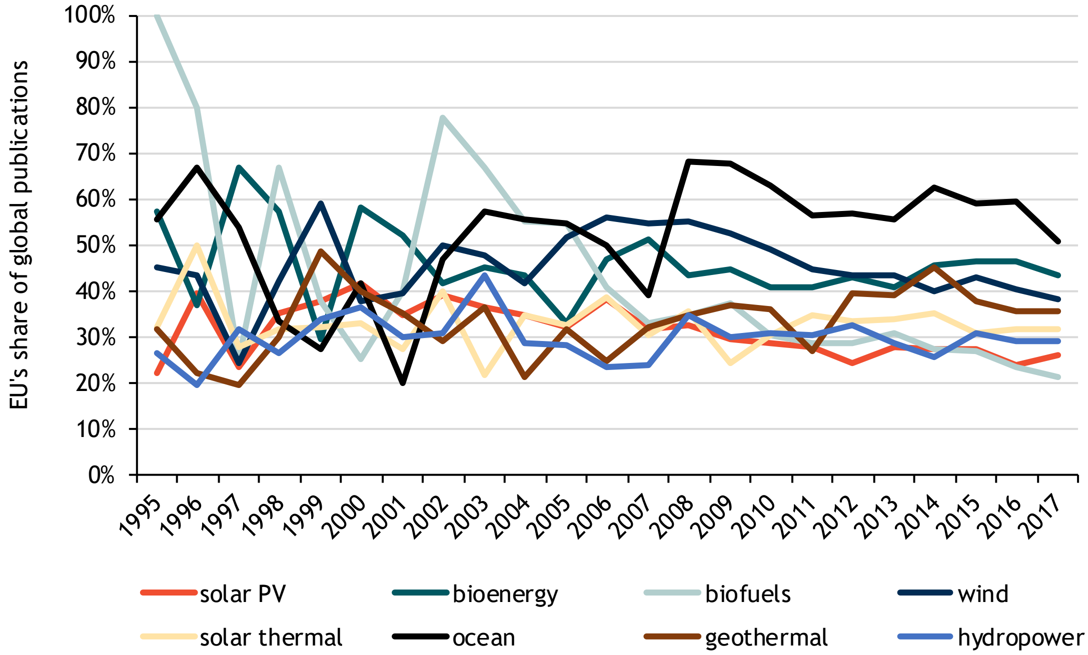

Figure 3-3 Evolution of EU's share of global publications per technology

The EU share of global patents has been declining for all technologies, from levels around 30 % in the early 2000s to levels around 10 % in 2014 (see Figure 3-4). This is due to increased patenting activity from other regions and in recent years also due to decreased patenting by EU organisations. The reasons for this are diverse and include a decreased tendency to patent by EU companies, less need for patenting as EU companies and their technologies matured and in some cases industrial decline (in particular for solar PV).

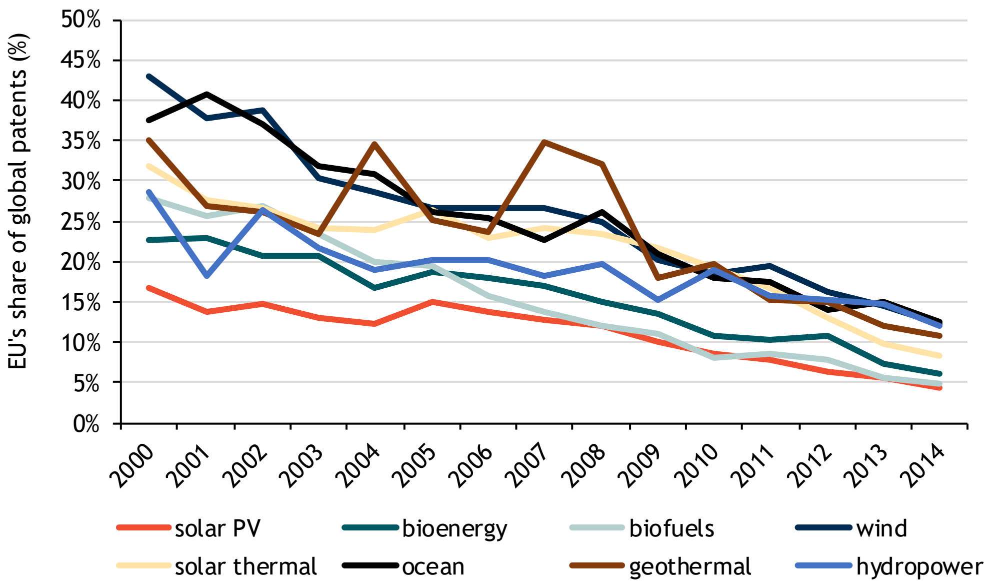

Figure 3-4 Evolution of EU's share of global patents filed per technology

Source: Own elaboration based on data from IRENA INSPIRE (2017)

It should be noted that patenting activity does not show a strong correlation with public R&D funding.[3] So while patents are a commonly used indicator to measure the impacts of R&D, we conclude that their relevance for measuring the effectiveness of public R&D funding for renewable energy technologies is limited. In addition to the reasons for the decline of patenting activity mentioned above, other factors that limit the relevance of this indicator are that the value of patents differs strongly and that the minimum requirements for filing patents differ significantly across the world.[4]

3.1.4 Cost reduction

The cost reductions are most pronounced for solar PV, wind energy and solar CSP. Each has experienced cost reductions over 20 % in the past 10 years with particularly high cost reductions for solar PV (70 %). For the other technologies there are less clear cost reductions due to a variety of factors. For geothermal and hydropower one of the primary reasons is that the most favourable sites have been exploited the first, leading to less favourable circumstances and higher costs for new capacities that are installed. For biofuels and bioenergy an important reason is the high share of biomass feedstocks in the costs of the energy delivered. These costs are not as susceptible to a steep learning curve as the conversion technologies and therefore limit the potential for cost reductions. For solar heating the diversity of technologies makes it hard to identify clear trends, whereas for ocean energy the lack of commercial scale applications results in a lack of reliable data to analyse the cost trends.

3.1.5 Energy generation

The biggest contributions in terms of energy generation come from hydropower, bioenergy and wind energy, followed at a distance by biofuels and solar PV. The contribution to EU energy consumption of the other technologies is still relatively minor. There is no clear correlation between public R&D funding and energy generation, which is not necessarily surprising as R&D may either aim to improve existing technologies that are already applied at scale, or to develop new technologies to allow these to be applied at scale in the future.

In the 2011-2016 period, all renewable energy technologies experienced growth in energy generation. The largest growth was for CSP (185 %), solar PV (132 %) and wind energy (68 %). However, it should be noted that for CSP this growth was from a very small base and that there has been hardly any growth in the past 2 years. There is a better correlation between public R&D funding and energy generation growth. The top five technologies in terms of funding also exhibited the strongest growth in energy generation over the past 5 years. However, large variations exist, with growth in solar PV and wind being two to four times that of bioenergy and biofuels, while attracting similar R&D budgets.

3.1.6 Industry development

The development of a leading industry has been most successful for bioenergy, wind energy and biofuels. Each industry has significant turnover, provides over 200 000 jobs to the EU economy and has a significant trade surplus (see Table 3-1). Other significant EU industries exist for solar PV (>95 000 jobs) and hydropower (>75 000 jobs). However, solar PV is the only industry with a persistent trade deficit, which is due to the decline of the EU PV manufacturing industry. The EU industries for solar thermal and geothermal are smaller but are competitive in the global context as illustrated by the trade surplus of these industries. For ocean energy there is no significant industry yet due to the lack of commercial capacities but based on the strong knowledge position and leading demonstration projects, the EU industry looks set to take a leading role once a market would emerge.

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[3] See technology sector reports for details
[4] Based on expert inputs gathered at the dissemination conferences for this study

The development of the EU renewable energy industries over time is illustrated in Figure 3-5. It shows that the EU industries in wind, bioenergy, biofuels and (small) hydropower[5] have grown over time, while the solar PV industry turnover decreased substantially. Overall the EU renewable energy industry remained at a similar size over the past 8 years, around EUR 120 000 million.

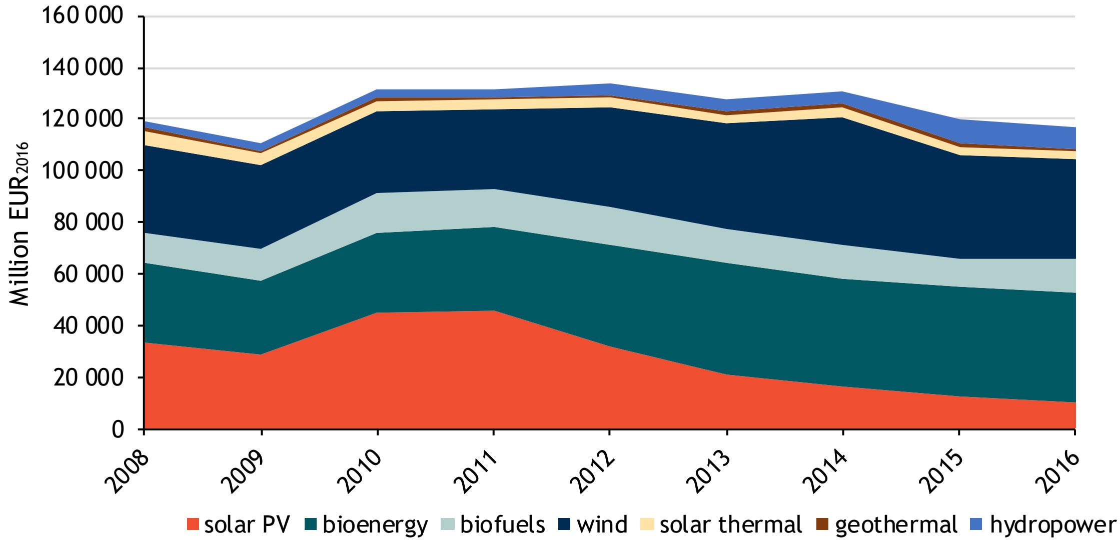


Figure 3-5 Turnover of EU renewable energy industries

Source: Own elaboration based on EurObserv'ER reports 2010-2017

[5] EU industry turnover estimates for hydropower exclude the large hydropower sector.

3.1.7 Summary table

Table 3-1 provides a high-level summary on the quantitative assessment for the eight renewable energy technologies. The most remarkable figures are highlighted in the table and have been discussed in the previous section.

Table 3-1 Key figures and trends for all renewable energy technologies

	R&D funding			Knowledge generation		Cost reduction	Energy generation		Industry development		
Technology	EU (FP5-H2020) (M EUR2016)	MS (1995-2015) (M EUR2016)	Share of OECD funding	Share of publications (2017)	Share of patents (2014)	Cost trend (LCOE - last 10 years)	Annual generation (GWh - 2016)	Growth ('11 - '16)	Industry turnover (M EUR, 2016)	Jobs (FTE, 2016)	Trade surplus (M EUR, 2015)
Solar PV	826	3 020	39 %	26 %	4 %	>70 % reduction	105 220	132 %	10 549	95 900	-6 454
Bioenergy	597	2 439	58 %	43 %	6 %	Stable / Mixed	337 718	37 %	42 285	454 500	4 024
Biofuels	591	1 638	27 %	21 %	5 %	Stable / Mixed	166 788	33 %	12 889	205 100	4 957
Wind	566	2 099	53 %	38 %	12 %	>20 % reduction	302 894	68 %	38 588	311 100	5 378
Solar thermal - CSP	400	1 430	54 %	32 %	8 %	>30 % reduction	5 579	185 %	3 323	29 000	N/A
Solar thermal - H&C						Stable / Mixed	24 660	30 %			523
Ocean	225	409	52 %	51 %	13 %	Not clear	501	5 %	N/A	N/A	N/A
Geothermal	144	441	24 %	36 %	11 %	Stable / Mixed	15 552	23 %	875	8 600	293
Hydropower	24	158	21 %	29 %	12 %	Stable / Mixed	350 121	12 %	8 475	75 900	601
Multiple RE technologies	182										
Total	3 554	11 633							116 983	1 180 100	9 322

Sources: EU R&D funding – Cordis (2018), MS R&D funding - OECD/IEA (2018), Share of OECD funding – Own elaboration based on CORDIS (2018) and OECD/IEA (2018), Share of publications – Web of Science (2018), Patents – IRENA INSPIRE (2017), Cost trend – IRENA, NREL and various other sources, Annual generation and growth – Eurostat (2018), Industry turnover and Jobs - EurObserv'ER, Trade surplus – Own elaboration based on Comext (2018) data.

Note on share of OECD funding: Total OECD funding covers Japan, Korea, Norway, US, Canada, Switzerland and Turkey and EU countries. Data for Chile, Iceland, Israel, Mexico and New Zealand is not available in the IEA/OECD database.

Notes: See technology sector reports for further details on assumptions and data limitations.

3.2 Impacts of EU funding

In addition to the high-level overview of the funding and developments in the eight sectors, an in-depth assessment on the impacts of the EU Framework Programmes has been performed to identify the main impacts of the R&D funding made available through the EU Framework Programmes. The next sections summarise the findings each of the eight sectors. A more elaborate description is available in the technology sector reports delivered as part of this study.

3.2.1 Bioenergy

At the start of FP5 in 1998, bioenergy was already one of the largest renewable energy sectors, providing the second most renewable electricity (after hydropower) and the most renewable heat. EU R&D budgets reflected this importance with over 30 % of budgets allocated to the sector in FP5 and FP6. During the past 20 years, the EU bioenergy sector has exhibited steady growth in terms of installed capacities and energy generated and remains one of the major sources of renewable energy for the EU. However, bioenergy's share of the total EU R&D budgets has decreased due to increasing debate around the sustainability of biomass sources and promising developments in other RE technologies.

The bioenergy sector includes a large variety of technologies which were at different stages of maturity at the start of FP5. EU-funded R&D enabled efficiency improvements, cost reductions and emission reductions for existing technologies and demonstration of novel technologies, contributing to a better and broader portfolio of bioenergy technologies available for the EU industry. Through EU funded projects, biomass-based fuels utilization in power and heat production was promoted, efficiency of co-firing improved and competitiveness of biomass-based fuels in power production increased (for example in projects BIOMAX and DEBCO). The existing installed capacities, commercial technologies and components such as boilers and burners were developed in terms of emissions reduction, performance and efficiency and new technical solutions were developed (for instance in the UltraLowDust project). Technologies such as gasification and pyrolysis started with the help of EU funding and moved to demonstration projects which contributed further to Europe's renewable energy portfolio (for example through projects such as UNIfHY and AERGAS). Europe's leading manufacturers of bioenergy production technologies such as Windhager and Valmet benefitted from these technological advances which allowed them to bring new products to the market.

Other key contributions of EU-funded R&D include the development of standards, which provided the basis for next generation energy carriers (e.g. in SECTOR and MOBILE FLIP) and increasing the sustainable utilisation of biomass for bioenergy. More efficient utilisation of biomass became possible through several projects (such as S2BIOM, CEUBIOM, BEE) gathering information on the availability and potential of biomass. The funding enabled to decrease fossil energy inputs and raw material losses by fuel supply chain development, for example in the INFRES project. Furthermore, EU funding contributed to bioenergy utilisation as a storage for intermittent energy production and combined production of heat, power and transportation fuels for example in project FLEXCHX.

Overall, the EU maintains a strong academic position with leading R&D budgets and EU authors contributing to more than 40 % of all publications worldwide. The EU Framework Programmes made a clear contribution to the EU's academic leadership by funding projects that delivered many publications and stimulating collaboration and knowledge sharing across the EU. The costs of bioenergy technology have remained relatively stable since the early 2000s but are at a level that is competitive with fossil fuel-generated electricity. The EU industry has established a strong position globally, with 40 % of global jobs and a large trade surplus. The only outlier is the EU share of global patents, which has been in continuous decline over the past 20 years. But as jobs and industry turnover are still growing, the EU bioenergy industry can be considered a global leader, which has been partly enabled by the support through the EU Framework Programmes.

3.2.2 Biofuels

The European Commission has played a pivotal role in the development of the biofuels sector in Europe. A significant amount of R&D funding was granted under the research programmes and EU policies have driven a fast increase in the use of biofuels in the EU Member States. In response to the critical discussion about deriving 'first' generation biofuels from edible products, the focus of R&D has been on developing production technologies for advanced biofuels. The funding has contributed to many publications, patents and other research outputs, such as the development of new and improved technologies or products, knowledge transfer, and public-private knowledge development. As a result of the funding, major technological developments were seen across different biofuels.

EU R&D funding has grasped opportunities for innovation and technological advancement across the entire spectrum of biofuels, contributing to the advancement of technology readiness levels (TRLs) for many advanced biofuels.

1. **EU funding contributed to the development of many biochemical pathways to produce cellulosic ethanol.** It moved from TRL 2 (concept development) to TRL 8 (complete and qualified system) and is now closest to commercialisation from all the advanced biofuels. Projects such as FP6 NILE and FP7 Eurobioref improved the enzymatic hydrolysis technique bringing the TRL to 5. The FP7-funded Sunliquid demonstrated on a pilot scale the production of cellulosic ethanol using an innovative fermentation process, without the need for externally added enzymes. After this successful project, a flagship cellulosic ethanol plant was announced with a production capacity of 50 000 tonnes/year to be built in Romania, which receives funding from the H2020 LIGNOFLAG project.

2. **EU funding supported the promising algae technology with grants for several R&D and demonstration projects, of which some have successfully demonstrated a sustainable process** (e.g. FUEL4me, DEMA). A special FP7 algae cluster has shown the feasibility of cultivating algae to produce fatty acid methyl ester (FAME) biodiesel (e.g. BIOFAT, ALL Gas, InteSusAL).

3. **EU-funded projects in support of pyrolysis oil have successfully demonstrated the technology.** Several research projects were funded, for example the FP6 Biocoup project which looked at the co-processing of biofuels in standard refinery units and the FP7 Bioboost project which improved the cost efficiency of pyrolysis oil production, moving the technology from TRL 3 to 5. The FP7 Empyro project demonstrated the production of pyrolysis oil. This has strengthened the confidence of investors, and the first fast pyrolysis plant on an industrial scale has been announced to be constructed in Finland.

4. **With support of the FPs, aviation biofuels have progressed from small pilot plants for biokerosene in 2010 to plants that can produce thousands of tonnes in 2015, which are being used by commercial flights.** Several important EU-funded projects contributed to advancements in jet biofuels. The FP7 ITAKA project investigated the production of biojet fuel from camelina oil and demonstrated the fuel use in real flights. Several large research projects have started under H2020, which focus on the production of biojet fuel from waste sources, aiming to advance the subsector further.

5. **The funding also contributed to the sector's need for an integrated biorefinery approach to produce biofuels and high value-added chemicals.** Several projects worked on this, such as FP7 EuroBioref and FP7 BIOREF-INTEG.

Aided by EU legislation and R&D funding, interest in biofuels grew in MS, and a substantial EU market was created. First generation biofuels are now the biggest source of renewable energy in the transport sector. The share of biofuels use in transport has risen from less than 1 % in 2004 to over 6 % today. The largest biofuel producers are also the largest EU R&D recipients (except for Spain), which facilitates efforts to develop and implement new technologies and biofuel projects. The sector is very sensitive to changing policies and harvests of agricultural products, which have affected the market. R&D efforts should therefore go hand in hand with supporting policies for the uptake of biofuels to achieve the greatest social, economic and environmental impacts.

As the sector is interlinked with agricultural produce, many jobs were created in MS with large agricultural sectors such as Romania and Hungary. The number of jobs for biofuels in the EU rose from an estimated 70 900 in 2008 to over 205 100 in 2016. Annual industry turnover ranges between EUR 11.5 and EUR 15 billion, depending on harvests. The EU industry also has a competitive position in the global market, with gross exports being 3.5 times the value of gross imports.

Second generation biofuels have started entering the market, but their impact is still very modest. Due to their infancy the capex, opex and LCOE are still high, but are expected to decrease as more plants will be built and demonstrated. Continued technological advancement can bring these and other advanced biofuels to the market, improving sustainability of land use, biomass and a significant reduction of GHG emissions.

The EU holds some of the leading research institutes, manufacturers and project developers in the sector, which is characterised by its wide array of technologies and specialisations. Interest in biofuel technologies is strong in the United States and rising in other countries, such as India, China and Brazil. Continued EU R&D funding can propel the momentum that Europe currently has in the sector.

3.2.3 Geothermal

The interest in geothermal energy has increased since 1995 alongside developments in climate and renewable energy policy. EU and MS R&D funding has grown over the years, especially after 2008. This trend is also visible outside of the EU, in countries such as the US and Australia. The combined EU and MS funding is at a level comparable to the US.

The EU has been successful in establishing and maintaining a leading academic position in the field of geothermal energy, as demonstrated by its consistent number one position in terms of global publications throughout the past 20 years. EU-funded projects have made a clear contribution to this leading position through publications as direct outputs of EU-funded projects, and through enhancing collaboration and knowledge sharing across the EU. An important project in this respect was the FP6 ENGINE project, which enabled the formation of the ENhanced Geothermal Innovative Network for Europe. This network was paramount in developing clear definitions for unconventional geothermal resources and enhanced geothermal systems, taking stock of current best practices, and establishing a future innovation agenda for the sector. The project provided the foundations for future geothermal R&D frameworks.

From a technology development perspective, EU funding has significantly helped to improve the appraisal of geothermal systems, enabling more accurate placing of wells and ultimately reducing the financial risk of geothermal projects. The FP7 IMAGE project has been a clear contributor to these efforts, which through the development and testing of exploration techniques tailored towards the needs of the geothermal sector, has helped to reduce the reliance on tools from the oil and gas industry. Furthermore, EU funding contributed to the development of enhanced geothermal systems (EGS), particularly through the development of stimulation techniques to improve the productivity of projects, which has contributed to the expansion of geothermal projects beyond areas of volcanic activity (Italy, Iceland), to sedimentary basins in other parts of Europe. But even in EU countries with volcanic activity, EU funding has facilitated the implementation of high-risk high-reward supercritical geothermal projects. An example is the successful H2020 DESCRAMBLE project. This project successfully drilled a geothermal well to a depth of 3 km, accessing a geothermal system with temperatures of over 500°C. Harnessing these supercritical systems can greatly improve the economics of geothermal power, enabling the technology to play a greater role in the energy transition. The development of monitoring tools and testing of materials capable of operating in such environments has been a key achievement in EU R&D projects.

The costs of geothermal energy do not show a clear trend due to the large impact of factors other than technology development, such as the site at which the technology is deployed, the reliance on equipment from the oil and gas industry, and efforts to improve environmental performance, such as the avoidance and/or treatment of co-produced greenhouse gas emissions from geothermal wells. In spite of the lack of a clear cost reduction trend, there have been several noteworthy impacts of EU-funded projects on the costs of the technology. Looking at bottom-up inputs from project developers and sector experts, it is clear that several projects contribute to cost reductions for the sector. The slight decrease in capex over recent years may be a sign that these efforts pay off, whereas the slight increase in LCOE may be due to the deployment of the technology at less favourable sites and increased attention to risk management, environmental performance and public engagement.

Installed capacities and associated generation of geothermal heat and electricity have doubled over the past 20 years, but the overall contribution of geothermal energy to EU energy consumption remains limited to 0.21 % (electricity) and 0.15 % (heat). Especially in the last couple of years, policy support for deploying additional capacities has been limited and the EU industry has not experienced any growth. However, the EU industry does have a positive trade balance, indicating that the R&D efforts have been effective in developing a competitive industry that can benefit from market growth worldwide.

3.2.4 Hydropower

Hydropower is the EU’s first RE technology: the long history of development means hydropower was established as a mainstream electricity source over 100 years ago. As a consequence, in 1995, EU hydropower capacity was already 106 GWe, rising by 21 % over the following 20 years to 129 GWe. Although installed capacity of wind and solar PV are (close to) surpassing that of hydropower, hydropower plants still generate the most renewable electricity of all RE technologies: 350 TWh per year, which is 10 % of gross final electricity consumption in the EU. Dammed hydro schemes and run of river schemes on the whole have higher capacity factors than a lot of onshore wind and solar PV projects. It has several other advantages over most other RE technologies, including a high level of reliability, low operating and maintenance costs, flexibility and large storage capacity, which can provide grid balancing services that can help system operators handle the variability of other RE technologies.

Hydropower receives relatively low R&D funding from the EU and MS. Despite the potential for small hydropower (SHP) and the features of hydropower as a dispatchable resource plus an option for storage, the EU and MS do not invest heavily in R&D for this technology. This could be because the core technology (hydro turbines and civils infrastructure) is well established and opportunities for technology improvements are often part of internal business improvements that do not require grant funding. Norway and Switzerland have higher R&D budgets, but all national R&D funding is very low compared to China, which spent about EUR 160 million per year on hydropower technologies between 2012 and 2016.

Nevertheless, EU funding has contributed to improvements of existing technologies and the development of new technologies in the hydropower sector. Given the maturity of the hydropower sector, R&D has included topics that help address barriers to new market segments or offer further improvements to the established technologies. Between FP5 and H2020, EU R&D funding has focused on three things: 1) improving the operational performance of existing installed capacity; 2) improving the design of existing technologies; and 3) development of new small hydropower (SHP) turbines and technology deployment.

1. **EU funding has contributed to improving the operational performance of the existing installed capacity**. One of the main topics in the EU-funded projects was the improvement and optimisation of resource analysis, material performance and deeper understanding of the operation through computational modelling. Thanks to projects such as Hyperbole, current IET standards for the operation of turbines have been assessed through modelling and in practice. If applied to operating schemes, these standards allow operators to increase their operating parameters and increase the range of electricity markets services that can be delivered, potentially benefiting other renewable energy technologies by facilitating increased penetration. Projects have also researched cost-effective methods to reduce the environmental impacts of hydropower schemes (e.g. Hydrogenie). Understanding of the water environment has increased, as has regulation to protect the water environment. More research is needed for the development of technologies that can take these environmental concerns into account.

2. **EU funding has also helped improve the systems and processes used for improving the design of existing hydropower technologies**. While there are few opportunities for new large sites within the EU, globally there is still a significant potential for large scale hydropower. The industry led CAVISMONITOR project, and projects like this, have developed new modelling tools that can be used by OEMs to improve the design of their turbines, improving performance and reliability, ultimately making the turbines more competitive on the global market, potentially increasing exports from the EU.

3. **The largest proportion of EU funding has been for small hydropower (SHP), where there is an estimated unutilised potential of 21 GWe in Europe (including non-EU countries)**. This has shaped the scope of the projects that have received R&D funding. Most of this funding went to the development of new small-scale turbines for low head sites such as weirs or on the river surface mounted technologies, and technology deployment. The funding of new SHP technologies has the potential to open up new sites that may otherwise not have been technically or economically viable. There are a large number of sites for smaller schemes, primarily run of river, that new technologies, such as those developed under the Hydrokinetic and River-Power projects, will be suitable for.

More generally, EU funding has contributed to knowledge development and knowledge sharing on investment opportunities, acquiring permits, and turbine design improvements, among other things. EU-funded projects have also led to the creation of patents and publications in areas where this is useful.

The capex and LCOE of hydropower do not show a decreasing trend. The most significant portion of the capex of a hydro scheme consist of the civil costs. These costs are not reducing, and only limited R&D funding has been allocated to this topic. There are also other developments that contribute to this trend, including the following: the policy context for hydropower has changed, and environmental legislation has become stricter; the most optimal sites are already covered, thus new installations are located in less optimal sites; and there is a growing share of SHP projects, which are inherently less cost-efficient than the conventional large-scale dams.

Being one of the biggest RE sources, growth of the hydropower sector has significant social, economic and environmental impacts. It provides 10 % of gross final electricity consumption in the EU, which was 37 % of all EU renewable electricity production in 2016, and creates substantial industry turnover and jobs. It also has a positive trade balance with the rest of the world. The EU holds a leading position and has significant exports to the rest of the world in both SHP technologies and large hydropower. Estimations of industry turnover for SHP plants show a substantial increase over the years, from less than EUR 3 billion in 2008 to over EUR 8 billion in 2016. The number of jobs for SHP in the EU rose from an estimated 15 000 to over 75 000 in the same period.

3.2.5 Ocean

Ocean energy technology refers to any technology used to harness energy from ocean currents, tides, waves, salinity gradients and temperature differences. Over the last decade, there has been an increased focus on development of technologies to utilise tidal currents and wave power. These have great technical potential in Europe, estimated at 48 TWh per year for tidal power and 2 800 TWh per year for wave power.

Between FP5 and H2020, the EU has taken a leading position in the research and development of ocean technologies, especially in tidal currents and wave power. The European Commission provided more funding than the four largest MS funders combined. Ocean is the only RE technology in which this is the case. The EU and its MS were also the first to provide R&D funding to ocean technologies and provide more than any other country in the world.

The funding has been effective in establishing and maintaining a leading academic position globally.

EU-based authors have been involved in more than half of the global publications between 1995 and 2017. The EU authored up to three times more publications than the USA and China. Interest in China is growing, but the number of publications is still far below that of the EU. The EU's share of global patents has been decreasing, as incentives and (test) project sites outside of the EU have increased over the past years. The reason is that the focus in the EU is on optimising ongoing developments and devices rather than developing new ones. This is also visible from the other impacts that EU R&D funding has had, such as knowledge development and knowledge transfer across the EU, more focus on the technologies in universities, the creation of spin-offs, and improvements of existing technologies (again with a focus on tidal and wave technologies).

EU support enabled tidal and wave technologies to increase their TRL level from TRL 2-3 (proof of concept) to TRL 5-6 (demonstration in relevant environment). It supported research projects that have benefitted both tidal and wave technologies, by developing a series of technology evaluation protocols (e.g. FP7 EQUIMAR) and design tools (FP7 DTOCEAN, H2020 DTOCEAN-plus). It also allowed learnings by failure for tidal and wave, which has helped understand the technologies better. For wave technologies specifically, EU support allowed a better understanding of the environment (e.g. SOWFIA) and enabled the testing of components and among others the Power Take Off (PTO), to gain in-depth knowledge and overcome the technological barriers that are still present. For tidal technologies, EU funding supported the testing and improving of components (e.g. PowerKite) and turbines (e.g. DirectDrive TT), and enabled the demonstration of integrated solutions for offshore tidal plants (e.g. InToTidal). The horizontal axis turbine technology is currently the most dominant technology, but other technologies are also present (e.g. vertical axis, oscillating hydrofoil, enclosed tips and tidal kites). The EU is funding several demonstration projects.

The tidal sector has progressed over the past years and now has the first tidal arrays in the water that generate electricity to the grid. The Meygen 1A project in Scotland, which has been supported by FP7 CLEARWATER and H2020 DEMOTIDE, is the largest installation so far with four 1.5 MWe turbines. It has delivered more than 8 GWh to the grid between April and August 2018.[6] This is an important step towards commercialisation.

Technological drawbacks have slowed down developments for wave technologies in the past years, but there are wave devices being planned for the coming years that have a capacity between 0.5 and 5 MWe. The Sotenäs wave pilot with a capacity between 1 and 3 MWe has been the largest so far, and allowed the company Seabased to learn and develop. The company has now signed a number of contracts for wave energy

[6] https://www.powermag.com/meygen-array-sets-global-records-for-harnessing-tidal-power/

developments in different parts of the world. However, in general, there are still many issues that need to be addressed before wave technologies can be deployed at commercial scale. High up-front costs and capital needs for first arrays, technological challenges relating to the harsh ocean environment, and regulatory challenges such as licencing are the main challenges in the sector.

Due to the infancy of the sector, the costs (capex, opex and LCOE) are very high and the ranges in values is still very broad. Nevertheless, the industry understands that if it wants to have a place in the energy mix, these values need to be similar to that of offshore wind. To get there, the sector will need large scale projects to gain a better understanding of the resources, the environment, and the behaviour of the devices. With the continued support of R&D funding, further technological developments and understanding can bring the ocean industry to this level of maturity.

3.2.6 Solar PV

At the time when FP5 was launched in 1998, PV was an expensive niche technology, used only in very specific applications. Installed capacities were negligible (100 MW) and the prospects of PV becoming a major source of electricity were not as clear as nowadays. Thanks to the combination of continuous R&D by the EU, Japan and the US, market incentives in the EU and industry development in China, the technology developed into a competitive source of electricity and experienced strong growth in installed capacities (>100 GW installed capacity in the EU in 2017).

EU R&D funding contributed to the progress in the PV sector by addressing the main research priorities and industry requirements at each stage of the sector's development:

- During FP5 (1998-2002), the EU R&D priorities included the development of higher efficiency PV devices based on crystalline silicon and thin-film technologies and transferring laboratory level results to industrial-scale. Moreover, the EU supported the development of improved production methods and machinery to achieve lower production costs of PV cells and modules. In the early 2000's when the PV market started to take-off in Europe, the more advanced production lines and semi-automated manufacturing facilitated the early success of the pioneering PV manufacturing industry in Europe.

- The FP6 period (2002-2006) coincided with the emergence of global PV industry and high demand of solar-grade polysilicon, which led to ever rising market prices for polysilicon. The EU R&D funding continued to support the efficiency advances and system level cost reductions of crystalline silicon (c-Si) technology but also funded several projects to develop novel methods to produce polysilicon to secure the EU industry a reliable and affordable access to polysilicon feedstock (e.g. through the SOLSILC, SPURT, SISI, and SOLSILC DEMO projects). Furthermore, projects to developed innovative wafering technologies characterised by less material usage were supported (e.g. CRYSTALCLEAR), as well as projects to pave the way towards silicon heterojunction technology (e.g. HETSI). This line of work was continued in FP7 (2007-2013) in projects such as 20PLμS, R2M-SI, CHEETAH and HERCULES.

- The FP6-7 period also extended the R&I support for lower cost PV technologies such as different thin-film technologies. At that time, the thin-film technologies were considered to provide viable alternatives to c-Si-based technology due to a less costly manufacturing process and reduced use of semiconducting material. Examples include the FP6 projects ATHLET and LARGIS, which explored thin-film technologies with the potential to achieve simultaneously lower costs and higher energy yield. FP7 continued to support the wide spectrum of thin-film technologies through projects such as HIPOCIGS and R2R-CIGS. Similarly, organic PV emerged a R&I funding priority due to the benefits associated to low-cost active layer materials and substrates, low energy input, and easy upscaling (example projects include MOLYCELL and X10D).

- Besides lower cost PV technologies, the FP6-7 period also explored expensive but very high-efficiency PV technologies such as multi-junction PV and concentrating photovoltaic systems (CPV) to further expand the EU PV technology portfolio beyond the silicon-based technologies. For example, the FULLSPECTRUM project developed novel materials, concepts and components enhancing light absorption and widening the use of solar spectrum, whereas the HICONPV, APOLLON and NACIR projects focused on lowering the costs of concentrating PV systems.

- Towards the end of the FP7 period, the EU manufacturers of c-Si PV cells and modules were seriously impacted by the decreasing global market prices of PV products and imports from the Asian market. At the same time, the market dominance of c-Si technologies had become clearer, and other PV technologies struggled to compete with it in terms of efficiency and costs. The FP funding portfolio was further extended to include exploration of novel very high-performance PV technologies, as well as new applications areas, like building integrated photovoltaics (BIPV), with the aim to differentiate the EU PV research and give a new boost to EU industry to become competitive at global scale. BIPV was seen as an opportunity to support the EU PV industry, since it generates local jobs and demand for local materials due to its links with the construction industry. The FP7 period also introduced sustainability considerations (in terms of material and rare metal use, recycling) and life-cycle assessment as an integral part of the EU research agenda, and the current H2020 framework programme continues seeking novel approaches (e.g. for recycling and re-using end of life PV modules through projects such as CABRISS). Also, projects aimed at optimising the PV system and downstream PV technologies such as integration of PV technology into the grid received more attention (e.g. PVCROPS and PERFORMANCE PLUS).

- The current H2020 framework programme (2014-2020) continues to support a wide spectrum of PV technologies which offer opportunities to rebuild the EU PV industry. On one hand, a significant proportion of the funding is dedicated to exploration of novel, emerging PV technology development avenues. Projects supporting discovery of innovative materials and PV concepts such as perovskite solar cells, c-Si tandem cells, bifacial cells, and a number of other higher performance c-Si architectures are currently on-going with very promising results (e.g. NANO-TANDEM, DISK and CHEOPS). On the other hand, H2020 has set focus on closer to market, and higher TRL level R&I activities. This is especially true for c-Si technology, where H2020 supports a large pilot project AMPERE to accelerate the heterojunction bi-facial solar cell technology market uptake, but also in respect to advancing the BIPV technology towards large-scale manufacturing in projects like PVSITES or ADVANCED-BIPV.

Overall, the EU Framework Programmes made a clear contribution to the EU's research and technology leadership by funding projects that delivered many publications and stimulating collaboration and knowledge sharing across the EU. The EU has a strong position in research with leading R&D budgets and EU authors contributing to 26 % of all publications worldwide. In addition, EU-funded research projects have contributed to the development of several new technologies, market introductions and the creation and development of several start-ups. Moreover, EU-funded projects have contributed to cost reductions of crystalline silicon and thin-film technologies through the exploration of new materials and improved manufacturing processes, and have facilitated closer cooperation between the private and public sector.

3.2.7 Solar thermal

Solar thermal energy refers to any technology that harnesses energy from the sun to generate thermal energy, which can be further converted into electricity or used directly as heat. Solar thermal energy consists of two main technology categories: concentrated solar power (CSP), and solar heating and cooling technologies. Approximately 60 % of EU R&D funding went to CSP and 40 % to solar heating and cooling. The EU has a strong academic position in the solar thermal sector, with leading R&D budgets and the number 1 position in terms of publications worldwide. The EU Framework Programmes made a clear contribution to the EU's academic leadership by funding projects that delivered many publications and stimulating collaboration and alignment of R&D agendas across the EU.

For CSP, EU R&D funding played an essential role in the scale-up and market uptake in Europe, supporting various commercial-scale demonstration activities in Spain (e.g. through the PS10, Andasol and SOLAR TRES projects) and Italy (ARCHETYPE SW550), and more recently, smaller-scale demonstration projects outside Europe (MATS and ORC-PLUS projects). Together with the policy support of Spain, this created strong growth in installed capacities and enabled the development of a globally leading EU industry. Sector experts describe EU Framework Programmes funding as essential for the early development of the CSP sector in the 2000s and for supporting continuity of research.

The technology development of CSP has led to clear cost reductions as shown by the downward trend in LCOE. EU-funded R&D has played an important role in enabling these cost reductions by financing research on many components of CSP technology. When interpreting the cost estimates, it is important to keep in mind that the installed capacities have been limited, which has led to limited opportunities for learning-by-doing and economies of scale. As a result, the LCOE is currently at a higher level than wind energy and solar PV, which poses a challenge to the sector. Nevertheless, the sector sees plenty of opportunities to improve the technology and reduce its costs. EU funding continues to play an important role in these developments by offering the necessary funding for promising technologies that are at present still too costly (e.g. in the NEXT-CSP project).

These activities - together with the EU support to research and test infrastructures through projects such as SFERA and SFERA II, and the alignment of the R&I activities in Europe through, for example, ECOSTAR (FP6) or STAGE-STE (FP7) - have enabled the EU research sector and industry to gain global technological leadership in the sector. At the moment, these capacities are leveraged in growing international markets.

The EU solar heating and cooling capacities have grown steadily over the past 20 years. EU-funded R&D has contributed to achieving cost reductions, improving technologies and facilitating market uptake. For example, EU funding has supported a number of activities to demonstrate the direct integration of solar systems to residential and non-residential buildings. These projects have explored new or improved materials and manufacturing processes for solar collectors, sought for novel solutions to reduce complexity and costs of the installation, and advanced the potential for solar hybrid generation and seasonal energy storage solutions. Thanks to the European Commission funding, innovative building integrated solar thermal (BIST) solutions have also been developed (e.g. in EINSTEIN, CHESS-SETUP and FLUIDGLASS).

EU funding has also contributed towards the integration of solar thermal energy into district heating systems (e.g. through SDHp2m, SDHplus and SDHtake-off). Combined with the efforts of leading Member States (e.g. Denmark) these efforts have been successful in achieving global leadership in solar district heating.

During recent years, the EU funding has supported the application of solar heat for industrial processes. Many projects (e.g. SOLAR BREW) have successfully demonstrated the feasibility of the technology in different industries, from low to high temperature solar processes. The H2020 project INSHIP is set to coordinate and align the EU R&I activities in this field.

Thanks to the efforts of the EU and MS, the EU solar heating and cooling industry has a strong global position with a significant trade surplus.

3.2.8 Wind

The EU wind energy sector is a prime example of how R&D efforts and steady market development can lead to a strong EU industry. Within the EU, the installed capacity for wind energy has been growing steadily from less than 20 GW in 2000 to more than 168 GW in 2017. Such growth has contributed significantly to the decarbonisation of EU's electricity consumption (of which 10 % originates from wind energy) and have provided a significant sales market for EU-based manufacturers. The EU industry has attained a global leading position with EUR 20 billion annual turnover and more than 300 000 jobs, accounting for 30 % of all wind energy jobs worldwide. Furthermore, it has a significant trade surplus, with net exports of EUR 6 billion/year.

The costs of wind energy have decreased significantly over the past 20 years, leading to a situation in which onshore wind energy is competitive with other electricity sources. Thanks to performance improvements and capex reductions, the LCOE for onshore wind energy decreased by more than 50 % between 2000 and 2017. For offshore wind, the costs increased in the early years of deployment (2007 to 2015) due to a range of factors including the move towards deeper waters and the need to adapt onshore wind energy technology to offshore conditions. From 2015 to 2017 a clear downward trend in the LCOE of offshore wind energy is visible, to be attributed largely to economies of scale.

EU framework programme funding contributed significantly to the development of larger wind turbines (resulting in major cost decreases), fixed-bottom offshore wind technology and floating offshore wind technology. Under FP6, the Upwind project determined that developing large turbines of up to 10 MW was feasible, but not yet cost-effective. This led to the FP7 INNWIND project, which brought together participants from 28 different leading industrial and research institutions to focus on the development and the demonstration of lightweight and innovative components, such as large 100-metre blades, supra-conducting generators and new fixed and semi-floating offshore substructures. This way INNWIND largely contributed to the development, the performance and the cost competitiveness of the offshore wind technology. SUPRAPOWER (SUPerconducting, Reliable, lightweight, And more POWERful offshore wind turbine) was another FP7 project which developed and patented a novel 10 MW lightweight and reliable generator, based on superconducting materials, resulting in a reduced LCOE, 30 % weight reduction and low maintenance requirements. Next to these component development interventions, projects such as LEANWIND (FP7) specifically addressed the logistical challenges of deploying, installing and operating large scale wind turbines in the range of 5 MW to10 MW. Overall, with the increase in unit capacity proving to be the key driver for LCOE reductions, funding focussed increasingly on the development of large offshore projects.

Costs for traditional offshore foundations, which are fixed to the seabed, become prohibitive in waters deeper than 50 metres. This sparked the development of floating solutions which the EU Framework Programmes have contributed to. Under FP7, floating turbines, moored to the seabed on a floating support, started to receive funding through several projects designed to remove design and implementation hurdles. ICFLOAT developed numerical models for analysing the stability, efficiency and feasibility of floating wind turbines. Simultaneously, the EERA-DTOC project produced a commercially available software tool that helps minimize the cost of planning, developing and operating offshore wind farms. Other FP7 projects such as FLOATGEN are demonstrating the technical feasibility and economic viability of floating wind turbines, providing unparalleled experience in terms of construction methods, deployment and operation.

The above are just a few examples of how EU supported research contributed to the advancement of wind technology in general and offshore wind technology specifically, allowing for wind turbines to be installed farther offshore, capturing stronger and steadier winds and avoiding the limitations of finding suitable on-land sites – thereby contributing to the commercialization and further exploitation of wind energy in Europe since the first offshore wind farm was installed in Denmark in 1991, and supporting Europe's world leadership in offshore wind power generation.

4 Market sector assessment

In addition to the assessment of the impacts per technology, an analysis per market sector (power, heating & cooling, and transport) has been performed to provide additional insights into the distribution and impacts of EU R&D funding across the different market sectors.

4.1 Distribution of funding per sector

The European Union has committed to reduce its greenhouse gas (GHG) emissions by at least 20 % below the 1990 levels by 2020 and by at least 40 % below the 1990 levels by 2030, with a long-term strategy to achieve climate-neutrality by 2050.[7] Renewable energy plays a significant role in helping to achieve these energy and climate objectives. The overall policy framework for the promotion of renewable energy in the EU is enacted in the Renewable Energy Directive (RED) (2009/28/EC).[8] This Directive established that 20 % of the EU final energy consumption in 2020 should be covered by renewables, with a target of 27 % by 2030 added later on and revised to 32 % by 2030.[9] In addition, it established a 10 % target for the share of energy consumption from renewable sources in each Member State's transport sector by 2020. The Directive was amended by Directive 2015/2013 to introduce a 7 % cap on the share of food crop-based (conventional) biofuels. It also introduced a non-binding target of 0.5 % for non-food based (advanced) biofuels. The revised RED (RED II) further supports the use of advanced biofuels with a minimum share of 1.5 % by 2021 and a target of 6.8 % by 2030. It also envisions a progressive shrinking of the cap for conventional biofuels to 3.8 % in 2030.

RE technologies will be the enablers of the energy transition required to achieve the above-mentioned goals. As already mentioned, the RE technologies described in the preceding chapter produce energy in the form of either electricity, heat or fuel. Depending on the final form of energy produced, RE technologies will have different market applications. Wind energy, solar PV, ocean energy and hydropower are electricity-producing technologies and thus contribute to the power sector. Solar thermal, bioenergy and geothermal energy can generate either electricity or heat and thus have applications in both the power and heating & cooling (H&C) sectors. Biofuels have their main application in the transport sector.

Figure 4-1 compares the relative share of EU R&D funding dedicated to different market sectors during each of the framework programmes (FP5-H2020). The power sector has received the largest overall share of funding over the duration of the four framework programmes (this includes H2020 up to mid-March 2018). In total, the sector received EUR 2193 million in EU R&D funding for RE technologies. During FP5, research on RE technologies with an end-use focus on the electricity market received 67 % of all EU funding dedicated to RE technologies. This share diminished to less than 50 % during FP6 but the share of funding grew again during FP7 and H2020 to similar levels as during FP5 (63 % and 64 % respectively).

[7] https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_en.pdf
[8] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, Official Journal of the European Union, L 140/16, April 23, 2009 https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32009L0028
[9] http://europa.eu/rapid/press-release_STATEMENT-18-4155_en.htm

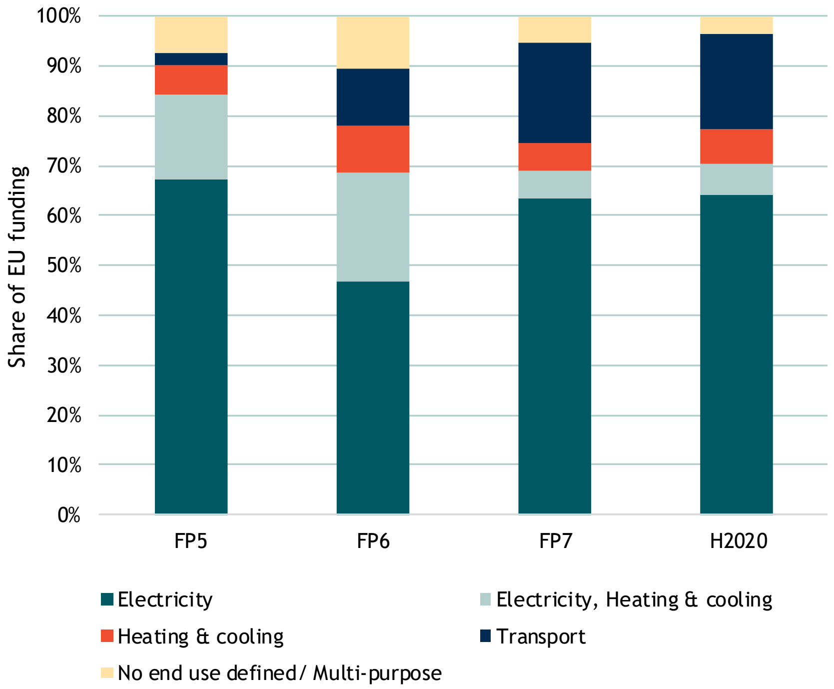


Figure 4-1 Share of EU funding per market sector

Source: Own elaboration based on CORDIS (2018) data

Note: the area 'No end use defined/Multi-purpose' includes projects in which the market sector could not be defined with the information available in the projects' description, or in which the description indicated the three market sectors were covered.

The category 'Electricity, Heating & cooling' encompasses research on the bioenergy, solar thermal and/or geothermal technologies in those cases where the projects have end-use application in both sectors. The total amount of funding for these projects amounts to EUR 340 million. Electricity and H&C projects received a higher share of EU-funding during the earlier FPs. During FP5 they received 17 % of the overall funding and during FP6 the share increased to almost 22 %. During FP7 and H2020 (up to mid-March 2018) this share decreased to around 6 %.

RE technologies with an end-utilisation in the H&C sector have received a small share of funding during each of the FPs. This share was smallest during FP5 and FP7 (5.8 % during both FPs) and highest during FP6 (9.4 %). In what has elapsed of H2020 (up to mid-March 2018) projects with a focus on the H&C sector have received 7 % of the total funding. The diminishing share of funding for the combined electricity and H&C sector has not translated into increased funding for H&C-specific projects. In absolute terms the total amount of funding for this sector amounts to EUR 236 million.

Research on RE technologies in the transport sector has received a total of EUR 574 million in EU R&D funding. The share of funding for the transport sector increased from less than 3 % in FP5 to almost 12 % in FP6. The share of funding for transport-related RE technologies was 20 % in FP7 and 19 % during H2020 (up to mid-March 2018).

In addition to projects with a clearly defined market utilisation, there are cases where the end-use of the energy generated by a RE technology is undefined. These type of projects represent less than 10 % of the total funding during FP5-H2020 and include predominantly research in bioenergy and biofuels. In total this category of projects received EUR 211 million in EU funding.

Overview of most funded RE technologies per market sector

Figure 4-2 provides more detail on the distribution of funding per market sector. It shows the three most funded RE technologies in each market sector and the amount of funding allocated to them per FP. In the case of the transport sector, only two categories of projects were considered in this study.

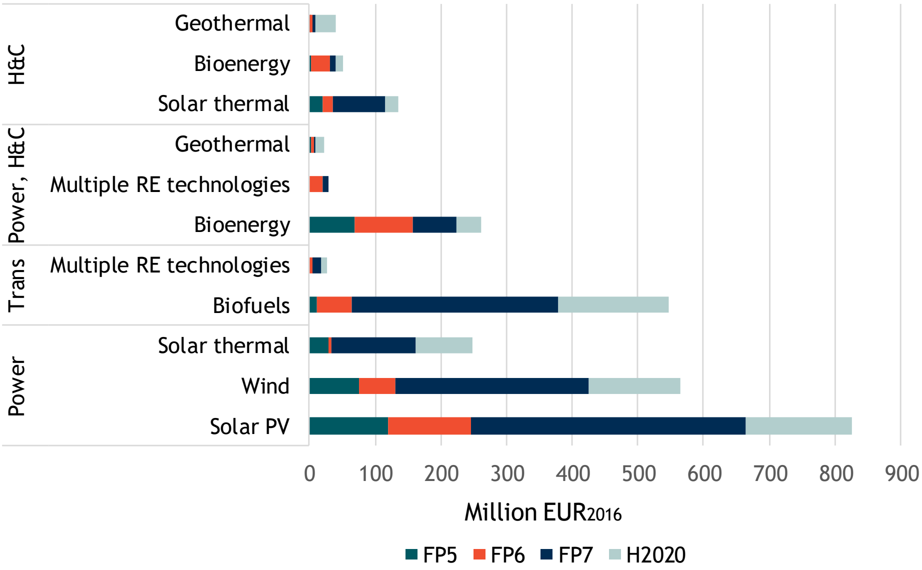


Figure 4-2 Most funded RE technologies per market sector

Source: Own elaboration based on CORDIS (2018) data

Solar PV is the most funded technology in the power sector. In total it has received EUR 826 million in funding. This money supported 462 projects and represents almost 38 % of all funding given to research on RE technologies in the power sector. Wind received the second highest amount of funding in the power sector. In total wind energy research has received EUR 566 million. This money has provided funding for 225 projects and represents almost 26 % of all funding dedicated to the power sector. Electricity-generating solar thermal technology (predominantly CSP) received a total EUR 248 million in funding. Together these three RE technologies received 75 % of all funding dedicated to the power sector. A more detailed discussion on the amount of funding of other electricity-generating technologies is available in the individual technology repots and the market sector report prepared for this study.

In the transport sector biofuels are the main technology being funded. They account for 95 % of all the EU funding directed towards R&D in the transport sector.

Out of those RE technology projects with a potential end-use in either the power or the H&C sectors, bioenergy is the most funded technology. 77 % of all funding for projects in this category has gone to research on bioenergy. It is important to note that the total amount of funding for bioenergy is not available from Figure 4.2 because bioenergy received additional funding under electricity-generating projects. However, the technology is not among the three most funded ones in the power sector. Bioenergy projects received significantly more funding than the second (multiple RE technologies) and third (geothermal) highest funded categories in this sector.

Out of the total amount of funding for the H&C sector, solar thermal projects received the largest share of money representing 57 % of the total funding for the sector. Bioenergy projects specific to the H&C sector received almost 22 % of the total funding. Geothermal energy projects for H&C received a total of EUR 40 million, which corresponds to ~ 17 % of the total funding.

4.2 Development of renewable energy for electricity, H&C and transport

Figure 4-3 presents the data shown in figure 4.2 in absolute terms rather than as shares. The funding for the 'Electricity, Heating & cooling' category has been incorporated into the power and H&C sectors to provide an estimate of the total funding with relevance for each of the three sectors, which we will compare with the developments in each sector in terms of decarbonisation and industry development.

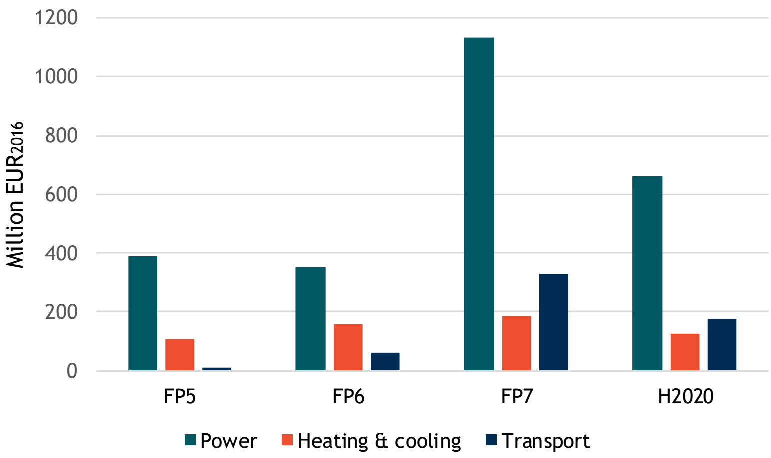


Figure 4-3 EU R&D funding per market sector

Source: Own elaboration based on CORDIS (2018) data

Note: The numbers for power and H&C are an aggregate of funding for each of the sectors plus the funding of projects in the 'Electricity, Heating & cooling' group. Funding for projects with no-end use is not shown thus the sum of the three columns does not correspond to the total amount of R&D funding per FP.

In 2016, the use of RES in relation to the gross final energy consumption in the EU reached 17 %.[10] Figure 4.4 illustrates the developments in the shares of energy consumption from renewable energy sources per market sector. The power sector has the largest share of renewable energy out of the three market sectors. From 2004 to 2016 this share grew on average by ~ 1.3 % per year. In 2016, the share of electricity consumed from RES was close to 30 %. For 2017, the European Environment Agency (EEA) estimates that 31 % of total electricity consumed was derived from RES.[11] In 2016, hydropower accounted for 37 % of renewable power generation, wind energy accounted for 32 %, bioenergy for 18 % and solar PV for 11 %. To achieve the EU's target of 32 % in the overall European final energy mix by 2030, it is estimated that more than 50 % of renewable electricity will be required.[12] To reach this target the annual growth in the share of energy consumption in the power sector must be higher than 1.3 %.

The share of energy consumption from RES in the H&C sector has increased from 10.3 % in 2004 to 19 % in 2016. On average the share of energy consumption from RES in the sector has grown by 0.7 % per year. Based on analysis presented in the market report, bioenergy represents the largest amount of this share. The share of bioenergy increased from 9.8 % in 2004 to 16.5 % in 2016. In contrast, geothermal and solar thermal energy constitute a minuscule share of the total energy consumption for H&C (0.1 and 0.4 % in 2016 respectively).

The transport sector has the lowest penetration of renewables in the final energy consumption. The share of RES grew from 1.4 % in 2004 to 7.1 % in 2016. Preliminary estimates from the EEA suggest that in 2017 this share equalled 7.2 %. On average, between 2004 and 2016, the share of RES in the final energy consumption mix for the transport sector has grown by ~ 0.5 % per year. If the 10 % target established in the RED is to be achieved by 2020 the share of RES in the energy consumption of the sector must grow by 1 % yearly, this is twice as fast as the rate of growth in the last years.

[10] EEA (2018) Trends and projections in Europe in 2018: Tracking progress towards Europe's climate and energy targets
[11] EEA (2018) Trends and projections in Europe in 2018: Tracking progress towards Europe's climate and energy targets
[12] Sandbag (2018) The European Power Sector in 2017

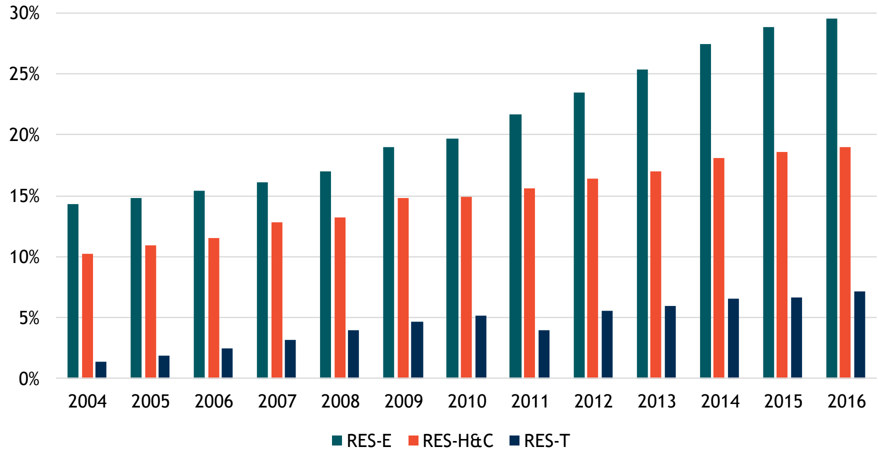


Figure 4-4 Shares of energy consumption from RES in the EU per market sector

Source: Eurostat (2018)

Figures 4.5 and 4.6 provide information on the relative contributions of the three market sectors to industry development based on employment numbers and industry turnover per sector. The power sector has the highest numbers in the case of both indicators. Based on the fact that two of the fastest developing RE technologies: wind and solar PV fall under the electricity-generating market it is not surprising that this sector is also the leading one in terms of industry turnover and employment. The number of jobs in the EU related to the renewable electricity sector has increased from approximately 510 000 in 2008 to 730 000 in 2016. In 2016, the renewable power sector provided ~ 3 times as many jobs as the H&C sector and 3.5 times as many jobs as the transport sector. In the same year, wind energy accounted for 43 % of the jobs in the power sector, bioenergy for 32 % and solar PV for 13 %.

The number of jobs in the transport sector more than doubled in the last three years analysed from 97 400 in 2014 to 205 1000 in 2016. In contrast, the number of jobs in the H&C sector has grown at a slower rate between 2008 (~220 000) and 2016 (~ 247 000). In 2016, bioenergy accounted for 88 % and solar thermal for 10 % of all jobs in the renewable H&C sector.

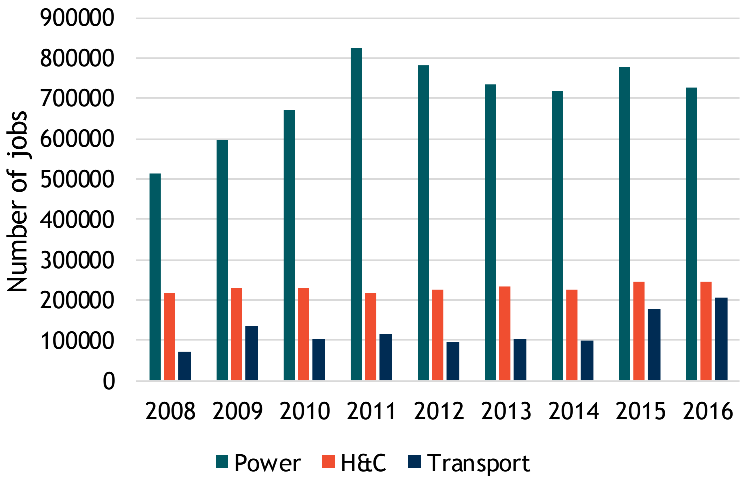


Figure 4-5 Number of jobs from RE technologies in the EU per market sector

Source: Own elaboration based on EurObserv'ER reports 2010-2017, and Eurostat, 2018.

In 2016, industry turnover for the EU power sector was more than 3 times larger than for the H&C sector and over 6 times larger than the turnover in the transport sector. The average turnover during the time period analysed was around EUR 90 billion. Turnover was highest in the years 2010-2012, with numbers above EUR 90 billion. In 2016, the renewable power sector had a turnover of EUR 80 billion. The wind energy industry accounted for 48 % of this turnover, bioenergy accounted for 27 %, solar PV for 13 % and hydropower for 11 %. In 2016, industry turnover in the renewable H&C sector amounted to EUR 24 billion. Turnover in bioenergy accounted for 86 % of the total turnover in the sector, in solar thermal for 12 % and geothermal 2 %. Turnover in the transport sector is solely based on the biofuels industry.

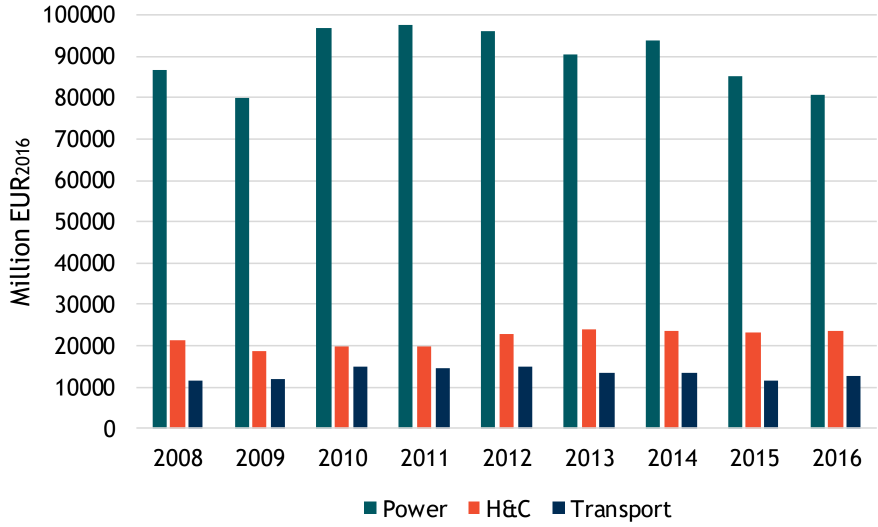


Figure 4-6 Industry turnover of EU RE technologies per market sector

Source: Own elaboration based on EurObserv'ER reports 2010-2017, and Eurostat, 2018.

Based on a comparative analysis of figures 4.3 to 4.6, it is possible to observe that the amount of funding for the power sector is consistent with the emphasis given by policymakers to decarbonizing this sector. In addition, the power sector is by far the largest of the three sectors in terms of employment and industry turnover. Wind energy and solar PV, two of the fastest developing RE technologies, contribute substantially to the leading position of the power sector in terms of employment and industry turnover. Hydropower technology plays an important role in contributing to the overall share of RES in the energy consumption of the power sector. Hydropower has historically had the highest share of renewable-electricity generation and continues to be one of the most importance sources of RE electricity.

H&C of buildings and industry accounts for about half of EU’s energy consumption. However, in 2016 renewables accounted for only 19.1 % of the energy generated in this sector. The share of energy consumption from renewable sources H&C has grown at a slower pace. It increased from 10.3 % in 2004 to 19 % (these numbers take into account heat pumps) in 2016. The vast majority of this share is based on bioenergy. The amount of funding for R&D that the sector has received is not proportional to the scale of the sector and its relevance in achieving the EU’s renewable energy and GHG emission reduction targets. It is important to note that important efforts are taking place in the area of energy efficiency and heat pump technology which are not considered in our analysis. Nonetheless, the data presented here suggests a need for further emphasis and support for the H&C sector to decarbonize it.

The analysis of the transport sector in this report focuses on the biofuels technology. Biofuels have increased their penetration in the transport sector over time. In 2016, they contributed to 5.8 % of the energy consumption in transport. This number represents an almost 10-fold increase from their penetration of 0.6 % in 2004. Even with the share of renewable electricity for transport the sector is lagging behind in relation to its 2020 target of 10 % renewables in the market. This is despite the fact that it received the second-highest contribution of EU funding at the market level.

5 Conclusions and recommendations

In this chapter, we present our final conclusions on the impact EU R&D funding for renewable energy technologies through the Framework Programmes for Research and Technological Development. The conclusions are based on our analyses of eight renewable technologies and the three market sectors as well as the insights gathered at the dissemination conferences. Where appropriate, we also provide recommendations for increasing the impact of future EU R&D funding.

While the EU FP funds are substantial, its impacts should be considered taking into account that national budgets of Member States are over three times larger.

The EU has provided considerable support for renewable energy technologies over the past 20 years. From Framework Programme 5 up to the first half of Horizon 2020, a total of EUR 3.6 billion has been made available to support the main eight renewable energy technologies. In the same period, EU Member States funded a further EUR 11.6 billion, leading to overall public R&D budgets of approximately EUR 15 billion. So while the budgets of the EU Framework Programmes are significant, the national budgets of EU Member States are substantially larger. The impacts should therefore be viewed within this context.

The EU has world-leading public R&D budgets, in particular for bioenergy, solar thermal, wind and ocean.

The combined EU FP and national R&D budgets are at a world leading level for most technologies. In particular for bioenergy, solar thermal, wind and ocean energy, the EU budgets are large compared to other countries and regions, with the caveat that R&D budgets from China are not fully known and may be at a similar or larger scale. For biofuels, geothermal and hydro the EU budgets are more modest.

EU R&D funding has been effective in establishing academic leadership while losing ground in patent applications.

For all renewable energy technologies, EU authors have a leading share of global publications. This is particularly true for ocean, bioenergy and wind energy where EU authors contribute to a third up to half of all academic publications. Moreover, the number of publications by EU authors correlates closely with the EU R&D funding levels, indicating a clear link between the funding and the academic leadership. For patents, on the other hand, the EU share of global patent applications is consistently decreasing. However, it should be noted that there are considerable limitations in the use of patents filed as an indicator for R&D success as the value of patents differs strongly, the minimum requirements for filing patents differ significantly across the world, and their enforcing is country specific, which makes a global comparison difficult.

EU FPs provide added value over national schemes by fostering pan-EU collaboration.

The stakeholders in all eight sectors clearly recognise the added value of EU R&D funding for stimulating collaboration with organisations from other countries within the EU. Large projects that coordinate research activities and foster collaboration across the EU have been funded in virtually all sectors and have delivered clear benefits for the organisations involved. Additionally, the requirements for cross-country consortia in project calls have stimulated the formation of partnerships in the context of specific R&D challenges.

EU R&D funding has enabled the development of several specific technologies and the continuation of research that would not be possible with private and/or national funding alone.

Several technologies have been developed to higher levels of maturity thanks to considerable support through the EU Framework Programmes. Technologies such as solar

CSP and fixed-bottom offshore wind benefited greatly from EU support to accelerate their development and market entry. For technologies such as tidal and wave energy, enhanced geothermal systems, advanced biofuels and floating offshore wind, such efforts are also made but require more time to assess the full effects. The stakeholders in these sectors assign significant importance to the role of EU funding for bringing these technologies to the market.

Continuity of research topics has allowed for high impact projects.

A common thread in best practice projects is that they leveraged upon the work of earlier EU-funded projects. There are numerous examples of successful projects that benefit from the results of previous EU-funded projects and show a clear succession in the work throughout the different Framework Programmes. On the other hand, there are also several examples of projects with no clear next steps after project closure, which limits their impact on the sector. Hence, we recommend a further focus on ensuring continuity and predictability in research topics to ensure continuity in funding. Furthermore, when evaluating project proposals, we recommend that particular importance is given to the prospects of delivering market-relevant knowledge and the plans for ensuring the project outputs are used to stimulate continuity at the project level.

Mixed impact on cost reductions across the different technologies.

While there are examples of EU-funded projects that contributed to cost reductions in each technology sector, the translation to clear cost reductions in the market differs strongly. For solar PV, CSP and wind energy, the cost reductions in the market are very clear. However, for the other technologies, there is less of a clear trend in the costs of the technology. While there are diverse reasons for this, this does indicate that the scope for cost reductions differs among the technologies and that it is not realistic to expect steep cost reductions for all renewable energy technologies.

Substantial differences in market penetration of the different technologies.

The success of the R&D efforts in pushing increased uptake of renewable energy technologies differs strongly across the technologies. For technologies such as wind and solar PV substantial growth in energy generation has been achieved, also thanks to market incentives. For other technologies the growth is more limited or at a much lower scale. In particular for bioenergy and biofuels, the growth in their uptake and the ability to push new technologies to the market is severely hindered by the lack of a supportive regulatory framework. But also for technologies such as CSP, geothermal and ocean the penetration of new technologies to the market faces substantial barriers, primarily due to the lack of schemes to support their cost-competitiveness. Overall, this has a negative impact on the prospects for R&D to deliver innovations that reach the market.

Mixed impact on industry development with overall EU renewable energy industry turnover at a constant level.

The impact in terms of developing a leading renewable energy industry in the EU differ strongly. For technologies such as wind energy and bioenergy the EU has been successful in establishing a leading and growing industry. In particular for solar PV, this has not been successful, with a strong decline in industry turnover since 2011. Overall, the EU renewable energy industry has remained at a constant level of turnover over the past eight years, with the decrease in solar PV industry turnover offsetting the growth in other sectors.

Funding for technologies to decarbonise the heating & cooling (H&C) sector is not in line with its share of energy consumption.

Less than 15 % of the EU R&D budget has been allocated to projects with relevance for the H&C sector while H&C is responsible for approximately 50 % of EU energy consumption. Additionally, progress in decarbonising the H&C sector has been slow compared to the electricity sector. Hence, funding for renewables to decarbonise the H&C sector is not in line with its energy consumption and its need for increased efforts to accelerate its decarbonisation. While it should be noted that some efforts to decarbonise the H&C sector are not included in our analysis (e.g. energy efficiency measures and heat pumps), we do conclude that the funding for H&C and power generating technologies are not balanced and that an increased focus on H&C should be considered.

Lack of direct correlation between R&D funding levels and the expected role of the technologies in the energy mix.

The link between the long-term plans and roadmaps to decarbonise the EU energy sector and the levels of R&D funding for the different renewable energy technologies is not fully evident for the stakeholders in the different renewable energy sectors. Hence, we recommend a closer correlation between the expected future role of the different technologies on the one hand and the associated R&D budgets on the other hand. This should take into account factors such as the maximum potential energy generation by the technologies, the scope for cost reductions and the prospects for EU industrial leadership to arrive at a distribution of funding that reflects the importance of the different technologies for the EU in a balanced way.

Annex 1

Technology Sector Report Geothermal energy

(Deliverable D2.1)

Authors:
Elske Veenstra (Trinomics)
Perla C. Torres Vega (Trinomics)
Onne Hoogland (Trinomics)
Tom Mikunda (TNO)

1 Introduction

This report is one in a series of eight technology reports for the study *Impacts of EU actions supporting the development of renewable energy (RE) technologies*, prepared for the European Commission. The report has two objectives: 1) describing how EU research and development (R&D) funding for the geothermal technologies has impacted the geothermal sector in the EU, and 2) describing more broadly the development of the geothermal sector to which the EU R&D funding has contributed. It is based on a compilation of data from several databases, a questionnaire send to coordinators of EU-funded R&D projects, case studies, interviews and literature research. The methodology applied for this study is documented in a separate deliverable.[1] Where relevant, limitations and assumptions are mentioned throughout this report.

Geothermal energy provides a clean, renewable and constant form of energy, which can be used for base load power generation in energy systems, to directly heat buildings, or as process heat in industrial processes. Geothermal projects involve drilling into the Earth's surface to access the thermal energy that is generated and stored there. This energy can be used directly, or it can be transformed into electricity via technologies such as dry steam power stations, flash steam power stations and binary cycle power stations.[2] Geothermal energy sources are generally classified as low to medium enthalpy, indicating heat sources between about 40 °C and 150 °C (water/steam), or high enthalpy, referring to heat sources above 150 °C (steam). The enthalpy of the heat source generally determines the type of geothermal technology used to exploit the resource. High enthalpy geothermal wells are commonly drilled up to 2km in depth. Low enthalpy wells may be much shallower.

In the EU, Italy has the largest installed capacity of geothermal power production, with 768 MW for electricity and 841 MW for heat generation.[3] The long-established capacity in geothermal projects has been developed around high enthalpy dry steam or single flash technologies. Recent geothermal capacity has been realised in Germany, using lower temperature geothermal resources in binary cycle plants.

[1] Trinomics (2018) - Study on impacts of EU actions supporting the development of renewable energy technologies – Literature review and methodology (Deliverables D1.1 and D1.2)
[2] Geothermal heat pumps are excluded from this sector because these are a distinct set of technologies that do not generate renewable energy but are rather seen as energy efficiency measures.
[3] Eurostat and EurObserv'ER

2 Historical R&D funding

2.1 EU R&D funding

The EU has made funding available for the development of geothermal energy through research and development programmes, and also bespoke policies to support technologies during the demonstration phase. Research and development funding has been made available through the Framework Programmes (FPs) for research and technological development. For geothermal energy, these FPs and the more recent Horizon 2020 (H2020) programme have provided EUR 144 million in funding to 37 projects (covering heat and electricity).

Table 2-1 EU funding per framework programme (1998 to mid-March 2018 in millions of 2016 euros[4])

Framework programme	Period	EU funding	No. of projects
FP5	1998-2002	13.64	11
FP6	2002-2006	17.35	5
FP7	2007-2013	22.12	6
H2020	2014-2020 *(data available up to mid-March 2018)*	90.80	15
Total EU funding		143.91	37

Source: CORDIS (2018)
Note: Funding includes all funds made available through the Framework Programmes. It is not limited to the energy challenges but also includes funding through other programmes/instruments such as the SME instrument.
H2020 includes all projects awarded and registered in CORDIS up to mid-March 2018. As H2020 runs from 2014 to 2020, not all funding had been awarded at this point.

2.1.1 Evolution of research topics

EU funding was divided across several sub-technologies and areas, as shown in Figure 2.1. Generally speaking, early research projects in for example FP5, tended to focus on knowledge sharing, identifying knowledge gaps, and setting the R&D agenda for future projects. More recent geothermal projects in the H2020 programme, have tended to focus on risk management of induced seismicity, after a small number of projects in the geothermal industry were cancelled due to unexpected seismic events.

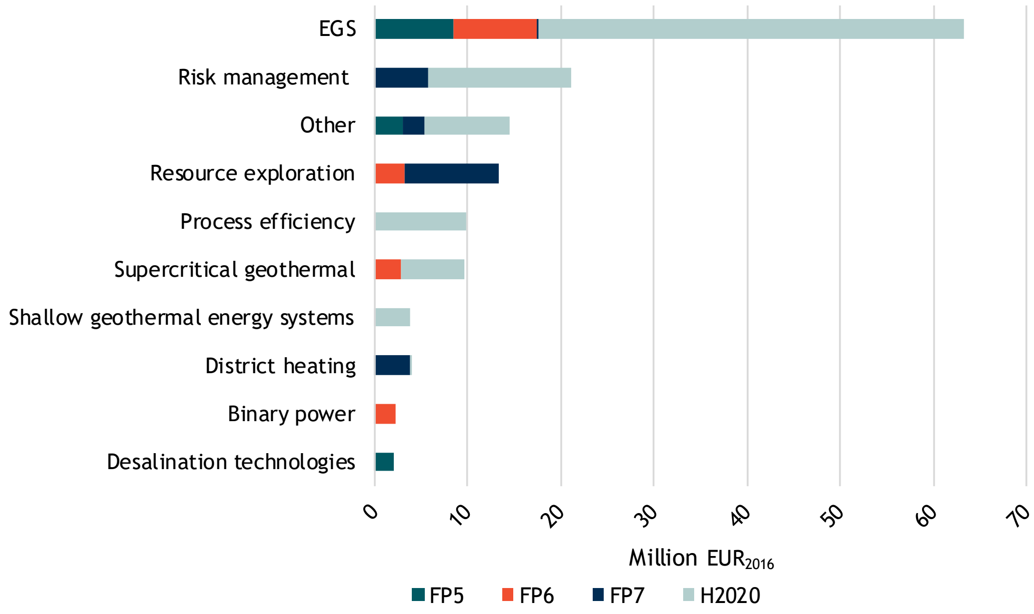
Enhanced Geothermal Systems (EGS) have received the most EU funding, with EUR 63.3 million being provided to nine different projects. The growth in interest in EGS has coincided with advances in the oil and gas industry around hydraulic fracturing techniques. These stimulation techniques have the potential to improve performance of geothermal projects in established regions, but also broaden the applicability of the technology to regions with less suitable geology (i.e. Switzerland, France, Austria). In H2020 the sub-technology received EUR 45.6 million, which is more funding than any of the other research topics have received. Risk management (EUR 21.2 million) and resource exploration (EUR 13.4 million) received the second and third highest levels of funding over the period from 1998 to 2018.

Regarding the number of projects, nine EGS projects were funded, and eight knowledge sharing projects. All other sub-technologies had up to three projects funded throughout the period. Resource assessment, desalination technologies, market development, binary power and shallow geothermal energy systems all had one project funded. Resource exploration and the development of low-cost

[4] Historical values have been inflation adjusted to arrive at 2016 constant values. This has been done to show the values of budgets, prices and other monetary indicators without the impact of varying price levels over the years so that they can be compared over time more accurately.

exploration tools and techniques have been constant themes in European R&D, as the geothermal industry attempted to become less dependent on the expensive services of the oil and gas industry.

Figure 2-1 EU funding per sub-technology/area (2016 million euro)



Source: CORDIS (2018)

2.1.2 Top recipients

The top 10 recipients of EU funding for geothermal energy technologies include six research institutes, two utilities, one project developer and one ministry (see Table 2-2). These organisations received 53 % of the EU funding over the most recent years (H2020 and part of FP7), which is high compared to other renewable energy (RE) sectors[5] and shows that geothermal R&D is concentrated in the hands of a limited number of companies and research institutes. Furthermore, especially the top five organisations show a healthy balance between research institutes and private companies, pointing to successful knowledge transfer from researchers to the private sector.

Table 2-2 Top 10 recipients of EU funding by organisation (2008 to mid-March 2018 in 2016 euros)

Rank	Organisation	Type of organisation	Funding
1	Helmholtz Zentrum Potsdam Deutsches GeoForschungsZentrum GFZ	Research institute	10 787 779
2	Fonroche Geothermie SAS	Project developer	8 411 728
3	Islenskar orkurannsoknir	Research institute	6 917 710
4	HS Orka hf	Utility company	6 810 395
5	Enel Green Power	Utility company	6 013 283
6	Nederlandse Organisatie voor toegepast natuurwetenschappelijk onderzoek TNO	Research institute	5 525 609
7	Bureau de Recherches Geologiques et Minieres	Research institute	4 588 942
8	Consiglio Nazionale delle Ricerche	Research institute	3 364 545
9	Vlaamse Instelling voor Technologisch Onderzoek n.v.	Research institute	2 947 223
10	Ministerie van Economische Zaken en Klimaat[6]	Ministry	2 091 804

Source: CORDIS (2018)
The source data covered H2020 funding and FP7 funding from 2008, which includes 76 % of total funding for geothermal energy identified in section 2.1. No data was available for recipients of FP5, FP6 and part of the FP7 funding. Projects under 'multiple RES technologies' are not included in this table.

[5] In RE sectors such as ocean (44%), geothermal (53%) and hydro (71%), the top 10 organisations attract a relatively large share of the total funding. For bioenergy (14%), solar PV (25%), wind (26%), biofuels (31%) and solar thermal (32%), the top 10 organisations attract much lower shares of the total funding available.
[6] Note that the ministry is not the final recipient of the funding as this concerns GEOTHERMAL ERA NET and GEOTHERMICA funding, which will be disbursed to research projects / organisations through these projects.

The main recipients of EU funding in terms of countries are Germany, France, Iceland, Italy and the Netherlands (see Table 2-3). These countries received 76 % of the total EU funding available for geothermal energy, which is high compared to other RE sectors and underlines that geothermal energy R&D is concentrated in a select number of Member States. With the exception of the Netherlands, these countries are also the countries with the highest installed capacities (see section 5.1).

Table 2-3 Top 10 recipients of EU funding by country (2008 to mid-March 2018 in 2016 euros)

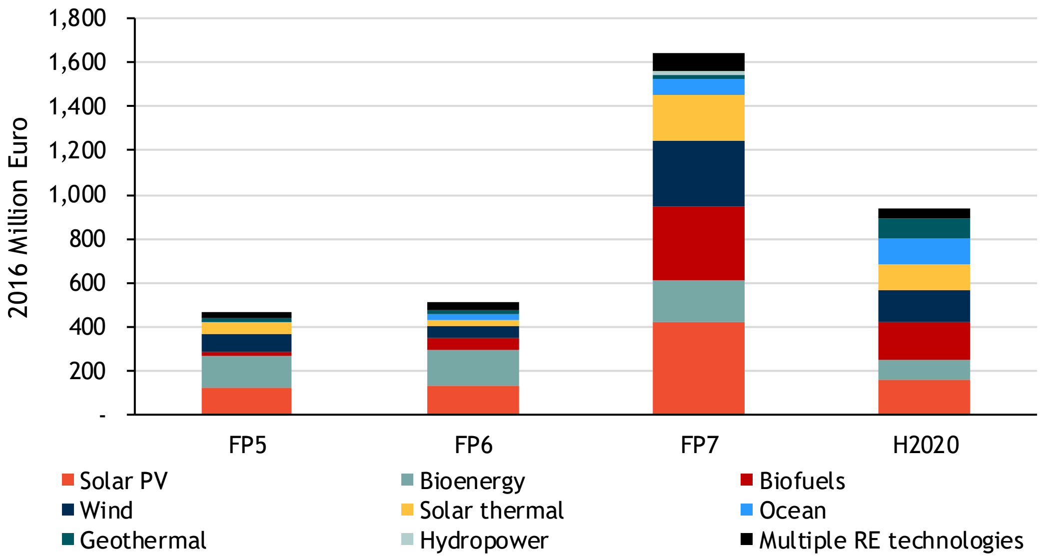
Rank	Country	Funding
1	Germany	20 436 305
2	France	19 608 627
3	Iceland	15 744 678
4	Italy	14 324 322
5	Netherlands	12 276 244
6	Belgium	4 763 302
7	Norway	4 026 481
8	Spain	3 702 275
9	Austria	2 989 639
10	United Kingdom	2 164 134

Source: CORDIS (2018)
The source data covered H2020 funding and FP7 funding from 2008, which includes 76 % of total funding for geothermal energy identified in section 2.1. No data was available for recipients of FP5, FP6 and part of the FP7 funding. Projects under 'multiple RES technologies' are not included in this table.

2.1.3 Share of funding for each sector in proportion to the overall funding of all RE technologies

Overall, geothermal energy projects received 4 % of the EUR 3 6 billion awarded to all RE technologies through the FP5, FP6, FP7 and H2020 programmes. In FP5, FP6 and FP7, it received less than 4 % with shares of 3.0 % (FP5), 3.4 % (FP6) and 1.3 % (FP7). In H2020, geothermal energy received a considerably larger share of the overall funds available so far, with 9.7 %. Overall, this shows that geothermal energy has received little support compared to other RE technologies, but that the level of support has increased in the last Framework Programme.

Figure 2-2 Share of funding for each technology sector in proportion to overall funding (H2020 only up to mid-March 2018)



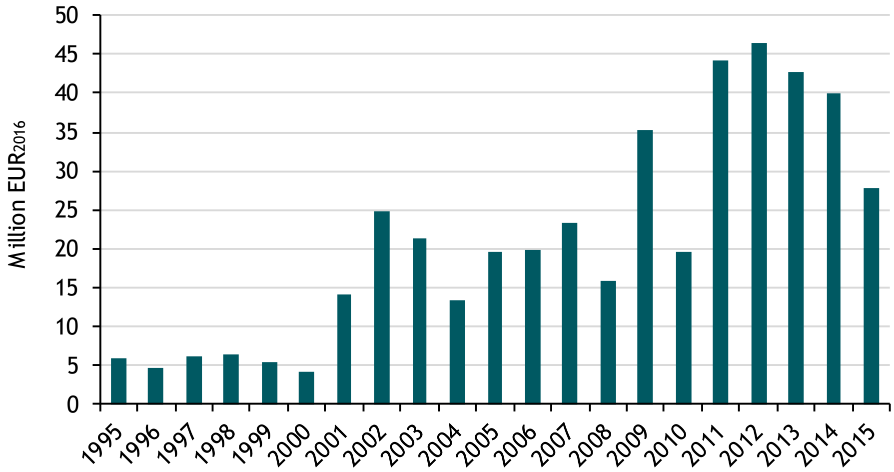
Source: CORDIS (2018)
The area 'multiple RES' includes projects of multiple RES technologies.

2.2 Member State R&D funding

2.2.1 Evolution over time

Annual geothermal energy R&D funding by EU Member States (MS) increased after 2000, from EUR 5.5 million on average between 1995 and 2000, to EUR 20.7 million on average between 2001 and 2010 (see Figure 2-3). This is about five times as high as the average annual EU funding from the FPs between 2001 and 2010 (EUR 4.1 million). MS funding increased further in the period 2011 to 2015, with on average EUR 40.2 million a year, which was about four times larger than EU funding in the same period. The decline in funding to 2015 is partly due to missing data for Italy (which had EUR 6.1 million in 2014), but also represents a real drop in funding.

Figure 2-3 Annual MS R&D funding in the EU for geothermal energy

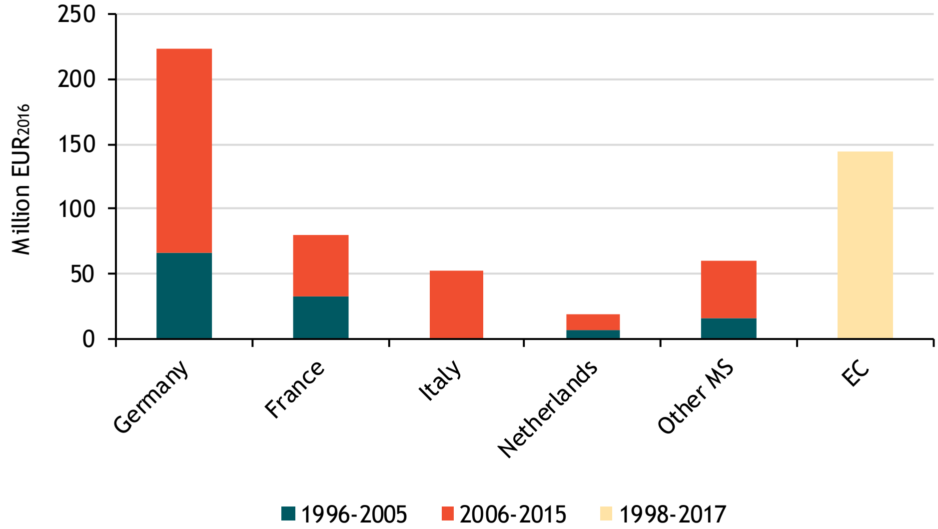


Source: Based on data from OECD/IEA (2018).
Note: Data for 20 EU countries was available in this source: The EU15 plus Czech Republic, Estonia, Hungary, Poland, Slovakia from the New Member States (NMS-13).

2.2.2 Largest MS funders

Figure 2-4 shows the EU funding compared to the largest four MS funders, which are Germany, France, Italy and the Netherlands. Together they have provided 86 % of total MS funding. Germany provided more funding than all other EU MS combined, even though it had a smaller amount of installed capacity and generated less geothermal energy than Italy and France.

Figure 2-4 Geothermal energy R&D budgets of the main Member States (1996-2015) and the EC (1998-2017)

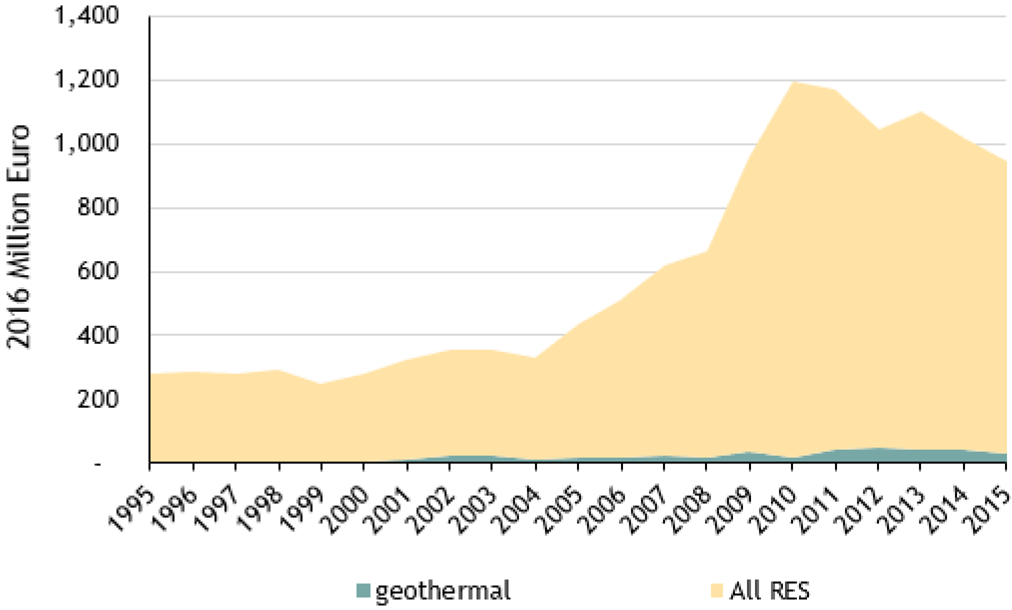


Source: Own elaboration based on data from OECD iLibrary and CORDIS (2018).
Note: Time window of comparison between MS and EC funding is shifted 2 years due to data availability of MS budgets for the scope of analysis (FP5-H2020).

2.2.3 Share of total RE technology funding

In the period of 1995 to 2015 Member States allocated 3.5 % of their National RD&D funding for Renewable Energy technologies to geothermal energy. From 1995 until 2000 the share of geothermal energy was relatively low, receiving around 2 % of the overall RE technology funding. From 2001 it increased sharply to peak levels of 6.9 % in 2002 and 6 % in 2003. From 2004 onwards, the share has oscillated around 3.5 % of the total RE technology funding. Overall, it can be included that geothermal energy has never been one of the top recipients of MS R&D funding, but has maintained a relatively stable share over the years.

Figure 2-5 Share of National R&D funding for geothermal energy in proportion to the overall funding for all RE technologies



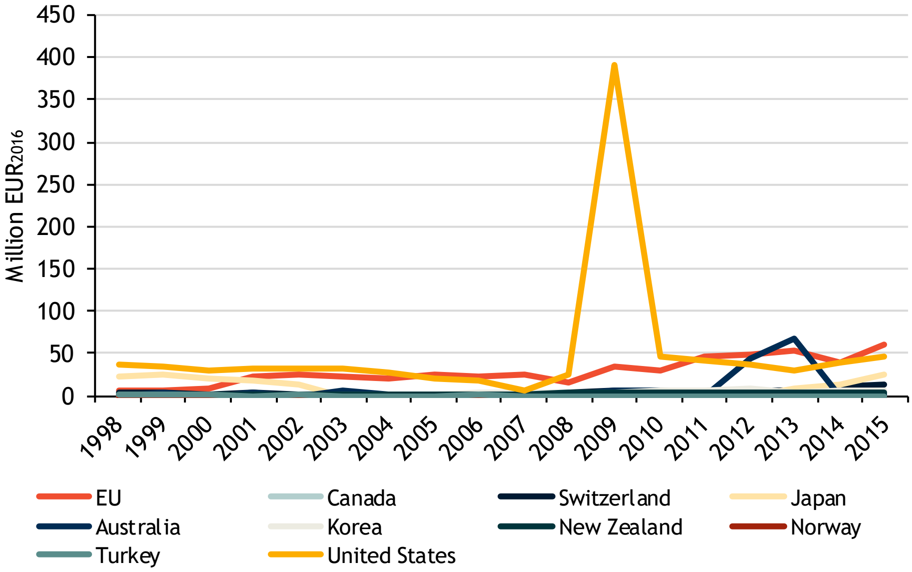
Source: Based on data from OECD/IEA (2018).
Note: Data for 20 EU countries was available in this source: The EU15 plus Czech Republic, Estonia, Hungary, Poland, Slovakia from the New Member States (NMS-13). Data for Italy was not available for 2010 and 2015, and data for the UK was not available for 2008.

2.3 Private and international R&D funding

2.3.1 International public R&D funding

The US had an exceptionally high R&D budget for geothermal energy in 2009[7], when President Obama signed a Recovery Act Funding of USD[8] 350 million for geothermal projects.[9] Apart from this year, it funded EUR 33 million per year on average throughout the period 1995 to 2015. This is higher than the EU, which funded EUR 25 million on average (EU and MS funding combined). Japan also had a significant budget of EUR 11 million on average. Australia had two exceptional funding years in 2012 and 2013, in which it funded a total of EUR 113 million, while in other years it funded on average EUR 2 million a year between 2003 and 2015. Korea has a substantial R&D budget for geothermal energy since 2003, funding on average EUR 4 million a year, and Switzerland and New Zealand each funded EUR 2 million a year between 1995 and 2015.

Figure 2-6 Comparison of international R&D funding for geothermal energy



Source: OECD/IEA (2018).
Note: EU: European Commission and Member State budgets combined.
National budgets for 2016 were excluded from the analysis because they are early estimates and lack reliability/coverage. Data covers 20 EU countries: the EU15 and Czech Republic, Estonia, Hungary, Poland, Slovakia. For countries outside the EU, national budgets were available for Australia, Canada, Japan, Korea, New Zealand, Norway, Switzerland, Turkey and the US.

2.3.2 Private R&D funding

Global private R&D for geothermal energy is estimated to be around USD 50 million in recent years (2016-2017), compared to an estimated global public R&D of USD 200 million.[10] As such, the public sector is the main funder of geothermal R&D, which is not surprising considering the limited size of the industry. It should be noted that the geothermal energy sector benefits from private R&D from other sectors such as the oil and gas sector which uses similar technology for instance for drilling. Hence, total private R&D funding with relevance for geothermal energy is much higher than the USD 50 million reported.

[7] Note from data source: This is a one-year appropriation (although actual expenditures may go into future years) and so 2010 saw a significant decrease.
[8] Where USD is the US dollar
[9] https://www.energy.gov/eere/geothermal/articles/president-obama-announces-over-467-million-recovery-act-funding-geothermal
[10] Source: Frankfurt School-UNEP Centre/BNEF – Global Trends in Renewable Energy Investment. 2017-2018 editions.

2.4 Conclusions

The share of geothermal energy R&D in the total RE R&D budgets of the EU and MS has been relatively low at about 4 %. Compared to MS funding, EU funding has been significant, ranking behind Germany but before the other Member States in terms of the amount funded. In absolute terms, EU funding for geothermal energy has increased considerably from the earlier FPs (FP5 and FP6) to the most recent ones (FP7 and H2020). From a global perspective, the combined EU and MS budgets are high and should provide a solid basis for EU leadership in the sector.

EU-funded R&D projects initially focused on knowledge sharing, particularly between countries with well-established geothermal sectors (Italy and Iceland), and other countries developing an interest in the technology (e.g. France, Germany, Hungary, Austria and Switzerland). Later, Enhanced Geothermal Systems (EGS) projects became the main focus of R&D, which coincided with developments of hydraulic fracking in the oil and gas industry and induced seismic events at EGS sites in Switzerland. The main recipients of EU R&D funding are the leading research institutes in the sector as well utilities in the countries with most developed geothermal sectors (Iceland and Italy).

3 Research effectiveness

R&D projects can lead to patents, publications, spin-offs and several other, less concrete but potentially important direct outputs such as standardisation and knowledge exchange. Such impacts are the most direct impacts of R&D funding and therefore provide the cleanest view on the effectiveness of research budgets spent. In this section we discuss patents, publications, spin-offs and other direct research outputs, and their relation to R&D funding for the geothermal energy sector.

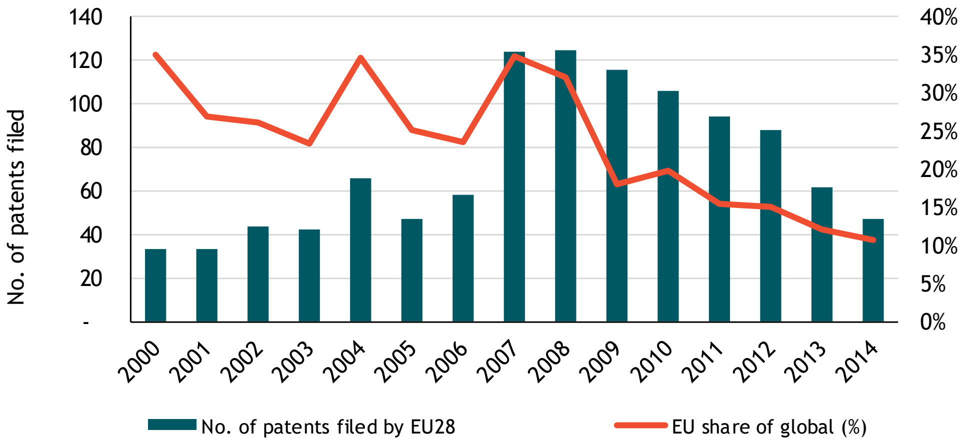
3.1 Patents

Patents are a commonly used indicator to measure the output of R&D funding as they provide a direct measurement of the impact in terms of novel knowledge generated. Furthermore, patent data are readily available, in a standardised form. However, some limitations have to be taken into account, such as the fact that filing a patent is not an objective of all research projects and that the economic value of patents varies significantly.

3.1.1 Evolution over time

Figure 3.1 shows the evolution of patents filed for geothermal technologies in the EU. The number of EU patents increased between 2000 and 2007, after which it gradually decreased again. The spike in patent applications from 2007 could be associated with the overall market growth for geothermal technology, brought about by the rapid increase in the number of geothermal projects realised since 2005. The majority of this growth can be attributed to the fast expansion of binary geothermal projects in Germany (nine projects realised since 2007).[11]

Figure 3-1 Evolution of geothermal patents filed by EU countries



Source: IRENA INSPIRE (2017)

There is a downward trend in EU's share of global patents filed for geothermal technologies. This is not only due to the decrease of EU-filed patents in absolute terms: the share dropped from 32 % in 2008 to 18 % in 2009, while the number of patents filed only decreased a little. Another key reason is the sharp increase in patents filed from the US, Japan and China. The US, which hosts the global market leader in binary cycle power plants (Ormat Technologies Inc), experienced a growth from 77 patents filed in 2008 to 131 patents filed in 2009. At the same time, Iceland has experienced steady growth in single/double-flash geothermal projects, using turbine systems from Japanese companies Fuji Electric Co. and

[11] EGEC 2017

Mitsubishi Heavy Industries Group. This is also visible in the statistics, with a sharp increase from 44 patents filed by Japan in 2008 to 94 patents filed in 2009. Furthermore, China also experienced a sharp increase in patents filed, from 63 in 2008 to 117 in 2009. So, the strength of US, Japanese and Chinese firms in the global geothermal market, combined with the decline in EU patent applications, explains why the EU share of global patents filed has experienced a steady decline from 2007 onwards.

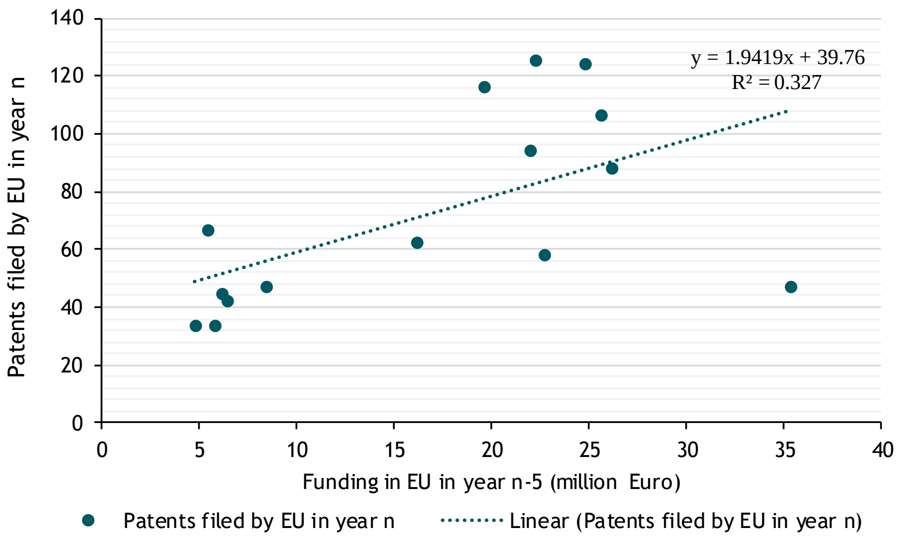
Almost half of the EU patents were filed in Germany (520), which is also the MS that provided more than half of the total MS R&D funding for geothermal energy in the same period. It is however not possible to conclude from this that the MS with the largest R&D budgets also filed the most patents: several MS with a large number of patents only had a small R&D budget. Austria nearly had the same number of patents filed as France (85), which made it the third-largest MS. It however only funded EUR 6.5 million for R&D during this period, while France funded EUR 76 million. Similarly, Poland, Spain, Sweden and the UK had a similar or higher number of patents filed as Italy (46) while they had smaller R&D budgets.

3.1.2 *Effectiveness of R&D funding in producing new patents*

In theory, higher R&D budgets in a region are expected to lead to an increase in the number of patents filed from that region. The extent to which this relation exists in the sector provides insight into the objectives of the research (is it targeted at technology development, so more likely to result to a patent application?) and the effectiveness of the research (was it successful in developing the technology so resulting in a patent application?).

Figure 3.2 compares the total amount of patents filed to the amount of EU R&D funding (MS + EU combined), accounting for a time lag between the moment of funding and the patent application. The highest correlation is visible with a time lag of 5 years. Even then, there is no clear correlation between the number of patents and the amount of EU funding; the funding levels do not explain the number of patents filed. This is in line with the findings for other RE sectors and underlines that patent applications are generally not a primary objective of a research project.

Figure 3-2 Patent effectiveness



Note: We tested a delay of 0, 1, 2, 3, 4 and 5 years for the patents filled between 2000 and 2014. 2015 data of patents was excluded because the source (IRENA) mentioned it is common to have delays of 3 years from a patent application and the year is reflected in the database. The correlation went up when 2015 data was excluded. A delay of 5 years between funding year and patents filed showed the highest correlation (R^2 = 0.327).

3.1.3 Contribution of EU funding

Out of the 13 project coordinators who responded to the questionnaire, one reported two patent application as an output of the project (GEOWELL) (see section 3.4 for more information on the questionnaire). Furthermore, one of the projects interviewed (SURE) reported a patent application that has been initiated. These projects are described in the 'project spotlight' boxes below. The results of the questionnaire seem to suggest that patents are a less common objective of EU-funded R&D projects, at least, in the geothermal energy technology sector.

Project spotlight: GEOWELL

GEOWELL is a H2020 project and has been completed for approximately two-thirds at the time of writing. One key issue faced by the geothermal sector with regards to well integrity, is that of expansion of steel well casings due to the very high temperatures experienced in some geothermal wells. The single most failure mechanism for high-temperature geothermal wells is buckling and mechanical overload of the casing string in the well due to constrained thermal expansion. To deal with this expansion, the partners of ISOR and SINTEF developed a new type of 'flexible coupling' to be placed between segments of well casings, which would accommodate for the expansion and prevent damage to top-side facilities. The technology has been developed from TRL 1 to TRL 4 as part of the project, with a patent filed in 2016.

Source: interview with project work package lead.

Project spotlight: SURE

SURE is a H2020 project that aimed to develop a nozzle for the coinjection of water and abrasives for radial jetting (TRL 4 to 7). Radial jet drilling involves cutting rocks around the geothermal wellbore using high-pressure water jets. However, water alone is only able to cut rocks of certain composition, and tougher rocks require the co-jetting of water and abrasives. The H2020 SURE project has developed a bespoke nozzle which allows the simultaneous jetting of water and abrasives. For this nozzle, a PCT patent application has been initiated.

Source: interview with project manager.

3.2 Publications

Publications of research papers are a useful indicator to measure the output of R&D funding, as there is enough data available to make a comparison between the EU's performance and the rest of the world. Moreover, publications have a close relation with public R&D funding, allowing us to differentiate the effect of public R&D funding from private R&D funding. Limitations to using this indicator are the possibility of a time lag between the funding year and the publication year due to the acceptance process for a research paper and the inclination of editors to publish specific topics in a certain year. Publications are categorised by country on the basis of the address of the author. If it has authors from different regions, the publication is counted for both regions.

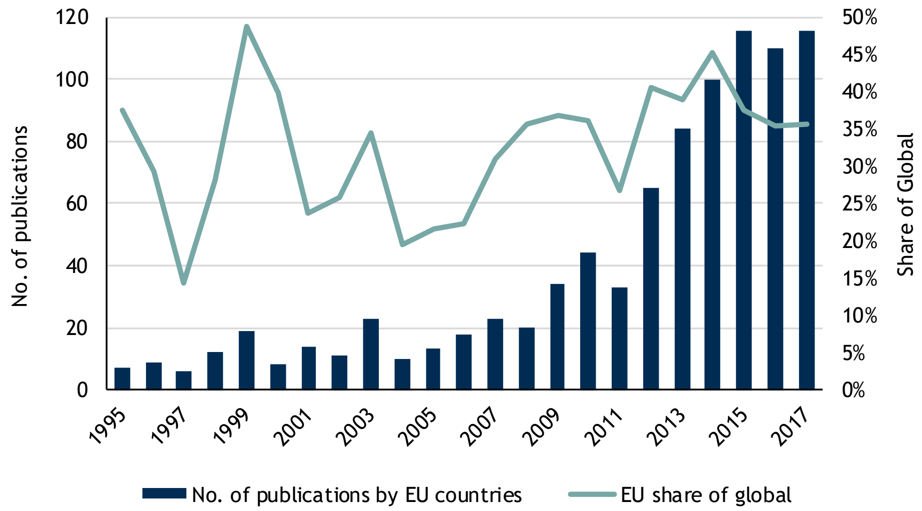
3.2.1 Evolution over time

Figure 3.3 shows the evolution of geothermal publications by EU-based authors over the years. The number of publications on geothermal energy had a fluctuating but upward trend over the years, similar to that of EU funding for geothermal energy. The growth in publications can be attributed to the growth in interest and the growth in R&D funding available for geothermal power across the EU in recent years. Stimulated by EU policy regarding renewable energy targets, numerous EU Member States have started to explore the potential for geothermal power in their energy systems. Increased European and national funding programmes will have therefore greatly contributed to the growth in EU publications.

For the period 1995 to 2017, 36 % of the global publications had EU authors. Three other major players during that period were the USA with 20 % of the global publications, China with 10 % and Turkey with 9 %. The years 2015 and 2017 had the most publications for the EU, with 116 publications in each year. However, the years where the EU had its highest percentage of global publications was in 1999: with 19 publications out of 39, it participated in 49 % of the global publications.

About a quarter of the publications in the EU had an author based in Germany, which made it the MS with the largest amount of publications. It is followed by authors based in Italy, the United Kingdom, and France. Germany, Italy and France are also the MS with the largest R&D budgets and largest installed capacity (together with Hungary). The MS with the fourth largest R&D budget, the Netherlands, only had authors in 6 % of the EU-based publications, and Hungary, one of the MS with the largest installed capacity, only 2 %.

Figure 3-3 Evolution of geothermal publications by EU authors



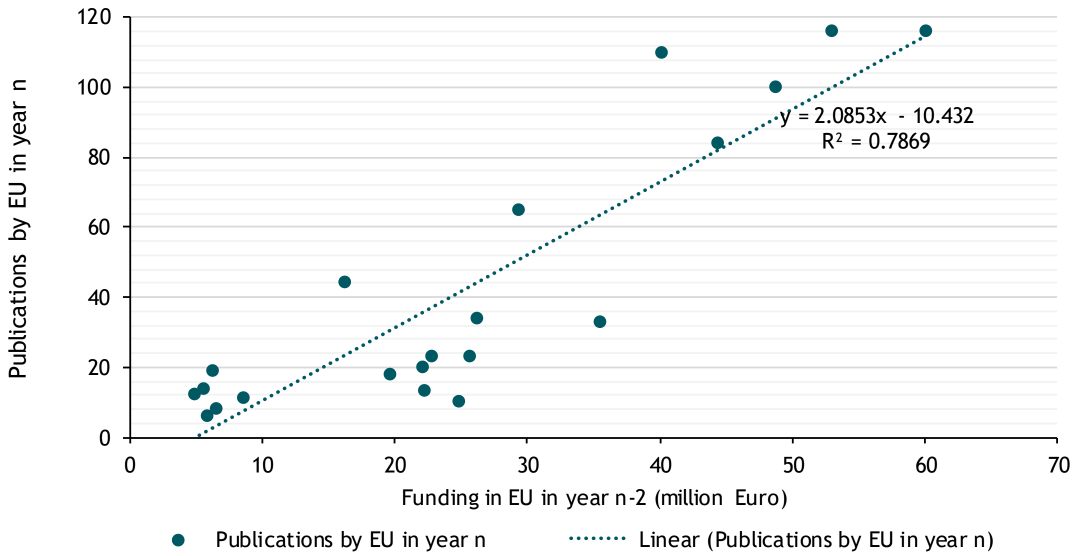
Source: Web of Science (2018), using keywords: 'geothermal energ"NOT"pump' in the title, topics and abstract of articles between 1995 and 2017.*
Note: One article can have multiple authors (therefore, also multiple countries). The count is the number of articles in which at least one author listed an EU MS as their address.

3.2.2 *Effectiveness of R&D funding in producing publications*

In theory, higher R&D budgets in a region are expected to lead to an increase in the number of publications from that region. The extent to which this relation exists in the sector provides insight into the objectives of the research (does it aim for a publication?) and the effectiveness of the research (is it successful in realising a publication?).

Figure 3.4 compares the total amount of EU publications to the amount of EU R&D funding (MS + EU combined), accounting for a time lag between the moment of funding and the publication. The number of publications correlates more closely to R&D funding than the number of patents, indicating that publicly funded R&D projects in the geothermal energy sector have a higher focus on publishing and/or are more effective at publishing. This is in line with the findings for other RE sectors and underlines that publishing is often one of the primary outputs of a research project.

Figure 3-4 Publication effectiveness



Note: We tested the publication effectiveness of R&D funding for the period 1995 to 2017.Funding in EU includes EU funding and MS funding. We tested different delays (0, 1, 2, 3, 4 and 5 years) to evaluate which one had the highest correlation. For each year of delay, the sample size was reduced by one number (e.g. with no delays the sample size was 23 years, with one delay the sample size was 22 years)
With no delays (n-0), the R^2 is the lowest of all the ones tested (0.458). The highest R^2 was found using 2 years of delay (0.7869). With higher delays the R^2 decreases.

3.2.3 Contribution of EU funding

Between 2008 and 2017, 57 publications explicitly reported benefitting from EU funding sources, which is 6 % of the total number of EU publications in these years. Not all publications report all sources of funding that they benefitted from, therefore it is likely that the real figure is higher.[12] The IMAGE project (see project spotlight box below) is an example of a project that delivered many publications. While not all of these are included in the statistics on geothermal publications, conference proceedings have been excluded from this analysis, it shows that the number of EU publications that benefitted from EU funding reported in this section is likely to be a conservative estimate.

Project spotlight: IMAGE

IMAGE is a project funded under FP7 and is a prime example of a project that led to multiple publications. The project has contributed to the advancement of new innovative exploration techniques and has delivered more than 200 publications in peer-reviewed journals and conference proceedings.

More information on the project is available as a case study in the annex of this report.

The questionnaire on the EU funded R&D projects conducted as part of this study indicates that 10 out of the 13 projects that responded delivered one or more publications (see section 3.4 for more information on the questionnaire). The projects that led to publications generally report multiple publications within the scope of their project. In general, also based on the results from other RE sectors, publications are one of the most prevalent results of EU-funded research.

[12] The authors only started to record their funding sources from 2008 onwards. Hence, the data series does not go back before 2008 and especially the data from the earliest years (2008-2010) has a significant number of data gaps. So, the real number of publications benefitting from EU funding is probably significantly higher.
EU funding sources used are not always specified and may therefore include funding from other instruments than the Framework Programmes for research and technological development, such as funding from the EIB.

The top EU organisations in terms of publications are listed in Table 3-1 below. It shows that the top EU organisations in terms of publications often also received considerable funding through the EU framework programmes with the top research institute in terms of funding (Helmholtz) also taking the number 1 rank in terms of publications. On the other hand, top publishing organisations such as INGV from Italy and CNRS from France are not among the top recipients of EU funding, but are located in the top Member States in terms of national R&D budgets for geothermal energy.

Table 3-1 Top organisations in the EU contributing to geothermal publications (1995-2017)

Rank	Institutions	Country	No. of publications (sample)	EU funding rank
1	Helmholtz Association	Germany	83	1
2	Helmholtz Center Potsdam GFZ German Research Center For Geosciences	Germany	43	1
3	Istituto Nazionale Geofisica E Vulcanologia (INGV)	Italy	34	30+
4	Consiglio Nazionale delle Ricerche (CNR)	Italy	33	8
5	Centre National de la Recherche Scientifique (CNRS)	France	30	30+
6	Karlsruhe Institute of Technology	Germany	24	14
7	Bureau de Recherches Géologiques et Minières (BRGM)	France	22	7
8	RWTH Aachen University	Germany	17	22
9	University Of Florence	Italy	17	30+
10	Delft University of Technology	Netherlands	16	24

Source: Web of Science (2018)
Note: Top organisations may include different entities from the same institute. Due to the risk of double counting when co-authors from both entities contributed to the same publication, these statistics could not be merged reliably and are reported separately.
The number of publications is limited to publications in Web of Science (2018), using the keywords 'geothermal energy"NOT"pump'. The scope is limited to avoid false positives (i.e. publications that meet the keywords but do no concern geothermal energy). Hence, these estimates should not be considered as exhaustive. Based on feedback from the industry, the actual number of publications is higher.*

3.3 Start-ups and spin-offs

The creation of start-ups and spin-offs is another potential impact of research projects, which can function as an important link between the research and the development of a European industry. However, start-ups and spin-offs are not reported consistently. Therefore, questionnaire results are used to provide insight into these impacts.

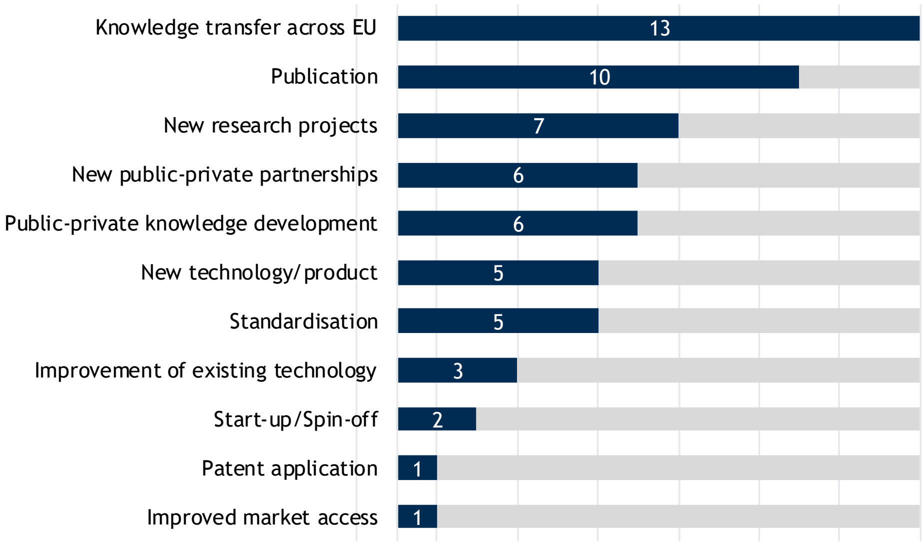
Two out of 13 EU-funded projects that replied to the questionnaire reported the creation of one or more start-ups. This is a low share in comparison with other RE technology sectors. However, it is important to note that some RE technologies are more akin to the creation of start-up/spin-off than others. In the geothermal sector the creation of start-up/spin-offs is difficult because the projects usually require high initial investments. In addition, due to the traditionally large-scale of the projects, these are often coordinated by public authorities. This may also explain that out of the 37 geothermal projects in scope of this study none was funded under the topic of support towards SMEs.

3.4 Other research outputs

EU-funded R&D projects contribute to the development of the geothermal energy sector in various ways that are not captured in statistics on patents, publications and spin-offs. To capture the full range of impacts better, a questionnaire was sent out to all project coordinators involved in geothermal R&D projects funded through the EU Framework Programmes of the last 20 years (FP5, FP6, FP7 and H2020). 37 EU-funded projects in geothermal energy were identified for this study. The overall response rate was 35 % (13 out of 37 projects). Project coordinators of FP7 and H2020 programmes constituted the large majority of responses.

The questionnaire among EU-funded research projects highlighted that knowledge transfer and publications are the most common impacts of EU-funded projects on geothermal energy (see Figure 3-5). Together with the relatively high number of new research projects that followed from the projects under consideration, this highlights that the geothermal projects are, for a large part, research focused and that EU funding contributes to better sharing of the research results.

Figure 3-5 Impacts of EU funding based on questionnaire results (out of 13 responses in total)



Source: own elaboration based on questionnaire conducted as part of this study.

Other noteworthy impacts are new public-private partnerships (6 out of 13) and joint knowledge development with the private sector (6 out of 13), indicating that EU-funded geothermal projects contribute to knowledge transfer from research institutes and universities to the private sector. Through these partnerships, the relevance of the research for the private sector is safeguarded.

The development of new technologies or products (5 out of 13) and cost reductions / performance improvements of existing technologies (3 out of 13) are less commonly reported as an impact. Part of the reason for this relatively low share may be that geothermal energy is not a highly standardised technology/product such as solar PV modules or wind turbines, which makes it less applicable to speak of a 'product' or 'technology' as a discrete item. A number of projects investigated actually focused on the application of existing materials and tools in the challenging environmental conditions experienced in high-temperature geothermal wells. In projects that did develop and test new equipment, the pioneering nature of these actions mean that it is generally too early to consider cost reductions. It must also be noted that the projects considered in scope did not all have technology development as a primary focus, but placed efforts on knowledge sharing, societal questions around geothermal energy, as well as coordination and support actions.

For the same reasons, the limited number of projects reporting start-ups and improved market access can be understood. Furthermore, many of the geothermal projects included manufacturers and utility companies, meaning that the creation of spin-off companies would not necessarily be required.

The ENGINE project, described in Annex 1A and summarised in the 'Project spotlight' box below, is a prime example of a project that contributed to the development of the sector at large through knowledge sharing, the development of tools and handbooks and alignment of R&D priorities.

Project spotlight: ENGINE

ENGINE is an FP6 project that ran from 2005 to 2008. ENGINE is a prime example of a project that contributed to the development of the sector at large through knowledge sharing, the development of tools and handbooks and alignment of R&D priorities. Although a relatively small project in terms of budget (~EUR 3 million), the project has played a key role in fostering increasing collaboration and coordination between European research institutes engaged in geothermal energy and managed to engage approximately 700 stakeholders through the organisation of three general conferences and seven specialised workshops. Additionally, the project delivered a best practice handbook, decision support system as well as a database of exploration tools.

More information on the project is available as a case study in the annex of this report.

3.5 Conclusions

The EU has been successful in establishing and maintaining a leading academic position in the field of geothermal energy. The EU is number one in terms of publications and has been able to preserve this leading position throughout the last 20 years. EU-funded projects have contributed significantly to this leading position, with virtually all EU projects reporting publications as one of their impacts. Furthermore, all EU-funded projects have contributed to knowledge sharing across the EU and many have fostered new collaborations and projects, hereby creating fertile ground for continued academic leadership.

In terms of patent applications, the EU has been less successful, with its share of global patents declining from 35 % in 2000 to 11 % in 2014. Until 2008 this was mainly due to increased patenting activity outside of the EU, but from 2009 onwards also the absolute number of patents filed by the EU declined. One should however be cautious in concluding that the R&D funding has not been effective, as not all of the R&D funding would logically lead to new patents. A large part of the EU funding went to risk management, resource exploration and knowledge sharing, which could contribute to an increased market uptake but not to any technological innovations that require a patent.

Other direct impacts of EU-funded research projects include several new public-private partnerships, new products and technologies and joint knowledge development. Overall, EU R&D funding for geothermal energy has been effective in fostering collaboration and knowledge sharing among the stakeholders in the EU geothermal energy sector.

4 Technology development

One of the core objectives of R&D funding on RE technologies is to contribute to the development of the technology to make it cost competitive and allow for increased uptake of the technology. The impacts on technology development can be assessed technologically, or from an economic point of view, looking at the costs, performance and competitiveness of the technology. This section focuses on key indicators that assess technology development from an economic point of view: capex, opex and Levelised Cost of Energy (LCOE).

4.1 Capex

Capex (capital expenditure) refers to the initial investment costs of the geothermal projects. Cost-reducing innovations can contribute to a downward trend in capex, which in turn can make the sector more cost competitive and increase the uptake of the technology. One of the main limitations of this indicator is that capex is highly location- and technology-specific, and will therefore vary between projects. To be able to provide an overview of the evolution of the capex over time, we consider global historic estimations of capex, including the estimations of regions outside the EU.

The capex for geothermal plants varies greatly for electricity and heat generation (see Figure 4.1 and Figure 4.2). Capex for electricity generation ranges from EUR 1 358/kW to EUR 9 409/kW, depending on sub-technology, year, and source of data. Single flash technologies have the lowest capex, and EGS the highest. Binary cycle power stations hold the middle ground. All data points taken together give an average of EUR 3 931/kW. Capex for heat generation is lower, with the highest reported capex at EUR 4 152/kW, and an average of EUR 1 751/kW. No clear cost trends can be discerned from the data. Only the data from IRENA shows a slightly decreasing capex between 2015 and 2017 for electricity generation.

Figure 4-1 Evolution of capex for geothermal electricity generation (global estimates)

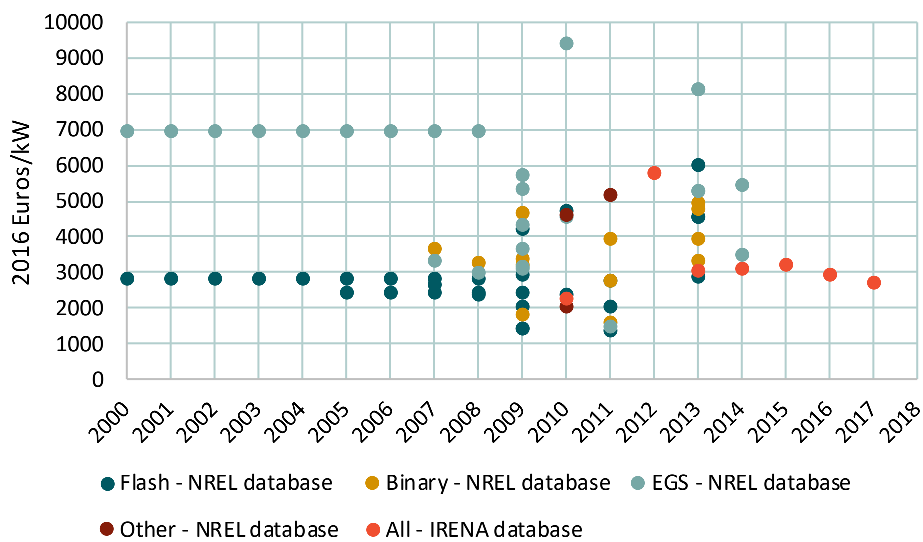
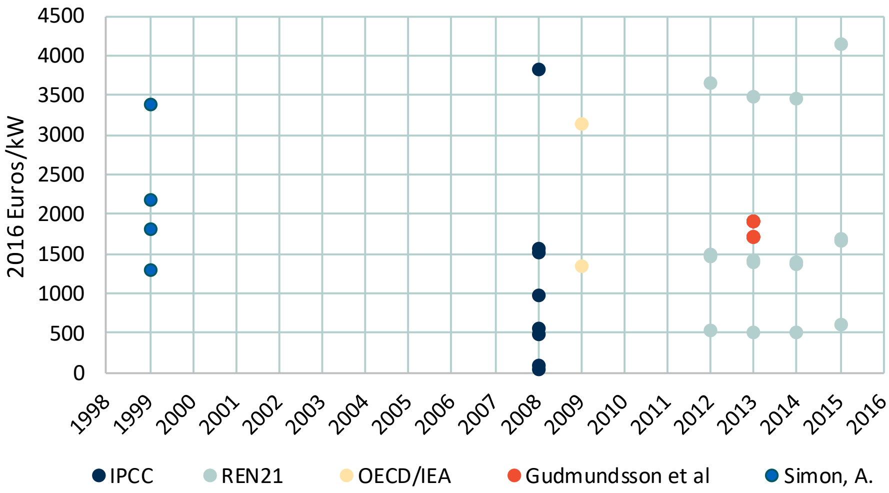


Figure 4-2 Evolution of capex for geothermal heat generation (global estimates)



Note: All figures are global, unless specified otherwise.
For heat generation, data was collected though a desk research. The main sources were IPCC (2008), REN21 reports (2005, 2007, 2010-2015), OECD/IEA (2010) and Gudmundsson et al (2013).
For the data from IPCC, the lowest values are representing greenhouses and aquaculture ponds. Then the report made a distinction between Heat for District Heating and Heat for Buildings. The highest capex reported by the IPCC was for buildings: ~EUR 3 800/kW.
REN21 values are very similar to those from the IPCC. REN21 only distinguished between District Heating and Buildings, District Heating ranges between EUR 500/kW and EUR 1 650/kW. Buildings range between EUR 1 400/kW and EUR 4 150/kW.
Gudmundsson et al only make an estimation for district heating and give a minimum and maximum range based on geothermal heat plants in Denmark and Sweden (1 700 to 1 900) in 2013.
The other desk research source (Simon, A., 2007) gave the earliest estimate of capex (in 1999), giving a range of minimum and maximum costs for small plants of less than 5MW (~EUR 1 800/kW to EUR 3 400/kW) and large plants giving an example of 30 MW as size (~EUR 1 300/kW to EUR 2 200/kW).
For electricity generation, data was taken from NREL database and from IRENA database. IRENA's data is the 'Global weighted average' based on their database with ~15 000 real projects.

4.2 Opex

Opex (operational expenditure) includes fixed and variable costs for operation and maintenance (O&M) of the plants. Similar to capex, cost-reducing innovations can contribute to a downward trend in opex, which in turn can make the sector more cost competitive. Opex is less location-specific than capex, but can show large variations between sub-technologies. Only global figures were available for the opex.

Compared to the relatively high capex for geothermal plants, the O&M costs are low. The power plant requires no fuel to operate, and dry steam and flash power plants can operate as base load for long periods of time. The turbines used in dry steam geothermal power plants are specially developed to withstand the corrosive effects of geothermal steam and are designed to last for the projects' economic lifetime. For binary power plants, the O&M costs are slightly higher primarily due to the high failure rate of submersible pumps which are often not designed for use in the salty brine conditions that are frequently present in geothermal wells.

Figure 4.3 and Figure 4.4 show the evolution of the opex for electricity generation and heat generation. The opex for electricity generation ranges from 0.7 to 5.9 EURct/kWh, depending on sub-technology, year, and source of data. Similar to the capex, the opex of single flash technologies is the lowest, and EGS the highest. All data points taken together give an average of 2.5 EURct/kWh. There is limited data available for the opex of heat generation, but estimations are three-to nine-fold lower than for electricity generation. Estimates range from 0.08 to 1.7 EURct/kWh according to Simon (2007) and 1.6

to 1.8 EURct/kWh according to Grudmundsson et al (2013). No clear cost trend can be determined from these sources.

Figure 4-3 Evolution of opex for geothermal electricity generation (global estimates)

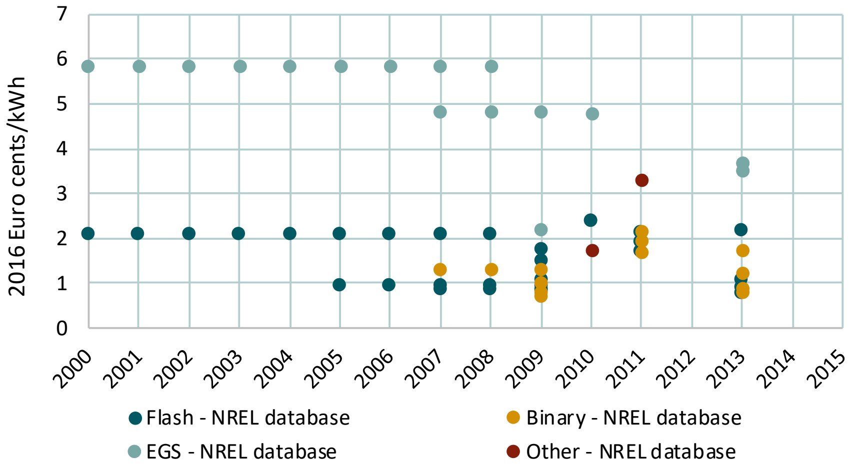
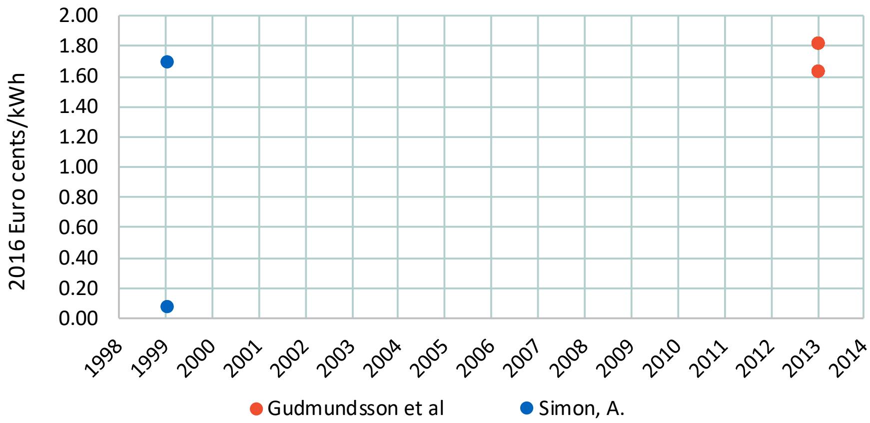


Figure 4-4 Evolution of opex for geothermal heat generation (global estimates)



Note: All figures are global, unless specified otherwise.
Estimates for O&M costs for heat production are not presented in literature, only two sources gave estimates: Gudmundsson et al (2013) used O&M as a function of capital costs (opex = 2.5 % of capital costs) in a study to determine the cost of district heating using low temperature geothermal, using as reference Denmark and Sweden for capex and opex. The other estimate comes from Simon A. (2007) for 1999, which only gives a range of minimum and maximum O&M costs, without specifying if it was for a large or small heat plant.

4.3 LCOE

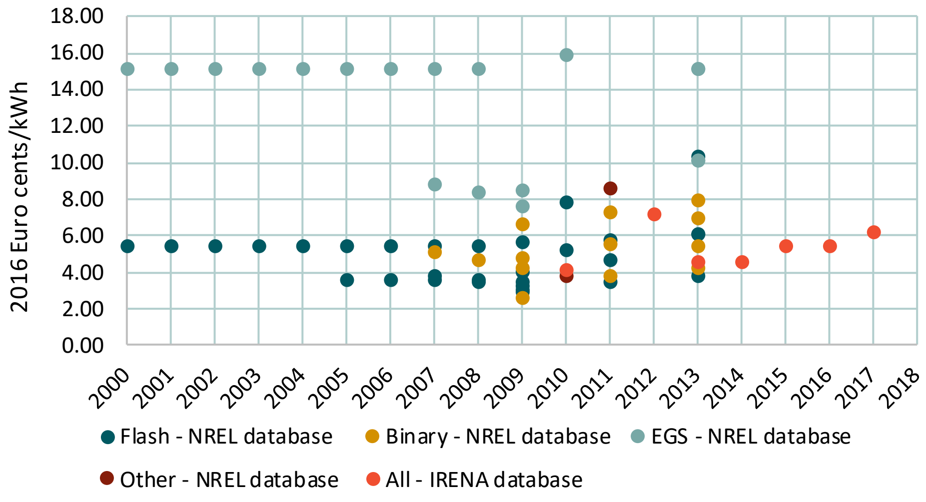
The Levelised Cost of Energy (LCOE) is an indicator to compare the project costs of different energy generation technologies.[13] LCOE is most commonly used in the context of electricity generation, with the 'E' denoting electricity. However, LCOE can also be applied to heat generating technologies, sometimes then denoted as Levelised Cost Of Heat. In this document, we use LCOE as Levelised Cost Of Energy, specifying in each case if this concerns electricity or heat.

Similar to capex and opex, cost-reducing innovations can contribute to a downward trend in LCOE, which in turn can make the technology more cost competitive. While LCOE is a relatively comprehensive measure of the technology's costs, it does not include all the costs for delivering energy, such as ancillary services and transmission and distribution costs.

Figure 4.5 and Figure 4.6 show the evolution of the LCOE for electricity generation and heat generation. The LCOE ranges from 2.6 to 8 EURct/kWh for binary plants, 2.8 to 10.3 EURct/kWh for flash technologies, and 7.6 to 15.9 EURct/kWh for EGS. Similar to capex and opex, no clear cost trend can be observed, but interestingly, data from IRENA shows an upward trend since 2013 while a downward trend in capex is observed. A possible explanation is that the earlier installations were all located in the high enthalpy areas of Italy, while newer installations are being built in less optimal regions, leading to lower performance which drives the LCOE upwards.

The LCOE for heat generation has a very broad range, of 0.4 to 60 EURct/kWh, depending on the type of application, year and source. No clear trend is visible, but the REN21 figures seem to indicate an increasing LCOE between 2005 and 2016. As only limited data is available for heat generation, no conclusions can be reached based on these figures.

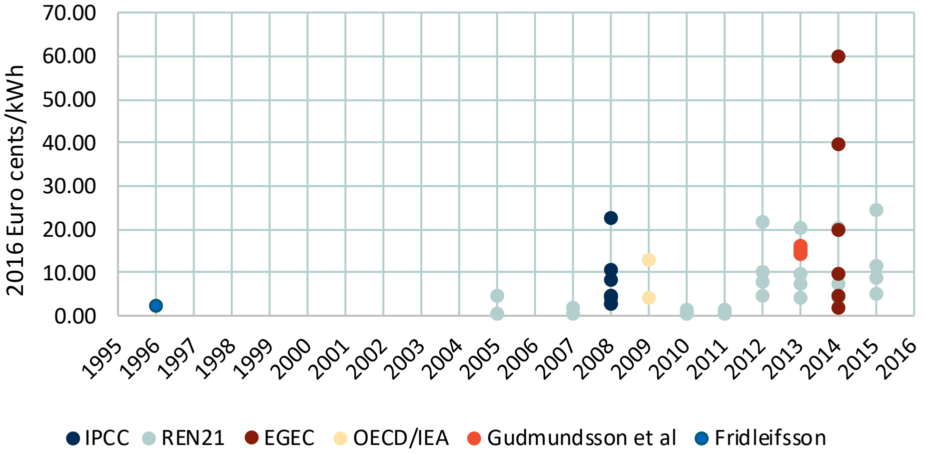
Figure 4-5 Evolution of LCOE for geothermal electricity generation (global estimates)



Note: For electricity LCOE was calculated for the NREL database values using the market values of NREL (72-95 % capacity factor, and between 20 and 30 years of plant lifetime). A discount rate of 7.5 % was used, taken from IRENA's methodology, and the capex was annualized using the Capital Recovery Factor Method.
LCOE from IRENA was taken directly from the database and converted to EUR$_{2016}$.

[13] There are different ways of calculating the LCOE; the method applied here is explained in the methodology document.

Figure 4-6 Evolution of LCOE for geothermal heat generation (global estimates)



Note: LCOE for heat generation was taken directly from the desk research data sources and converted to EUR_{2016}. EGEC (2014) assesses district heating and direct uses of heat for balneology, greenhouses, agro-industrial processes, etc. It gives minimum, maximum and average values for the two different heat applications: district heating (2, 20 and 60 EURct/kWh respectively), and for direct uses (EUR 5/kWh, EUR 10/kWh and EUR 40/kWh).

For the industry experts interviewed for this study, the lack of a clear trend in the capex, opex and LCOE data is not surprising for several reasons. Firstly, the resource bases (areas of high geothermal gradients) are being developed against a marginal cost curve, where the most attractive resources are exploited first. So potentially the 'low hanging fruits' in these regions have already been picked, meaning that consequent projects may face higher costs and lower energy output, leading to a higher LCOE. Improvements in exploration, planning and production may help to balance the higher costs in less favourable areas. Secondly, the cost of developing geothermal wells is linked to fluctuations in the oil and gas industry, particularly with the availability of drilling rigs. Hence, cost reductions thanks to technological advances may be offset by higher costs of drilling rigs in some years, while the cost reductions may be increased in other years when drilling rigs are cheaper.

Another important point is the environmental considerations of these projects. The Larderello geothermal system is the largest in the EU, with 800MW production capacity. The project developers are looking at developing and investing in new systems that do not release CO_2 or other non-condensable gases during the extraction of the geothermal heat. These new systems may have higher costs but do improve the environmental performance of geothermal energy projects. A similar example can be seen in the Netherlands, where the price of developing geothermal projects has not dropped, because geothermal wells sometimes release small amounts of associated hydrocarbons which need to be removed from the geothermal system at the surface. Although these hydrocarbons can either be used on site or sold, the separation equipment needed leads to elevated capital costs of the overall project. Finally, additional emphasis on risk reduction, such as induced seismicity may also increase the costs of projects.

For all these reasons, it is not possible to conclude that the lack of a clear downward trend in LCOE is an indication of a lack of effectiveness of the R&D in reducing the costs of the technology. On the contrary, several projects had identified ways to cost reductions for the sector, as illustrated by the 'project spotlight' boxes on the SURE and IMAGE projects below. The slightly downward trend of capex in recent years may very well be a sign of effective R&D efforts to bring the costs down, while the slightly upward trend in LCOE may point to the deployment of the technology at less favourable sites.

Project spotlight: SURE

SURE is a H2020 project and runs from 2016 to 2019. The project contributed to cost reductions in the sector through the development of a downhole geophone memory tool, which is used to provide seismic data of the rock layers around the geothermal well. This tool provides a low-cost solution for quickly assessing the geology surrounding the geothermal well.

Source: interview with project manager.

Project spotlight: IMAGE

IMAGE is an FP7 project and ran from 2013 to 2017. The project involved the testing of 20 novel geological, geochemical and geophysical exploration methods and techniques. For example, the project contributed to cost reductions in the sector through the development of improved software for low cost and more effective geothermal resource exploration. The new software, termed the Non Local Means (NLM) algorithm, is able to cheaply reprocess vintage seismic data in resource assessment workflows. The use of vintage seismic to good effect can effectively prevent the need for new seismic surveys which can lead to cost savings of approximately EUR 200 000 per geothermal project. In addition, the project contributed the advancement of passive seismic exploration techniques, or ambient noise seismic interferometry (ANSI), for use in the exploration of sedimentary basins. Active seismic campaigns using seismic vibration trucks and receivers are costly, but in IMAGE portable seismometers were demonstrated to improve the image of the subsurface at a much lower cost.

A large number of methods and technologies developed in IMAGE have been applied in industry workflows such as new processing techniques of vintage seismic in the Bavarian Molasse Basin. The technique for the optimisation of vertical seismic profiling (VSP), which has a favourable cost-benefit ratio, has been used in the exploration phase of the ultra-deep IDDP-2 geothermal project in Iceland, completed in 2017.

More information on the project is available as a case study in the annex of this report.

4.4 Conclusions

The technology development indicators do not show a clear trend in the costs of geothermal energy projects over time. Part of the reason why no cost-reducing trend can be observed is the high impact of the location-specific characteristics of geothermal plants and the fact that the best locations have been used first. As a result, newer projects generally have less favourable conditions than older projects, potentially offsetting the cost reductions through technology advances. For instance, plants in regions with high enthalpy, such as Italy, are more cost-effective than in areas with medium temperature basins such as Germany. Another example is that innovations in sub-technologies such as EGS have the potential to improve the performance of projects in established regions, but they also broaden the applicability of the technology to regions with less suitable geology, where plants are by default more expensive to build and operate.

Other reasons for the lack of a clear trend in the costs of geothermal energy are the impact of the oil and gas industry on the price of drilling rigs and the increased focus on environmental performance and risk reduction. As such, it is difficult to conclude from the quantitative data to what extent the R&D activities in the geothermal energy sector have contributed to making the technology more cost-competitive. Looking at bottom-up inputs from project developers and sector experts, it is clear that several projects contribute to cost reductions for the sector. The slight decrease in capex over recent years may be a sign that these efforts pay off, whereas the slight increase in LCOE may be due to the deployment of the technology at less favourable sites and increased attention to risk management, environmental performance and public engagement.

5 Social, economic and environmental impacts

Public R&D funding for RE technologies is justified by several social, economic and environmental impacts. In this section we evaluate a range of indicators that provide insight into these impacts: installed capacity, annual generation, industry turnover, imports/exports, jobs and share of energy consumption.

A direct link between these indicators and R&D funding is hard to establish, as the impact of R&D funding is confluent with numerous other factors that drive or prevent deployment, such as subsidies, regulation and public acceptance. Still, the indicators presented in this section are relevant indicators to assess the evolution of the geothermal energy sector over time.

5.1 Installed capacity

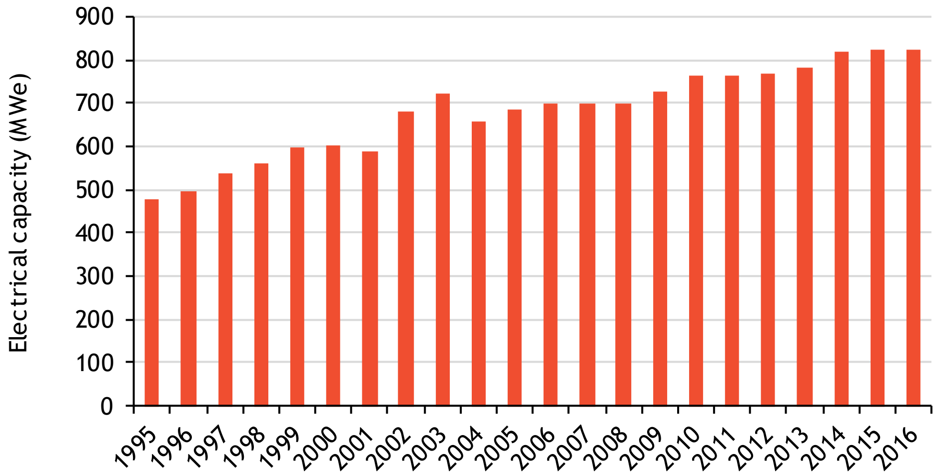
As installed capacities for RE technologies provide (near) carbon free energy that prevents the need for fossil fuel-based energy, they can be considered a measure of the environmental impacts. Installed capacity refers to the maximum installed generation capacity. This is expressed in MWe for electricity and MWth for heat production.

At the end of 2016, a total of 53 geothermal power plants operated in the EU. The total installed capacity of these plants combined amounted to 824 MWe and approximately 3 460 MWth. The large majority of installed capacity for electricity uses dry steam technologies. Other technologies used are single flash and binary technologies.[14]

The installed capacity for direct use of geothermal energy for heat in the EU has increased considerably in recent years, particularly in France, Hungary and Italy, where it is mainly used in district heating systems. Further growth in the European geothermal sector, both for power and heat, is expected through the use of Enhanced Geothermal Systems (EGS). EGS are engineered reservoirs, created to produce energy from geothermal resources that are otherwise not economical due to lack of water and/or permeability. Additionally, the development of geothermal technology to access supercritical conditions could provide access to additional geothermal resources. The recently completed DESCRAMBLE project is an example of how EU funding supports such developments (see project spotlight box below).

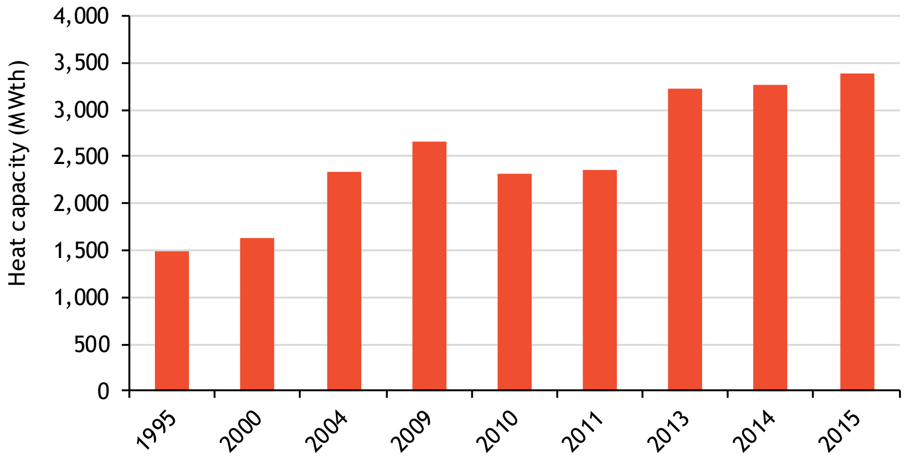
[14] EGEC (2017), EGEC Geothermal Market Report – 2016.

Figure 5-1 Installed capacity of geothermal electricity plants in the EU



Source: Eurostat (2018)

Figure 5-2 Installed capacity of geothermal heat plants in the EU



Source: Freeston (1995), Lund and Freeston (2001), Lund et al (2005, 2010), and EurObserv'ER (2009-2016)
Note: Data for the installed heat capacity of geothermal plants is less accurate than data for electricity capacity. Figures for 2009 to 2015 are based on EurObserv'ER's annual overviews, which state that 'sector monitoring at European level is patchy' and 'many countries have not updated their capacity figures for several years'.[15]
EurObserv'ER's data is partially based on information from the European Geothermal Congress (ECG) and the European Geothermal Energy Council (EGEC) and partially from national statistical offices.
Figures for 2012 are not included in the graph because data was not available for several Member States with significant installed capacity (Bulgaria and Spain).
Malta, Cyprus and Luxembourg are not mentioned by the reports, and are assumed to have zero installed heat capacity. Eurostat also reports no heat generation by these three Member States (see section 5.2 below).
The data issues are clearly visible in the annual data for several EU Member States, for instance:
Bulgaria went from 77.7 MWth in 2010 to 3.5 MWth in 2011, and no data is available for 2012. In 2013, the total is back up again to 83.1 MWth.
Italy went from 418 MWth in 2010 and 2011 to over 700 MWth from 2012 onwards. This sharp increase is explained by better calculation of geothermal capacity used in balneology.

[15] EurObserv'ER State of Renewable Energies in Europe, edition 2012

Project spotlight: DESCRAMBLE

Efforts to exploit greater geothermal resources and improve the productivity of projects have meant that developers have to drill far deeper into the earth's crust than before. DESCRAMBLE is a H2020 project which was completed in the spring of 2018. This pioneering project successfully extended an existing geothermal well from approximately 2 km to 3 km, with the well accessing 'supercritical' geothermal resources with in-situ temperature of 500 °C. The DESCRAMBLE team had to ensure that all equipment, specifically the wellhead, casings, drilling fluids, cement, rock bit and mud cooling systems were able to operate in the expected supercritical conditions. None of the equipment selected had been used in a supercritical geothermal project before. Furthermore, a bespoke pressure and temperature (P&T) monitoring tool was developed to be able to operate up to 450 °C for a minimum of 6 hours, as the only available existing tools were designed to withstand in-situ temperatures of 350 °C for a maximum of 4 hours. The new tool completed two logging runs during the project and as a result the technology readiness level (TRL) of the tool increased from four to seven.

More information on the project is available as a case study in the annex of this report.

5.2 Annual generation

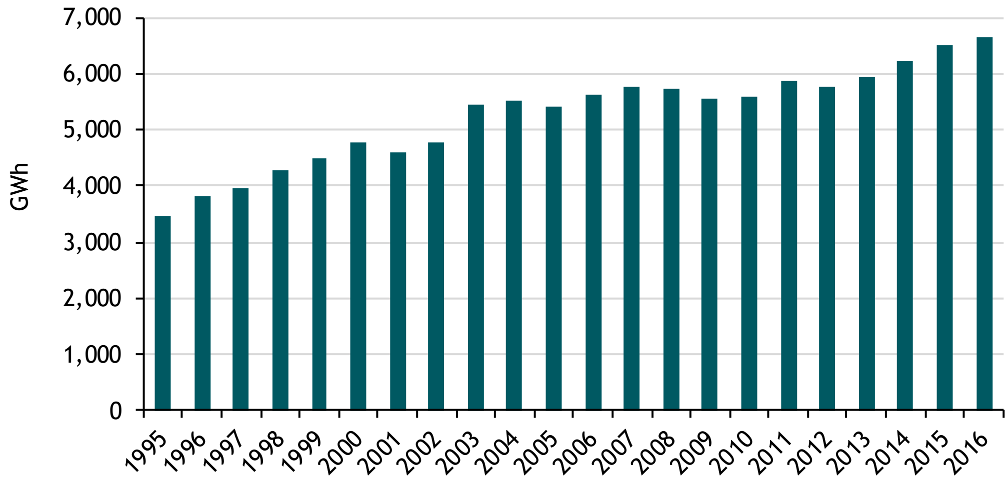
While installed capacity is a commonly used indicator to measure the progress in deploying RE technologies, it can be somewhat misleading due to differences in capacity factors. Annual generation includes the effects of these differences and is therefore a valuable indicator to complement the statistics on installed capacities.

Annual generation from geothermal energy has been rising for electricity and heat. Overall, it is still a minor source of energy in the EU (see section 5.3).

Between 1995 and 2016, only five MS have generated electricity from geothermal energy (Austria, France, Germany, Italy and Portugal). Italy is by far the biggest producer, generating 99 % of the total electricity in 1995 and 95 % in 2016.

Electricity generation from geothermal energy has increased by 91 % between 1995 and 2016, with an average annual growth rate of 4.3 % (see Figure 5-3). Most of this growth occurred in Italy. Germany grew the quickest, starting with 18 GWh in 2008 and rising to 175 GWh in 2016.

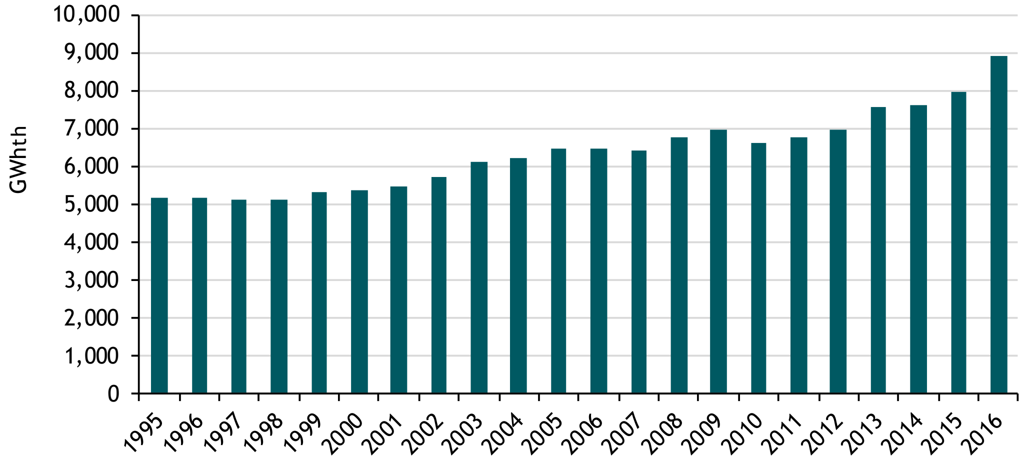
Figure 5-3 Annual electricity generation in the EU from geothermal energy



Source: Eurostat (2018)

Heat generation from geothermal energy grew from 445 kilotonnes of oil equivalent (ktoe) (5 200 GWh) in 1995 to 766 ktoe (8 900 GWh) in 2016 The growth in heat generation can be ascribed to the accelerated deployment of district heating systems attached to geothermal plants. France has realised 20 of these systems since 1995, with a similar figure for Hungary. France and Hungary generate by far the most heat (72 % of the total generation in the EU).

Figure 5-4 Annual heat generation in the EU from geothermal energy



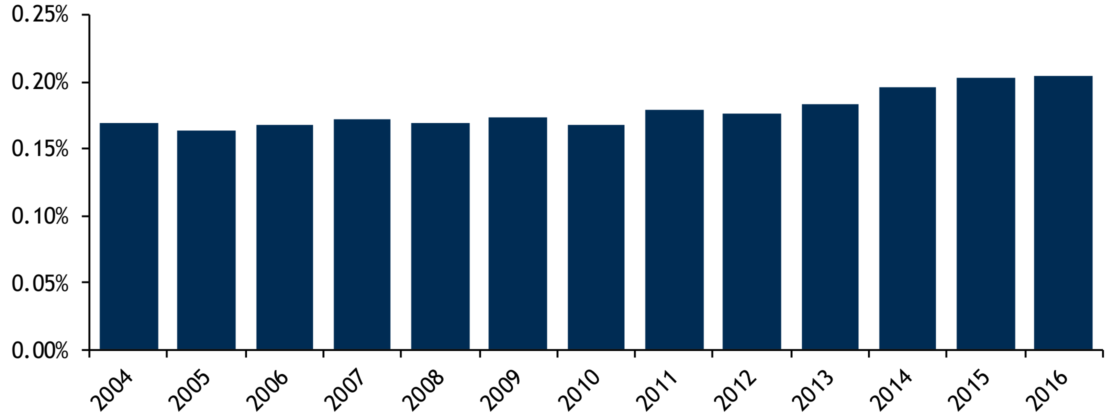
Source: Eurostat (2018)
Heat generation: No figures reported for eight MS: Five of these are assumed to have no geothermal energy for heat; EurObserv'ER did not report any installed capacity for these MS either (Cyprus, Estonia, Finland, Luxembourg, Malta). Three (Czech Republic, Latvia and Sweden) do have installed capacity according to EurObserv'ER (see section 5.1), but have no heat generation according to Eurostat. Together, these MS had 550.2 MWth of installed capacity in 2015, which is 16 % of total installed capacity in the EU in 2015. One MS (Ireland) has reported installed capacity in the past (2007-2010), but the current status is unknown. According to Eurostat, it has not generated heat between 1995 and 2016.

5.3 Share of energy consumption

Share of energy consumption refers to the participation of geothermal energy in the gross final energy consumed in each market sector (electricity, heating and cooling, and transport). This indicator allows us to analyse the participation of the geothermal sector in the overall target of increasing the share of energy from RES in the EU's gross final energy consumption.

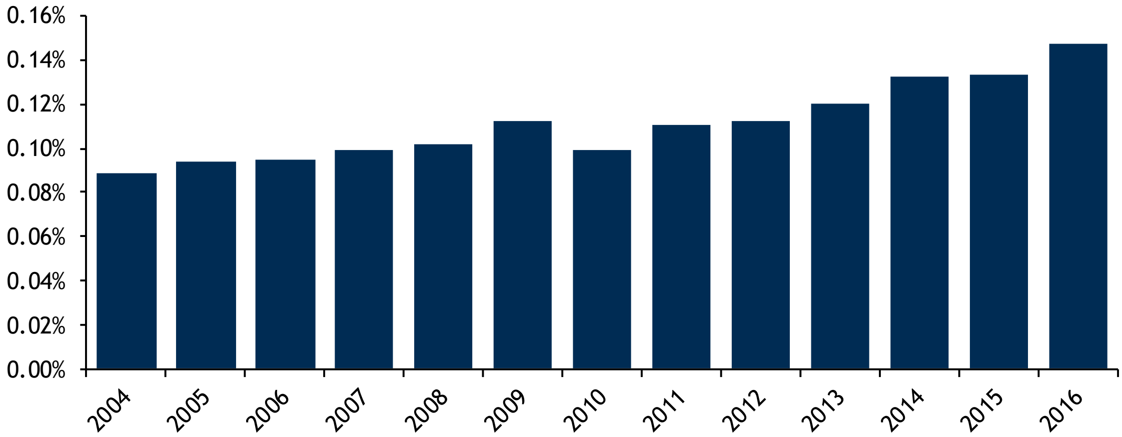
The shares of gross final electricity and heat consumption from geothermal energy in the EU are 0.21 % and 0.15 % respectively. It is slowly increasing since 2004, especially heat consumption, which can be attributed to the increasing capacity and generation from geothermal heat in the EU.

Figure 5-5 Share of gross final electricity consumption from geothermal in the EU



Source: Eurostat (2018)

Figure 5-6 Share of gross final heat consumption from geothermal in the EU



Source: Eurostat (2018)

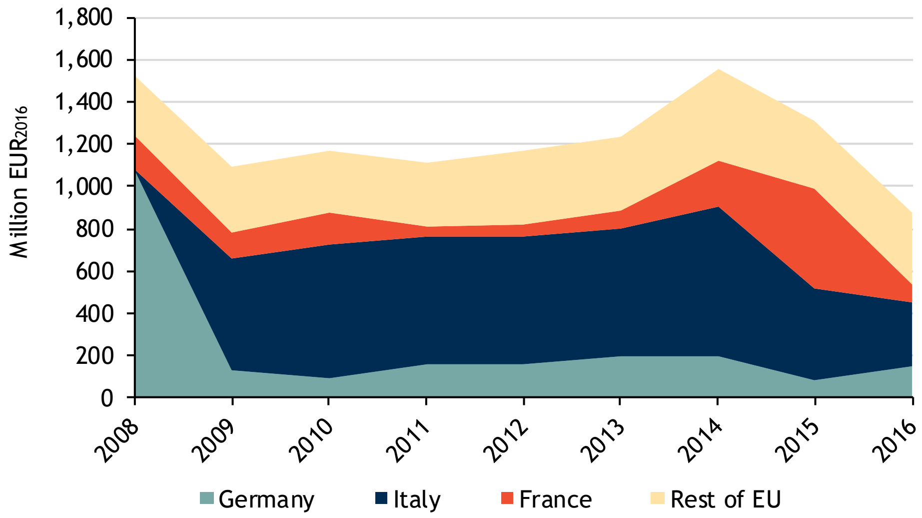
5.4 Industry turnover

Industry turnover is the total amount invoiced from the market sales of goods and/or services supplied to third parties by all sellers in the geothermal sector. Following the definition in EurObserv'ER, it focuses on the main economic activities of the supply chain including manufacturing, installation of equipment and operation and maintenance (O&M).

The industry turnover has been relatively static for a number of years, which is due to the lack of new installed capacity for geothermal power across Europe. The only countries that have seen increases in installed capacity since 2012 have been Germany (37 MWe) and Italy (41 MWe).[16] The lack of growth is partly due to changes in the feed-in tariff systems in Germany and France which have led to delays in the realisation of planned projects and the lack of renewable energy support in Italy. Furthermore, the poor performance of the flagship Landau project in Germany which surfaced around 2012/2013 may have contributed to reduced investments and industry turnover in the sector. Overall, it should be noted that geothermal energy projects have high capital costs (EUR 20 million to EUR 30 million) and a long development time, resulting in large impacts for the industry when a few projects are cancelled. Additionally, increased policy support will only lead to clear impacts over a longer period of time.

[16] EGEC (2017), EGEC Geothermal Market Report – 2016.

Figure 5-7 Geothermal industry turnover in the EU



Source: EurObserv'ER reports 2010 to 2017.
Note: Data excludes heat pumps. Collected in current values and converted to 2016 million euros.
The data of each year is collected from the most recent report. For the year 2010, estimates were taken from the 2011 report, since the 2012 report did not split heat pumps from geothermal. Several MS could not be included:

- *Ireland, Finland, Cyprus, Estonia, Malta and Luxembourg were excluded due to lack of reliability in 2015 and 2016 estimates.*
- *From the NMS-13 countries, only Bulgaria, Hungary, Poland, Romania, Slovakia and Slovenia could be included for the entire time series. Values for Czech Republic, Latvia and Lithuania were included starting in 2011, and Croatia in 2012.*
- *For the EU15 MS, data is missing for Italy and Spain in 2008, and for Austria in the period 2010 to 2011. Greece and Sweden were included starting in 2011.*

5.5 Jobs

Employment is an important indicator to understand the socio-economic impact of RE technology deployment. Linking jobs to R&D funding is difficult due to the number of confounding factors, but it is possible to make a connection between RE deployment and jobs. Different methods exist for estimating employment figures. A consistent time-series was only available for the period 2008 to 2016.

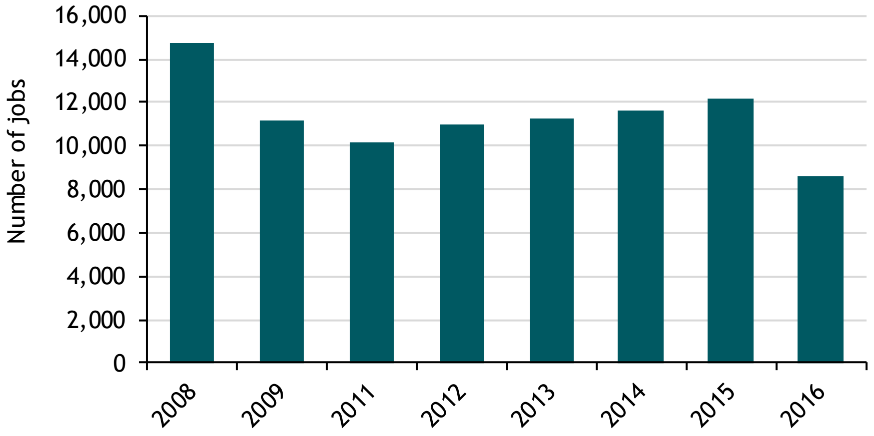
Direct jobs in the geothermal sector consist of geologists and engineers, drillers and workers in equipment factories, and project managers. The sector also generates indirect jobs, for example with suppliers of raw materials and induced jobs. With an estimated 8 600 jobs in 2016, the geothermal sector has the smallest amount of jobs compared to the other RE technologies that are commercially deployed in the EU. Over the last years, little new capacity has been installed, causing the largest part of employment to be in O&M of existing energy generating facilities, which requires only a small number of employees.[17] It should be noted that the reported sharp decrease in the number of jobs in 2016 is likely overestimated. The methodology used for estimating these jobs uses capacity additions as an input for calculating jobs. With the lack of new capacities, a sharp decline in jobs is estimated. But industry experts do not recognise this sharp decline and indicate that a large share of these jobs are still there and service projects outside of the EU (e.g. in Turkey).

Figure 5-8 shows that there is no upward trend in the number of jobs created, despite growth of the installed capacity of geothermal energy. Italy has the most jobs, estimated at 2 300 in 2016, which declined compared to 2015 due to a reduction of the newly installed capacity. The biggest change

[17] http://www.knowres-jobs.eu/en/upload/Documents/Knowres%20-D1.4.6%20-%20Geothermal%20sectoral%20report.pdf

between 2015 and 2016 took place in France, where the estimated jobs dropped from 3 500 to 600. The reason for this change may also be found in the reduction of newly installed capacity, as several plants have been delayed due to changes in the feed-in tariff system in France. In contrast, Germany saw a doubling of jobs from 600 in 2015 to 1 200 in 2016, becoming the second largest MS in terms of jobs, sharing this position with Hungary. Both MS have a large amount of installed heat capacity (285 MWth and 752 MWth respectively in 2015), with Germany's capacity growing for electricity and heat generation in recent years.

Figure 5-8 Evolution of EU jobs (direct and indirect) in the geothermal energy sector



Source: EurObserv'ER (2010-2017). Data for year 2010 included heat pumps, so it is not included in the graph. Includes direct and indirect jobs of electricity and heat generation

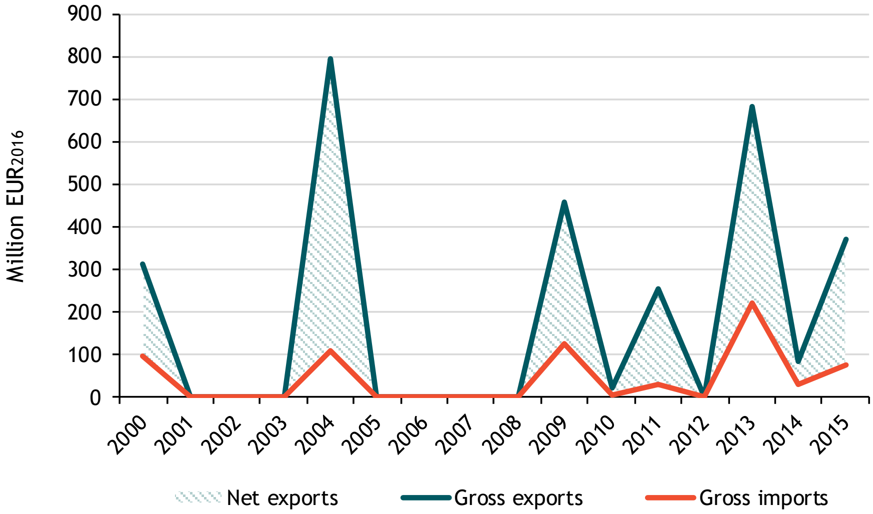
5.6 Imports/exports

International trade can provide a measure of the market uptake of geothermal energy and development of the geothermal energy sector itself. It allows us to examine the extent of the external market for these goods, with increasing exports leading to increased growth of the domestic sector. Similarly, increased activity in the sector will lead to an increase in demand for intermediate goods used in the manufacture of renewable energy technologies, a proportion of which may be imported. Increasing imports of these intermediate goods also provide an indication of the growth within the technology sectors.

The import and export figures for geothermal energy show strong fluctuations over the years due to the irregular additions of new capacities. In years where new capacities are realised, trade volumes emerge, while the trade volumes become zero in years without capacity additions.[18] Overall the EU exports more than what it imports. For the whole of the 2000 to 2015 period, the total value of exports was four times the total value of imports, indicating that the EU geothermal industry has a competitive position in the global market.

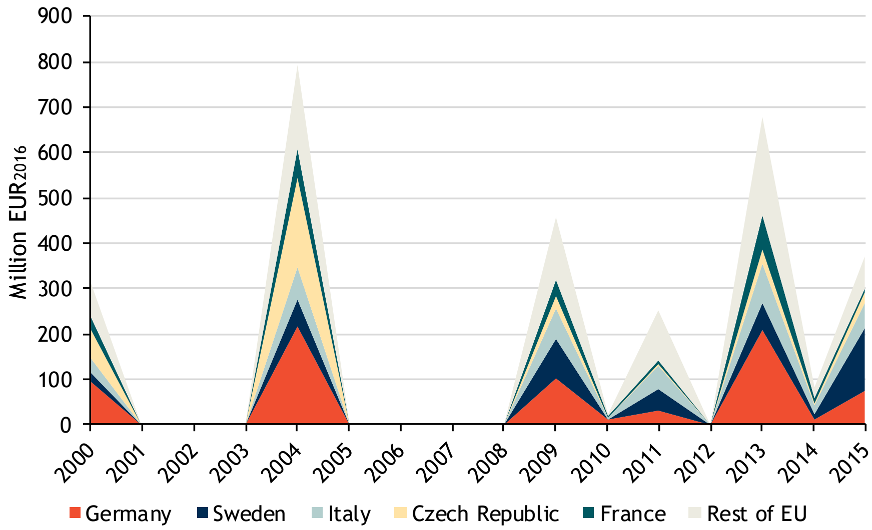
[18] This is partly a consequence of the methodology chosen as the exact timings of the purchases are not known and an assumption needs to be made to allocate trade volumes related to new installed capacities to periods of time. In our methodology these trade volumes are allocated to the year in which the capacity was registered. In the absence of continuous capacity additions over the years, this leads to a spike in certain years.

Figure 5-9 Trade balance for geothermal in the EU



Based on Comext (2018), JRC (2015), Eurostat (2018) and Jha, V (2009).
Note: Hungary's imports: 0. Data for 1999 and 2016 was 0 for all countries so it was excluded.
For an explanation of the methodology used, see Annex 1B.

Figure 5.10 Total value of exports of geothermal energy components from the EU (extra EU28 trade)



Based on Comext (2018), JRC (2015), Eurostat (2018) and Jha, V (2009).
Note: Hungary's imports: 0. Data for 1999 and 2016 was 0 for all countries so it was excluded.
For an explanation of the methodology used, see Annex 1B.

5.7 Conclusions

Geothermal electricity and heat generation has increased steadily over the past 20 years, with capacities and generation approximately doubling for electricity and heat generation. Overall, geothermal energy still plays a limited role in the EU energy system, accounting for 0.21 % and 0.15 % of electricity and heat consumption respectively.

In spite of the steady increase in the uptake of the technology, the EU industry has not experienced growth over the time period studied (2008-2016). Jobs and industry turnover remained at a relatively stable level with a decrease over the last year. The reasons include the limited additional capacities in recent years due to a lack of support in the main markets (France, Germany, Italy) and the limited labour requirements for operating existing capacities.

Looking at the import and export volumes, the EU industry does appear to be competitive with exports four times as high as imports. As such, the R&D efforts have been effective in establishing a competitive EU industry which can benefit when geothermal energy would be applied more extensively globally.

6 Conclusions

The interest in geothermal power has increased since 1995 alongside developments in climate and renewable energy policy. EU and MS R&D funding has grown over the years, especially after 2008. This trend is also visible outside of the EU, in countries such as the US and Australia. The combined EU and MS funding is at a level comparable to the US.

The EU has been successful in establishing and maintaining a leading academic position in the field of geothermal energy, as demonstrated by its consistent number one position in terms of global publications throughout the past 20 years. EU-funded projects have made a clear contribution to this leading position through publications as direct outputs of EU-funded projects, and through enhancing collaboration and knowledge sharing across the EU.

From a technology development perspective, EU funding has significantly helped to improve the appraisal of geothermal systems, enabling more accurate placing of wells and ultimately reducing the financial risk of geothermal projects. The focus on the development of enhanced geothermal systems (EGS), particularly through the development of stimulation techniques to improve the productivity of projects, has contributed to the expansion of geothermal projects beyond areas of volcanic activity (Italy, Iceland), to sedimentary basins in other parts of Europe. But even in EU countries with volcanic activity, EU funding has facilitated the implementation of high-risk high-reward supercritical geothermal projects. The development of monitoring tools and testing of materials capable of operating in such environments has been a key achievement in EU R&D projects.

The costs of geothermal energy do not show a clear trend due to the large impact of factors other than technology development, such as the site at which the technology is deployed and efforts to improve environmental performance, such as the avoidance and/or treatment of co-produced greenhouse gas emissions from geothermal wells. In spite of the lack of a clear cost reduction trend, there have been several noteworthy impacts of EU-funded projects on the costs of the technology. The slight decrease in capex over the past few years may be a sign that the technology development is paying off, whereas the slight increase in LCOE may be due to the deployment of geothermal energy at less optimal locations.

Installed capacities and associated generation of geothermal heat and electricity have doubled over the past 20 years, but the overall contribution of geothermal energy to EU energy consumption remains limited to 0.21 % (electricity) and 0.15 % (heat). Especially in the last couple of years, policy support for deploying additional capacities has been limited and the EU industry has not experienced any growth. The EU industry does have a positive trade balance, however, indicating that the R&D efforts have been effective in developing a competitive industry that can benefit from market growth worldwide.

Annex 1A - Case studies

Case study 1: IMAGE

Author:	Tom Mikunda	**Approver:**	Jan Hopman, Project Manager of IMAGE
Project title:	FP7 – Integrated Methods for Advanced Geothermal Exploration – IMAGE		
Lead partner:	TNO, Anna van Buerenplein 1, 2595 DA Den Haag, The Netherlands		
Project location*:	Coordinated in The Netherlands, research conducted across multiple sites in Europe.		
Technology area/s:	Geothermal energy		
Start and end date:**	November 2013 to October 2017		
Project cost:	EUR 13 402 774	**EC funding:**	EUR 10 051 044
Other funding sources	In-cash/in-kind contributions from industry		
Further information*:**	Project website Project Manager – Mr Jan Hopman, Project Manager, Applied Geosciences, TNO. Visiting address, Princetonlaan 6, 3584 CB Utrecht. T +31 (0)88 866 64 05. E jan.hopman@tno.nl		

If multiple - give the location of the lead partner. ** Month and year (i.e. January 2015 to December 2017). * Link to project website, final report or contact person.*

Project description

Geothermal energy is a clean, abundant and sustainable technology to generate heat and power. Its deployment in Europe is generally limited to high-enthalpy projects in volcanic regions of Iceland and Italy. One key barrier to the wider use of geothermal energy in Europe, in volcanic and in lower-temperature sedimentary basins, is the investment risk associated with the capital costs of drilling geothermal wells. The costs of geothermal wells are an average between EUR 2 million to EUR 3 million each. Therefore, an under-performing well, due to either insufficient temperature and/or flow rate, can lead to considerable financial losses for a project developer. With a more efficient appraisal of geothermal systems, exploration wells can be drilled more accurately, and therefore reducing the risk of project failure.

The geothermal exploration sector has long been dependent on the exploration, drilling and production tools from the oil and gas industry. However, the profit margins from the production of hydrocarbons are generally higher compared to heat and power production. Therefore, geothermal projects face high relative high development costs, which prevents the wider proliferation of the technology. The IMAGE (Integrated Methods for Advanced Geothermal Exploration) project was launched in 2013. The aim was to develop geothermal exploration methods to extend the resource base for potential geothermal projects, and to improve the accuracy of the placement of wells, contributing to educed risk and increased success rate of future projects. The applied R&D in the IMAGE project aimed to achieve three primary objectives:

1. Understanding the processes and properties that control the spatial distribution of critical exploration parameters at European and local scales. The focus was on the prediction of temperatures, in-situ stresses, fracture permeability and hazards, which can be deduced from field analogues, public datasets, predictive models and remote constraints;
2. Improving well-established exploration techniques for imaging, detection and testing of novel geological, geophysical and geochemical methods to provide reliable information on critical subsurface exploration parameters;
3. Demonstrating the benefit of an integrated and multidisciplinary approach for site characterization and well placement, based on conceptual advances, improved models/parameters and exploration techniques developed under objectives 1. and 2. The project also aimed to provide recommendations for a standardized European protocol for resource assessment and supporting models.

The IMAGE project was a joint initiative between private utility companies, research institutes, universities and engineering consultancies. The primary beneficiaries of the project are the commercial companies of the consortium, who likely benefit from the development of new exploration tools and processes, which have the potential to reduce the capital costs and therefore the associated project development risk. The consortium consisted of a number of utility companies, specifically ENEL Spa (Italy), AXPO Power AG (Switzerland) and HS Orka (Iceland), all of which have an interest in the development of geothermal power plants. In addition to utility companies, the project also included engineering consultancies and specialist technology suppliers resulting in significant private sector representation (40 %). Also, academia, R&D institutes, and user entities were represented which enabled the project to address different stages of the technology development.

Outputs and impacts

The primary output of the project were publications, which included:

- Documentation of 20 novel geological, geochemical and geophysical exploration methods and techniques, of high relevance to industrial workflows;
- Five best practice documents, catalogues and databases to be used for guidance in exploration workflows and constraints for models;
- Over 200 publications in peer-reviewed journals and conference proceedings;
- 50 reported deliverables in line with the project plan.

IMAGE contributed to the advancement of new innovative exploration techniques, rather than the standardisation of technologies. Indeed, the project aimed to move away from a standardised workflow for geothermal project development to identify potential cost reduction strategies.

An example of a new cost reduction technology is the development and use of new software, termed the Non Local Means (NLM) algorithm, which is able to reprocess vintage seismic data in resource assessment workflows at a low cost (Carpentier & Steeghs, 2016). The use of vintage seismic to good effect can effectively prevent the need for new seismic surveys which can lead to cost savings of approximately EUR 200 000 per geothermal project.[19]

[19] TNO in-house estimate

Another example of potential cost reductions is the advancement of passive seismic exploration techniques, or ambient noise seismic interferometry (ANSI), for use in the exploration of sedimentary basins. Active seismic campaigns using seismic vibration trucks and receivers are costly, but in IMAGE portable seismometers were demonstrated to improve the image of the subsurface at a much lower cost (Verdel, Vandeweijer, Carpentier, van Haeringen, & Meekes, 2017).

A large number of methods and technologies developed in IMAGE have been applied in industry workflows such as in the new processing techniques of vintage seismic in the Bavarian Molasse Basin. The technique for the optimisation of vertical seismic profiling (VSP), which has a favourable cost-benefit ratio, has been used in the exploration phase of the ultra-deep IDDP-2 geothermal project in Iceland, completed in 2017. Also, other techniques developed in the IMAGE project can be directly applied in the geothermal industry. However, the cost saving potentials are often difficult to quantify as there have been limited number of geothermal projects developed since the end of the IMAGE project in 2017.

The impacts of the project have been somewhat limited by the lack of a sustainable business case for geothermal power in Europe. Except for the high-enthalpy regions such as Iceland and parts of Italy, it is still difficult for geothermal heat and power to compete with the conventional hydrocarbon-based power generation.

Outlook and commercial application of the outputs

The NLN algorithm to reprocess vintage seismic is currently being considered by the energy company ENGIE in de-risking the development of geothermal resources in the province of Utrecht, the Netherlands. In addition, a number of the exploration techniques advanced in the IMAGE will undergo further testing and development in the H2020 project DESCRAMBLE.

The role of EU funding

The IMAGE project received funding from the European Union's Seventh Programme for research, technological development and demonstration. The funding programme has since been replaced by the Horizon 2020 programme. The EU funded 77 % of the project cost, while the industrial partners provided the remainder of the funding in the form of in-kind and in-cash contributions. The contributions from the private sector can be explained by the perceived benefits from the development of low-cost exploration techniques for future projects.

The work completed within IMAGE was achieved through a combination of desk research, geological modelling, and field tests of innovative and novel exploration techniques. The IMAGE project aimed to reduce costs of geothermal exploration by developing and testing innovative and potentially low-cost exploration techniques. Given the immaturity of many of these techniques, it is likely that these would not have been developed further, or their development would have been delayed, without the funding from the EU.

Full project participant list

Organisation	Country	Type
Nederlands Organisatie Voor Toegepast Natuurwetenschappelijk Onderzoek - TNO	The Netherlands	Research institute
Axpo Power AG	Switzerland	Utility company
Bureau de Researches Geologigues et Minieres	France	Research institute
Consiglio Nazionale delle Ricerche	Italy	Research institute
ENEL Spa	Italy	Utility company
Eidgenoessische Technische Hochschule Zurich	Switzerland	Academic institute
Fonroche Geothermie SAS	France	Private company
Geomedia S.R.O.	Czech Republic	Private company
Helmholtz-Zentrum Potsdam Deutsches Geoforschungszentrum	Germany	Research institute
HS Orka HF	Iceland	Utility company
Institutt for Energiteknikk	Norway	Research institute
Islenskar Orkurannsoknir	Iceland	Research institute
Landsvirkjun Sameignerfelag	Iceland	Utility company
Petratherm Espana Sl	Spain	Private company
BKW Energie AG	Switzerland	Utility company
Technische Universitaet Darmstadt	Germany	Research institute
Universita Degli Studie de Bari 'Aldo Moro'	Italy	Academic institute
Universite Montpellier 2 Sciences et Techniques	France	Academic institute
Universiteit Utrecht	The Netherlands	Academic institute
Volcanic Basin Petroleum Research AS	Norway	Research institute

Case study 2: ENGINE

Author:	Tom Mikunda	**Approver:**	Dr Jan Diederik van Wees, project stakeholder - TNO
Project title:	FP6 Enhanced Geothermal Innovative Network for Europe (ENGINE)		
Lead partner:	BRGM, 3 avenue Claude-Guillemin - BP 36009 45060 Orléans Cedex 2 - France		
Project location*:	Coordinated in France, research conducted across multiple sites in Europe.		
Technology area/s:	Geothermal energy		
Start and end date:**	November 2005 to April 2008		
Project cost:	EUR 2 302 289	**EC funding:**	EUR 2 302 289
Other funding sources	n/a		
Further information*:**	ENGINE website		

If multiple – give the location of the lead partner. ** Month and year (i.e. January 2015 to December 2017). * Link to project website, final report or contact person.*

Project description

Geothermal energy is a clean, abundant and sustainable technology to generate heat and power. Its deployment in Europe, however, is generally limited to high-enthalpy projects in volcanic regions of Iceland and Italy, where high temperature water/steam is available at relatively shallow depths (500 m to 1 000 m below sea-level). Unconventional geothermal, or enhanced geothermal systems (EGS), refer to geothermal project developments in non-volcanic regions, where geothermal wells must be drilled far deeper (~<2 000 m) into geological layers. These projects are riskier because of lack data and information about the potential wells. In EGS projects, the in-situ geology is often chemically and/or hydraulically manipulated to improve the fluid flow towards the well. Therefore, knowledge development and sharing on this subject could potentially accelerate the wider use of geothermal energy in Europe.

The ENGINE project (Enhanced Geothermal Innovative Network for Europe) was a co-ordination action supported by the 6th Research and Development framework. The overarching goal of the project was to enhance the co-ordination of the present research and development initiatives for unconventional geothermal reservoir and EGS, from resource investigation and assessment stage through to exploitation monitoring. The specific objectives of the ENGINE were to:

1. Provide an updated framework of activities concerning geothermal energy in Europe, including the integration of scientific and technical know-how and practices, and the evaluation of socio-economic and environmental impacts;
2. Define innovative concepts for investigation and the use of unconventional geothermal reservoirs (UGR) and EGS; to be presented in a 'Best Practice Handbook';
3. Produce a scientific and technical 'European Reference Manual' including the information and dissemination systems developed during the Co-ordination Action.

To achieve the technical objectives of the project, information and know-how gathered from a number of active geothermal projects, including sites in Soultz (France), Bouillante (Italy) and Icelandic geothermal fields. The project also involved input from 'third party countries' (i.e. the Philippines, Mexico and El Salvador), which also have considerable geothermal energy potential.

The ENGINE project has a number of direct beneficiaries. Many of the project outputs, such as the Best Practice Handbook, and an Excel-based performance assessment tool, are valuable to geothermal project developers and engineering companies. The many scientific institutions have benefited from the opportunity in terms of knowledge sharing and gaining access to learnings from the active geothermal projects associated with ENGINE. Finally, policy-makers and research programme managers can form the recommendations for innovation needs in the geothermal sector, which have shaped the future research goals for geothermal energy in Europe through the FP7 and H2020 programmes.

The ENGINE consortium was composed of national research institutes (60 %), private companies (30 %) and academic institutes (20 %). The project has a wide geographical spread in Europe, involving 13 EU Member States or Members of the European Economic Area (EEA). The project also included multiple countries from outside Europe. The broad coverage of the ENGINE consortium can be seen a considerable achievement in its own right.

Outputs and impacts

Two of the three objectives listed above focus on fostering increased collaboration and coordination between European research institutes engaged in geothermal energy. They also encourage project developers and engineering involved to communicate the technical and non-technical challenges to structure and shape a future research framework for geothermal energy in Europe. The outreach and communication was facilitated through the organisation of three general conferences and seven specialised workshops. Approximately 700 scientists, industrial partners and journalists attended these meetings for which approximately 240 presentations were produced.

In addition to the coordination and collaboration efforts, the ENGINE project also resulted in a number of scientific outputs, namely:

- A Best Practice Handbook – produced by leading experts in ENGINE, the handbook presents an overview of the investigation, exploration, and exploitation of UGR and EGS. The handbook contains technical recommendations for project developers, and information regarding the environmental and socio-economic aspects of geothermal projects that are relevant for politicians and decision makers;
- ENGINE Decision Support System – a techno-economic performance assessment model for deep geothermal projects. The model can be used to calculate the performance of the geothermal systems, investigating sensitivities of the performance due to natural uncertainties (e.g. flow characteristics, subsurface temperatures), engineering options (bore layout and surface facilities options) and economic uncertainties (e.g. electricity price, tax regimes). This tool can be used by project developers and engineers to calculate the expected performance of different geothermal projects;
- Database of exploration tools – a database of the exploration tools used by ENGINE partners for geothermal investigation and exploration. The database is organized by the methodology used for exploration, and it includes the equipment, hardware and modelling software. This database is useful for potential project developers and for knowledge sharing purposes.

Although the project did not result in any formal standardisation of technologies, the Best Practice Handbook can be considered the first step towards the standardisation of workflows for the identification and exploitation of geothermal power using enhanced geothermal techniques.

Outlook and commercial application of the outputs

The Decision Support System developed within ENGINE has contributed to the development of the ThermoGIS tool, developed by TNO. ThermoGIS is a publicly available tool, which combines the known geological characteristics of the Netherlands with techno-economic modelling to allow users to calculate the economic feasibility of national geothermal projects.

The role of EU funding

The ENGINE project received funding under the Framework Programme 6 - Sustainable Development, Global Change and Ecosystems: thematic priority 6 under the Focusing and Integrating Community Research programme 2002-2006. 100 % of the project costs were covered by EU funding. Although private companies were involved, the lack of leverage of private funding is understood to be due to the fact that no technologies were to be developed within the project. All of the outputs of the project have been made publicly available. The EU funding certainly led to strategic collaboration of EU / non-EU research institutes in the area of enhanced geothermal systems.

Full project participant list

Organisation	Country	Type
BRGM	France	Research institute
GeoForschungsZentrum Potsdam	Germany	Research institute
ÍSOR	Iceland	Research institute
SIEP B.V.	The Netherlands	Private company
Nederlands Organisatie Voor Toegepast Natuurwetenschappelijk Onderzoek – TNO	The Netherlands	Research institute
The Institute for Geothermal Research	Russia	Research institute
Consiglio Nazionale delle Ricerche	Italy	Research institute
CFG services	France	Private company
Institute for Energy and Environment	Germany	Research institute
Loránd Eötvös University	Hungary	Academic institute
Centre National de la Recherche Scientifique	France	Research institute
GGA institute	Germany	Research institute
Geothermie Soultz	France	Private company
National Lithuanian Research Institute for Earth Sciences	Lithuania	Research institute
MeSy GeoMeasuringSystems GmbH	Germany	Private company
Vrije Universiteit Amsterdam	The Netherlands	Academic institute
Centre for Renewable Energy Sources	Greece	Research institute
National Centre of Scientific Research 'DEMOKRITOS'	Greece	Research institute
Geoproduction Consultants	France	Private company
Institute for Energy Technology	Norway	Research institute
Polish Geological Institute	Poland	Research institute
Geological Survey of Denmark and Greenland	Denmark	Research institute
University of Oradea	Romania	Academic institute

Organisation	Country	Type
GEMRC IPE RAS	Russia	Research institute
Russian Academy of Sciences	Russia	Academic institute
Intergeotherm	Russia	Private company
DHM	Switzerland	Private company
Geowatt AG	Switzerland	Private company
ORME Geothermal Inc.	Turkey	Private company
Instituto Geológico y Minero de España	Spain	Research institute
CERTH	Greece	Research institute
FEDCO	Philippines	Private company
Instituto Nacional de Electricidad y Energias Limpias	Mexico	Research institute
Centro de Investigación Científica y Educación Superior de Ensenada	Mexico	Academic institute
LaGeo	El Salvador	Private company

Case study 3: DESCRAMBLE

Author:	Tom Mikunda	**Approver:**	Adele Manzella, Senior researcher, Italian National Research Council
Project title:	H2020 - Drilling in dEep, Super-CRitical AMBient of continentaL Europe – DESCRAMBLE		
Lead partner:	Enel Green Power SpA, Via Andrea Pisano 120 56122 Pisa, Italy.		
Project location:	Larderello, Italy		
Technology area/s:	Geothermal energy, enhanced geothermal systems		
Start and end date:	May 2015 to April 2018		
Project cost:	EUR 15 615 955	**EC Funding:**	EUR 6 753 635
Other funding sources	In-cash/in-kind contributions from industry		
Further information:	Project website Adele Manzella (Work package leader), Consiglio Nazionale delle Ricerche		

Project description

High enthalpy geothermal systems have been used to produce electricity for over 100 years. In general, high enthalpy systems have fluids with temperatures of between 150 °C and 300 °C. Geothermal systems with temperatures of above 250 °C are located in active volcanic centers with higher temperature gradients. These gradients are caused by heat flow which in turn is caused by shallow intrusions of magma. In Europe, Italy and Iceland are the two main countries where high temperature geothermal projects are in operation. With the advancement in drilling technology, geothermal wells can now be drilled far deeper into the earth's crust, accessing depths characterized by very high in-situ temperature and pressure. Geothermal reservoirs are considered 'supercritical' when the fluids have temperatures and pressures above 374 C and 221 bar respectively. These geothermal resources are considered to have great untapped potential for economically feasible power production. However, the development of supercritical geothermal systems faces considerable technical challenges, particularly associated with drilling risk, material use for handling of supercritical fluids and the use of monitoring tools in high temperature/pressure environments.

The DESCRAMBLE project aimed to address these challenges by drilling in continental-crust, supercritical geothermal conditions, and to test and demonstrate novel drilling techniques to control gas emissions. In addition, the project tested equipment targeted to environments characterised by high temperature/pressures. The project aimed to improve knowledge of deep chemical-physical conditions for predicting and controlling critical drilling conditions. Specifically, the main objectives of DESCRAMBLE were to:

1. Demonstrate safe drilling of a deep super-critical geothermal well;

2. Reduce the technical and financial risks of drilling and exploiting deep geothermal wells by improving the knowledge of the physical and chemical conditions in deep geothermal formations;
3. Reduce pre-drill uncertainty in the exploration of deep geothermal wells;
4. Improve in-situ characterisation by developing a special tool for extremely high temperature and pressure measurements while analysing fluid and rock samples of deep, supercritical conditions;
5. Investigate the economic potential of exploiting chemicals and minerals by analysing fluid samples for valuable raw materials.

To achieve the objectives, the project has used an existing dry well in Larderello (Tuscany, Italy) called Venelle 2, and increased its depth from 2.2 km down to 2.9 km. The target for the well extension was a deep seismic marker name 'K-horizon'. Experts had interpreted the high seismic impedance of this marker as being due to magmatic/metamorphic fluids, possibly in supercritical conditions. Exploiting the supercritical conditions and harnessing is geothermal energy could potentially increase the standard productivity of high-enthalpy geothermal power installations by a factor of 10.

The project was led by industry party ENEL Green Power (Italy), who have extensive experience of geothermal exploration and production in the area for decades. ENEL Green Power is a utility company, part of the Enel Group business line dedicated to the development and management of energy production from renewable sources like solar, geothermal and wind. ENEL Green Power was the main beneficiary of the project, and was supported by academic and research institutes from Germany, Italy and Norway. ENEL Green Power was the only direct beneficiary from industry in the project. A number of oil and gas service providers including Halliburton, Smith and Weatherford provided equipment for the drilling demonstration, but were not direct beneficiaries.

It was not the intention of ENEL Green Power to develop the deeper Venelle 2 well into a working geothermal power plant. The primary driver for the project was to improve the understanding and resource exploration for supercritical geothermal projects. The learnings derived from DESCRAMBLE are relevant for other high enthalpy regions in Europe such as Iceland, and also for countries such as Japan and Mexico. DESCRAMBLE has benefitted from the outcomes of the EU FP7 project IMAGE, particularly with regards to work completed on the appraisal geothermal systems in high-temperature systems related to volcanism.

Outputs and impacts

The efforts of DESCRAMBLE have been well documented including approximately 35 deliverables and 15 publications. Whereas the majority of the project deliverables are restricted to consortium members and the European Commission, many of the publications such as conference proceedings and website articles are publicly available. An overview of the deliverables and publications is available on the DESCRAMBLE website. The project has not yet resulted in the registration of patents or led to the creation of spin-off companies.

The primary output of the project is the deepening of the Venelle 2 geothermal well, which has facilitated extensive learnings regarding accessing supercritical geothermal reservoirs. The DESCRAMBLE project can be considered to have had three major impacts, which can support the development of the geothermal sector in Europe and beyond:

- **Selection, testing and evaluation of existing equipment in supercritical conditions** – To achieve the deepening of the existing geothermal well, equipment available from primarily oil and gas service providers had to be selected and tested. Earlier attempts to reach the 'K-horizon' with an exploration well in 1979 were associated with an induced well blow-out and the eruption of large amount of magmatic rock fragments. Therefore, the DESCRAMBLE team had to ensure that all equipment, specifically the wellhead, casings, drilling fluids, cement, rock bit and mud cooling systems were able to operate in the expected supercritical[20] conditions. None of the equipment selected had been used in a supercritical geothermal project before. Despite of the unexpected behaviour of the drilling mud due to high temperatures, the drilling was a success and the well reached a depth of 2.9 km with a temperature of between 507 °C and 517 °C. The evaluation of the selected equipment can inform future supercritical geothermal endeavors;

- **The development of a first-of-a-kind temperature/pressure (P&T) logging tool able to withstand temperatures of up to 450 °C** – Prior to DESCRAMBLE, only P&T logging tools were available designed to withstand in-situ temperatures of 350 °C for a maximum of 4 hours. This was unsuitable for the Venelle 2 well, with a target temperature of 450 °C at a depth of 2.9 km. P&T logging is essential to ensure the safety and efficiency of the geothermal installation, and the availability of tools for high temperature projects is vital. SINTEF, partner in the DESCRAMBLE project, developed the bespoke SINTEF PT Tool, designed to withstand temperatures of 450 °C for a minimum of 6 hours of operation. As no electrical wireline cables are suitable to this temperature, the tool is based on logging to internal memory and power by high temperature resistance batteries. The tool has completed two logging runs at Venelle 2 and as a result the technology readiness level (TRL) of the tool increased from four to seven. This can be considered a key output of the project;

- **The development of new numerical codes for the simulation of supercritical geothermal reservoirs** – The DESCRAMBLE project also included extensive reservoir modelling of the area around the Venelle 2 well. With regards to simulating the production scenarios of the well, the Consiglio Nazionale delle Ricerche (CNR) used a commercial version of TOUGH 2 – EOS2 with Petrasim interface. The TOUGH ('Transport Of Unsaturated Groundwater and Heat') set of software codes are multi-dimensional numerical models for simulating the coupled transport of water, vapour, non-condensable gas, and heat in porous and fractured media. However, there were no software codes available to handle the modelling of supercritical water, and therefore the team developed three software modules. These modules can be used to better predict the production scenarios of geothermal projects operating in supercritical environments.

Outlook and commercial application of the outputs

The Venelle 2 well has now been plugged safely using a temporary cement plug. Although the well revealed extremely high temperatures and supercritical conditions (the objectives of the project), the drilling did not prove the existence of a reservoir or fluids which could be brought to the surface to feed a geothermal power plant. However, the site still has potential to be developed into an enhanced geothermal system, producing supercritical fluids from injected water. Effectively operating as a

[20] Supercritical geothermal systems are very high-temperature geothermal systems that are located at depths near or below the brittle-ductile transition zone in the crust where the reservoir fluid is assumed to be in the supercritical state, that is when pure water, temperature and pressure are, respectively, in excess of 374 °C and 221 bar.

subsurface heat exchanger, the Venelle 2 well could feed a geothermal installation with a power capacity of between 20 MW and 40 MW. More testing is needed before any further developments can take place

Overall, the DESCRAMBLE project has proven the possibility of identifying potentially supercritical geothermal resources, and the technical feasibility of reaching them. Therefore, this project can have a profound impact on encouraging further research and innovation in the area to then allow commercial developments to take place. It is understood that SINTEF has been approached by Icelandic geothermal power project developers with an objective of using the SINTEF PT tool developed in the project.

The role of EU funding

It is highly unlikely that the extension of the Venelle 2 geothermal well would have taken place without the availability of EU funding. There is no immediate business case for the project, and the technical and financial risk of developing the first supercritical well in the region were significant. Furthermore, the EU funding ensures that the detailed knowledge generated is shared with the European Commission, and considerable information also disseminated to the geothermal sector and wider public.

Project participants

Organisation	Country	Type
ENEL Green Power	Italy	Utility company
Consigio Nazionale Delle Richerche (CNR)	Italy	Research institute
Rheinisch-Westfaelische Technische Hochschule Aachen	Germany	Academic institute
Christian Albrechts Universitaet zu Kiel	Germany	Academic institute
Technische Universität Bergakademie Freiberg	Germany	Academic institute
SINTEF Petroleum AS	Norway	Research institute
SINTEF AS	Norway	Research institute
Stiftelsen SINTEF	Norway	Research institute

Annex 1B - Methodological note on imports and exports

The value of the following components were assessed for geothermal:

HS6-digit code	Description
730431	Tubes, pipes and hollow profiles, seamless, of circular cross-section, of iron or non-alloy steel, cold-drawn or cold-rolled ‘cold-reduced’ (excl. Cast iron products and line pipe of a kind used for oil or gas pipelines or casing and tubing of a kind used for drilling for oil or gas)
730441	Tubes, pipes and hollow profiles, seamless, of circular cross-section, of stainless steel, cold-drawn or cold-rolled 'cold-reduced' (excl. Line pipe of a kind used for oil or gas pipelines, casing and tubing of a kind used for drilling for oil or gas)
730451	Tubes, pipes and hollow profiles, seamless, of circular cross-section, of alloy steel other than stainless, cold-drawn or cold-rolled ‘cold-reduced’ (excl. Line pipe of a kind used for oil or gas pipelines, casing and tubing of a kind used for drilling for oil
741121	Tubes and pipes of copper-zinc base alloys ‘brass’
741122	Tubes and pipes of copper-nickel base alloys 'cupro-nickel' or copper-nickel-zinc base alloys 'nickel silver
841950	Heat exchange units (excl. Instantaneous heaters, storage water heaters, boilers and equipment without a separating wall)
850239	Generating sets (excl. Wind-powered and powered by spark-ignition internal combustion piston engine)

For the imports, the following NACE2 codes were considered:

NACE2-digit code	Description
24	Manufacture of basic metals
28	Manufacture of machinery and equipment (other than electrical equipment)
27	Manufacture of electrical equipment

Annex 1C - Literature

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Annex 1D - List of EU-funded projects

Acronym	Rcn	Project title	EC funding (2016 EUR)	Programme	Topic
CHPM2030	199012	Combined Heat, Power and Metal extraction from ultra-deep ore bodies	4235568	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-02-2015
CLENSYS	63710	Conference: 'cleaner energy systems through utilization of renewable geothermal energy resources'	19289	FP5-INCO 2	
CLUSTHERM	89009	Creating a Central European Thermal Water Research Cluster	223209	FP7-REGIONS	REGIONS-2007-2-02
DEEPEGS	199917	DEPLOYMENT OF DEEP ENHANCED GEOTHERMAL SYSTEMS FOR SUSTAINABLE ENERGY BUSINESS	20049740	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-03-2015
DESCRAMBLE	193730	Drilling in supercritical geothermal condition	6770519	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-02-2014
DESTRESS	199957	Demonstration of soft stimulation treatments of geothermal reservoirs	10713409	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-03-2015
DG ETIP	211166	Support to the activities of the European Technology and Innovation Platform on Deep Geothermal	587336	H2020-EU.3.3.3.;H2020-EU.3.3.2.	LCE-36-2016-2017
EGS PILOT PLANT	73985	European geothermal project for the construction of a scientific pilot plant based on an Enhanced Geothermal System (EGS PILOT PLANT)	6181403	FP6-SUSTDEV	SUSTDEV-1.2.6
ENGINE	78504	ENhanced Geothermal Innovative Network for Europe	2785811	FP6-SUSTDEV	SUSTDEV-1.2.6
ESGEA	78142	Esgea	67075	FP5-HUMAN POTENTIAL	1.4.1.-3.1.
GEISER	93424	Geothermal Engineering Integrating Mitigation of Induced Seismicity in Reservoirs	5747453	FP7-ENERGY	ENERGY.2009.2.4.1
GE-ISLEBAR	89212	Removal of barriers to the development of geothermal resources in European peripheral islands	756660	FP5-EESD	
GEMex	205825	GEMex: Cooperation in Geothermal energy research Europe-Mexico for development of Enhanced Geothermal Systems and Superhot Geothermal Systems	9999793	H2020-EU.3.3.2.	LCE-23-2016
GEO PAC RET	194653	GEO PAC RET an Innovative Heat Pump for Geothermal district heating in Europe	50120	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
GEOCOM	100462	Geothermal Communities - demonstrating the cascading use of geothermal energy for district heating with small scale RES integration and retrofitting measures	3803983	FP7-ENERGY	ENERGY.2008.8.4.1
GEOCOND	209743	Advanced materials and processes to improve performance and cost-efficiency of Shallow Geothermal systems and Underground Thermal Storage	3889016	H2020-EU.3.3.2.	LCE-07-2016-2017
GEOTHERMAL ERA NET	103525	Geothermal ERA NET	2046084	FP7-ENERGY	ENERGY.2011.10.2-2
GEOTHERMICA	206851	GEOTHERMICA - ERA NET Cofund Geothermal	8444330	H2020-EU.3.3.3.;H2020-EU.3.3.2.	LCE-34-2016
GEOTHERNET	57654	Improving a European Geothermal Information Network to Raise the Acceptability of Geothermal Energy	803959	FP5-EESD	1.1.4.-5.2.5
GeoWell	199591	Innovative materials and designs for long-life high-temperature geothermal wells	4704914	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-02-2015
HITI	81195	High-Temperature Instruments for supercritical geothermal reservoir characterization and exploitation	2892382	FP6-SUSTDEV	SUSTDEV-1.2.6

Acronym	Rcn	Project title	EC funding (2016 EUR)	Programme	Topic
HOT DRY ROCK ENERGY	54136	European geothermal project to utilise hot dry rock/hot fractured rock resources: first phase of the construction of the scientific pilot plant. (HOT DRY ROCK ENERGY)	8531094	FP5-EESD	1.1.4.-5.
HySM	103052	Hydraulic Stimulation Modeling in Geothermal Systems	171251	FP7-PEOPLE	FP7-PEOPLE-2011-IEF
IGES	57611	Integrated Use of Geothermal Energy for Sustainable Development	1207346	FP5-EESD	1.1.4.-5.2.5
I-GET	75909	Integrated geophysical exploration technologies for deep fractured geothermal systems	3267040	FP6-SUSTDEV	SUSTDEV-1.2.6
IMAGE	110846	Integrated Methods for Advanced Geothermal Exploration	10129861	FP7-ENERGY	ENERGY.2013.2.4.1
ITHERLAB	201131	In-situ thermal rock properties lab	171461	H2020-EU.1.3.2.	MSCA-IF-2015-EF
LOW-BIN	85717	Efficient low temperature geothermal binary power	2224529	FP6-SUSTDEV	SUSTDEV-1.1.1
MATChING	200817	Materials Technologies for performance improvement of Cooling Systems in Power Plants	9706414	H2020-EU.2.1.3.	NMP-15-2015
MIDES	57624	Milos Geothermal Energy Driving ORC Turbo generator and Seawater Desalination Plant	2012244	FP5-EESD	1.1.4.-5.2.5
MIGRATE	202128	MINERAL-SCALE HETEROGENEITY OF GRANITES: A NEW APPROACH INTEGRATING MICROCHEMICAL ANALYSIS AND THERMO-MECHANICAL MODELLING TO DISCLOSE THE THERMOCHEMICAL EVOLUTION OF THE CONTINENTAL CRUST	187420	H2020-EU.1.3.2.	MSCA-IF-2015-EF
PROTU	87164	Promotion of geothermal energy utilisation in Turkey	125562	FP5-EESD	
REINJECTION HUNGARY	70491	Implementation of innovative Geothermal techniques through Installation Of Injection Well For Significant Improvement O	*Not available*	FP5-EESD	1.1.4.-5.2.5
SURE	199554	Novel Productivity Enhancement Concept for a Sustainable Utilization of a Geothermal Resource	5892165	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-02-2015
ThermoDrill	193791	Fast track innovative drilling system for deep geothermal challenges in Europe	5394448	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-02-2014
WGC200 INDUS EXHIB	57760	Exhibition of European Geothermal Industry and Technologies at the World Geothermal Congress 2000	114027	FP5-EESD	1.1.4.-5.2.5
No acronym	59617	EUROPEAN SUMMER SCHOOL ON GEOTHERMAL ENERGY APPLICATIONS	*Not available*	FP5-HUMAN POTENTIAL	1.4.1.-3.1S4

Annex 2

Technology Sector Report
Solar thermal energy

(Deliverable D2.2)

Authors:
Onne Hoogland (Trinomics)
Elske Veenstra (Trinomics)
Perla C. Torres Vega (Trinomics)
Iñigo Iparraguirre Torres (Tecnalia)
Hanna Kuittinen (Tecnalia)

1 Introduction

This report is one in a series of eight technology reports for the study *Impacts of EU actions supporting the development of renewable energy technologies*, prepared for the European Commission. The report has two objectives: 1) describing how EU research and development (R&D) funding for the solar thermal technologies has impacted the solar thermal sector in the EU, and 2) describing more broadly the development of the solar thermal sector to which the EU R&D funding has contributed. It is based on a compilation of data from several databases, a questionnaire among coordinators of EU-funded R&D projects, case studies, interviews and literature research. The methodology applied for this study is documented in a separate deliverable.[1] Where relevant, limitations and assumptions are mentioned throughout this report.

Solar thermal energy refers to any technology that harnesses energy from the sun to generate thermal energy, which can be further converted into electricity or used directly as heat. In contrast to solar photovoltaic (PV), solar thermal technologies do not exhibit the PV effect. Solar thermal energy consists of two main technology categories: concentrated solar power (CSP), and solar heating and cooling technologies:

- CSP is a system that uses mirrors or lenses to concentrate a large area of sunlight into a smaller area to heat a medium (usually a liquid or gas) that is then used in a heat engine process (steam or gas turbine) to drive an electrical generator, thereby generating power;
- Solar heating is the collection of heat from the sun. The most common technologies for this process include evacuated tube collectors, glazed flat-plate collectors and unglazed water collectors. Solar cooling can be accomplished via desiccant or absorption chiller systems. In addition, PV-thermal hybrids (technology that converts solar radiation into thermal and electrical energy at the same time) are also classified under this category. This is because normally the aim of hybrid systems is to produce thermal energy first and then electricity.

1.1 Concentrated solar power

The first CSP plants were built more than 30 years ago (SEGS I-V in Dagget, California). These first plants were based on the Parabolic Trough design. In recent years, other concepts such as Linear Fresnel, Dish Stirling and Solar Tower have also been developed. Especially the tower systems are currently considered to be the natural evolution of the technology.

The central elements of a solar tower system include a receiver placed on top of a tower structure, a number of heliostats (mirrors) surrounding the receiver tracking and directing the sunlight to the receiver, a steam generation system, and a storage system. Typically, the system utilises molten salts as heat transfer medium to generate steam that drives the turbine for the generation of electricity and the molten salt system allows energy storage beyond the daylight hours.

Plant efficiencies in this solar tower configuration are considerably higher than parabolic trough plants. Due to the higher temperature being realised in the heat transfer fluid, higher temperature and pressure steam conditions are achieved and thus higher efficiencies are obtained in the turbine.

[1] Trinomics (2018) - Study on impacts of EU actions supporting the development of renewable energy technologies – Literature review and methodology (Deliverables D1.1 and D1.2)

Together with this, solar tower configuration still is considered to have an important learning curve ahead. In the past, almost all CSP plants were based on Parabolic Trough technology and important cost reductions have been achieved thanks to the knowledge gained from one plant to another. This is now happening in solar tower configuration and there is a strong consensus in the sector that tower technology will realise important cost reductions in the next years.

The future of CSP is linked to its thermal energy storage capability. Compared to other renewable energies, CSP is considered one of the few dispatchable renewable energy sources (RES) for large-scale electricity generation. This dispatchability is achieved due to the availability of low cost heat storage via molten salts. (Large-scale electrical storage via batteries is not yet robust enough or economically viable). So, CSP currently can produce electricity in a dispatchable way and thereby generate electricity in periods of the day where there is a shortage of generation capacity and when electricity prices are high. This is one of the main advantage of this technology compared to photovoltaics or wind energy.

For CSP, environmental requirements are likely to become more important, since CSP plants are expected to be located in regions outside Europe with more aggressive environmental conditions where water scarcity is a major issue, and this will have a significant impact on plant design and materials. Locations outside Europe will allow local industries to offer products/services for the sector and thus the European industry will face increased competition, particularly as many countries have adopted policies aimed at increasing the local content of CSP projects. For instance, South Africa defined a minimum local content requirement of 20 % in 2011 and has increased this to 45 % in 2015.

Within the EU, Concentrated Solar Power (CSP) is predominantly applied in Spain. In terms of deployment, the technology is still at an early stage compared with other renewables such as solar PV and wind.

1.2 Solar heating and cooling

The solar heating and cooling market consists of four types of applications:

a) solar water heating – a mature market facing increasing competition from PV systems and heat pumps;
b) solar-supported district heating and cooling (DH&C) systems;
c) solar heating and cooling applications in the commercial and industrial sector;
d) solar air-conditioning and cooling (by way of absorption and adsorption chillers).

Solar water heating is a mature market that is facing increasing competition from PV systems and heat pumps. District heating and cooling systems on the other hand have an increasing market uptake. By the end of 2016, 300 large-scale solar thermal systems more than 350 kWth (500 m^2) connected to heating networks and 18 systems connected to cooling networks were in operation. Denmark is the worldwide leader in solar DH&C. The use of solar heat for industrial processes (SHIP) is also growing, but mainly outside Europe. Different types of technologies coexist in this market, depending on the size of the installation and its operating temperature(s). Solar cooling is one of the most promising markets, thanks to the simultaneous occurrence of sunshine and demand for cooling. However, the market uptake is hindered by the high costs of the installations, which currently only offer a pay back in niche markets (hospitals and hotels, especially in island regions).

Although some of the solar thermal technologies are already mature and competitive, large research challenges remain to bring down costs and to advance towards the solar trigeneration concept (heating and cooling + electricity), which would allow solar energy to be the single source of energy, for example in zero-energy buildings, in areas of high solar irradiation.

2 Historical R&D funding

2.1 EU R&D funding

The EU has funded solar thermal technologies through its research and development programmes. Since FP5, the technologies have received EUR 400 million for 168 research projects, and another EUR 38 million for 16 projects on solar thermal in combination with other technologies (see Table 2.1).

Table 2-1 EU funding per framework programme (1998 to mid-March 2018, 2016 million euros[2])

	Solar thermal		Solar thermal and other RES	
Framework programme	**EU funding**	**No. of projects**	**EU funding**	**No. of projects**
FP5	56.48	47	1.91	4
FP6	21.92	22	7.75	2
FP7	207.95	53	22.77	9
Horizon 2020 (H2020) *(data available up to mid-March 2018)*	113.15	46	5.93	1
Total EU funding	**399.50**	**168**	**38.36**	**16**

Source: CORDIS (2018)
Note: Funding includes all funds made available through the Framework Programmes. It is not limited to the energy challenges but also includes funding through other programmes/instruments such as the SME instrument.
H2020 includes all projects awarded and registered in CORDIS up to mid-March 2018. As H2020 runs from 2014 to 2020, not all funding had been awarded at this point.

There was a step change in EU R&D funding for solar thermal technologies between FP6 and FP7 when funding grew by a factor of 10. The total funding under Horizon 2020 (H2020) is not yet known as the programme has not finished, but the funding that has been allocated so far is already higher than the funding under FP5 and FP6, and is likely to reach a similar level to the funding available under FP7.

2.1.1 Evolution of research topics

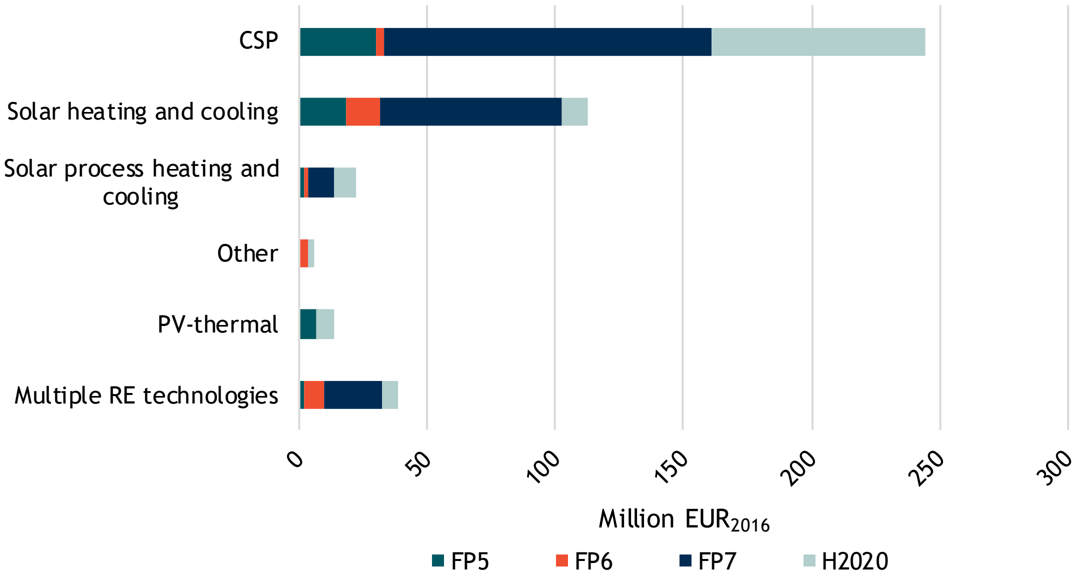
EU funding was divided across several sub-technologies, as shown in Figure 2.1. Most of the funding was allocated to CSP, which received EUR 245 million in total, while most projects focused on solar heating and cooling (see Figure 2.2). Other sub-technologies that received funding focused on process heating and cooling, and PV-thermal hybrids.

Analysing the technological fields funded in CSP projects, it clearly shows that CSP is still in its technological infancy, and many different technologies have been funded: Solar Tower concepts using innovative Heat Transfer Fluids (gases, particles, etc.), Dish Stirling systems, combined solar thermionic-thermoelectric systems, hybrid CSP plants, small/medium CSP plants based on Organic Rankine Cycle systems, etc. A number of projects have also focused on cross-cutting issues such as water use reduction, materials technologies, innovative thermal energy storage systems, and advanced systems for improved operations and maintenance (O&M). Several EU-funded projects linked to the evolution of the CSP sector in Europe in the last years such as SOLAR TRES by SENER INGENIERÍA Y SISTEMAS S.A. or the currently finished STAGE-STE (both projects are described in the detail in the case studies in Annex A).

[2] Historical values have been inflation adjusted to arrive at 2016 constant values. This has been done to show the values of budgets, prices and other monetary indicators without the impact of varying price levels over the years so that they can be compared over time more accurately.

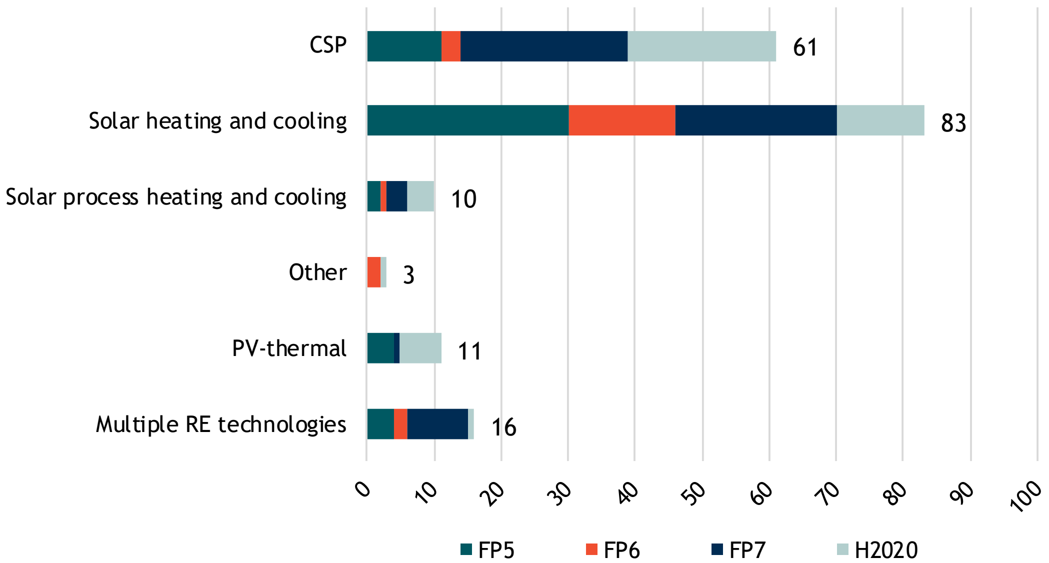
In the case of the Solar Heating and Cooling projects, solar thermal energy has been proposed for many different purposes, such as: heating, cooling, desalination, cogeneration of heating and electricity, trigeneration of heating, cooling and electricity, and thermochemical processes. The application areas vary from individual residential and non-residential buildings to district heating and cooling systems and solar heating or cooling used in industrial processes. Research activities have addressed developments in the areas of improved components, and easier installation. Novel materials (e.g. polymers) for solar collectors also have been explored, and new concepts such as hybrid solar thermal/photovoltaic systems, and building integrated solar thermal collectors have been developed. Similar to CSP projects, several projects have also supported the development of novel thermal energy storage systems. Inside the solar thermal heating projects, importance is given to projects that link to large-scale heat generation for district heating and/or process heat.

Figure 2.1 EU funding per sub-technology/area (2016 million euros)



Source: CORDIS (2018)
The area 'multiple RES technologies' includes projects in which solar thermal is one of multiple RES technologies.

Figure 2.2 Number of projects per sub-technology/area



Source: CORDIS (2018)
The area 'multiple RES technologies' includes projects in which solar thermal is one of multiple RES technologies.

2.1.2 Top recipients

The top 10 recipients of EU funding for solar thermal technologies include 8 research institutes, 1 manufacturer and 1 engineering, procurement and construction (EPC) company (see Table 2.2-2). These organisations have received 32 % of the EU funding over the most recent years (from 2008).[3] The research institutes included in the top 10 are all active in CSP, some exclusively while others also have activities in solar heating and cooling. The manufacturer in the top 10, Laterizi Gambettola, is an Italian manufacturer of solar thermal collectors (solar heating). The EPC company, Cobra Instalaciones y Servicios, is a Spanish company that participated in the construction of many CSP plants. Further down the list, other industrial players such as Salvatore Trifone e Figli (#11), Acciona (#13) and Brightsource Industries (#16) can be found, showing that while the research institutes are the main recipients, there is also substantial industry involvement in the EU-funded solar thermal R&D projects.

Table 2.2-2 Top 10 recipients of EU funding by organisation (2008 - mid-March 2018, in 2016 euros)

Rank	Organisation	Type of organisation	Funding
1	Deutsches Zentrum Fuer Luft - Und Raumfahrt Ev (DLR)	Research institute	16 494 547
2	Centro De Investigaciones Energeticas, Medioambientales Y Tecnologicas-CIEMAT	Research institute	10 982 765
3	Centre National De La Recherche Scientifique	Research institute	8 271 057
4	Fraunhofer Gesellschaft Zur Foerderung Der Angewandten Forschung E.V.	Research institute	7 492 800
5	Agenzia Nazionale per le Nuove Tecnologie, L'energia e lo Sviluppo Economico Sostenibile	Research institute	6 517 304
6	Laterizi Gambettola SRL	Manufacturer	5 204 009
7	Commissariat a L Energie Atomique et aux Energies Alternatives	Research institute	5 112 382
8	Fundacion Tekniker	Research institute	4 365 992
9	Cobra Instalaciones Y Servicios S.A	EPC company	4 220 716
10	The Cyprus Institute	Research institute	3 847 665

Source: CORDIS (2018)
The source data covered H2020 funding and FP7 funding from 2008, which includes 58 % of total funding for solar thermal identified in section 2.1. No data was available for recipients of FP5, FP6 and part of the FP7 funding. Projects under 'multiple RES technologies', as mentioned in the introduction of section 2.1, are not included in this Table.

The main recipients of EU funding in terms of countries are Spain, Germany and Italy (see Table 2-3). These countries received 56 % of the total EU funding available for solar thermal.

Table 2-3 Top 10 recipients of EU funding by country (2008 - mid-March 2018, in 2016 euros)

Rank	Country	Funding
1	Spain	56 594 944
2	Germany	38 801 344
3	Italy	32 227 030
4	France	24 786 685
5	United Kingdom	14 785 561
6	Switzerland	7 538 961
7	Austria	5 081 884
8	Cyprus	4 969 840
9	Israel	4 187 347
10	Greece	4 067 424

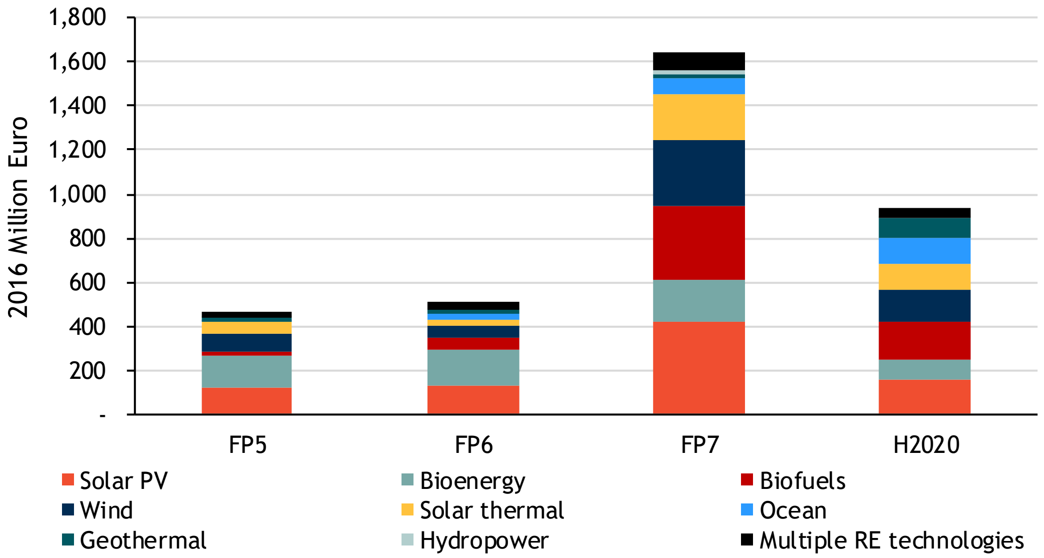
Source: CORDIS (2018)
The source data covered H2020 funding and FP7 funding from 2008, which includes 58 % of total funding for solar thermal identified in section 2.1. No data was available for recipients of FP5, FP6 and part of the FP7 funding. Projects under 'multiple RES technologies', as mentioned in the introduction of section 2.1, are not included in this Table.

[3] In RE sectors such as ocean (44 %), geothermal (53 %) and hydro (71 %), the top 10 organisations attract a relatively large share of the total funding. For bioenergy (14 %), solar PV (25 %), wind (26 %), biofuels (31 %) and solar thermal (32 %), the top 10 organisations attract much lower shares of the total funding available.

2.1.3 Share of total RE technology funding

Overall, solar thermal projects received 11 % of the EUR 3 6 billion awarded to all RE technologies through the FP5, FP6, FP7 and H2020 programmes (so far). In FP5 it received 12.2 % of total funding, but in FP6 the share was reduced to 4.3 %. The highest share was in FP7, when it accounted for 12.7 % of the funding, while under H2020 it decreased to 12.1 %. Overall, this shows that solar thermal has received considerable support, but has not been one of the premier technologies that EU R&D focused on (see Figure 2.3).

Figure 2.3 Share of funding for each technology sector in proportion to overall funding (H2020 only up to mid-March 2018)



Source: CORDIS (2018)
The area 'multiple RES' includes projects of multiple RES technologies.

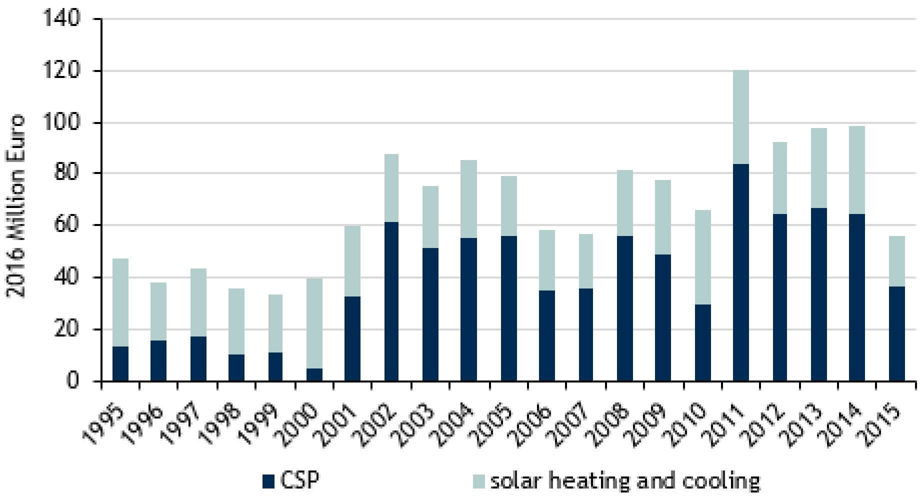
2.2 Member State R&D funding

2.2.1 Evolution over time

Annual R&D funding by Member States (MS) increased after 2000, from EUR 40 million on average between 1995-2000, to EUR 73 million on average between 2001 and 2010 (see Figure 2.4). This is about 5.5 times as high as the average annual EU funding from the FPs between 2001-2010 (EUR 13.4 million). MS funding increased further between 2011 and 2015 to an average of EUR 93 million a year, which was about twice as large as EU funding in the same period, which also increased substantially. Funding in 2010 and 2015 is lower because data was not available for Italy, which is one of the largest funders of solar thermal technologies.

MS R&D funding for solar heating and cooling has been stable during the last 20 years, which between 1995 and 2000 was the largest recipient of R&D funding for solar thermal technologies. In CSP, clear variations are visible. Starting in 2001, MS R&D funding for CSP increased quickly. Even though no new installed capacity has been added since 2013, R&D budgets have not decreased. R&D funding for CSP continues to play a big role in the overall funding for solar thermal technologies, taking up two-thirds of the total funding. The experience gained during previous installations have permitted EU industry to be active in almost all the CSP projects around the world.

Figure 2.4 Annual MS R&D funding in the EU for solar thermal



Source: Based on data from OECD/IEA (2018).
Note: Data for 20 EU countries was available in this source: The EU15 plus Czech Republic, Estonia, Hungary, Poland, Slovakia from the New Member States (NMS-13). Data for Italy was not available for 2010 and 2015, and data for the UK was not available for 2008.

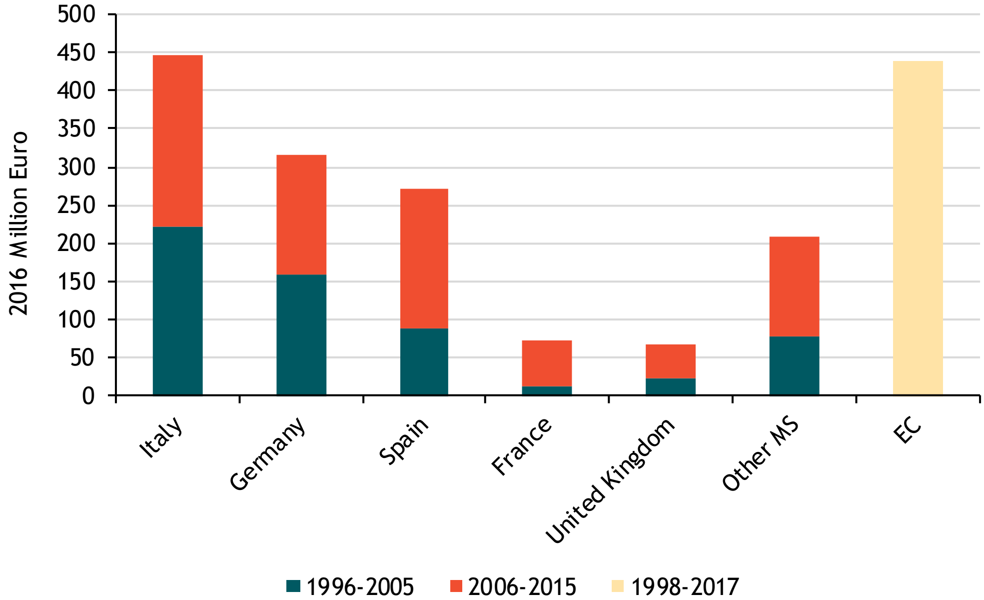
2.2.2 Largest MS funders

Figure 2.5 shows the EU funding compared to the largest five MS funders, which were Italy, Germany, Spain, France and the United Kingdom. Together, they accounted for 90 % of all MS R&D funding. The largest two funders of CSP are Spain and Italy, which are countries with a lot of solar resources. They respectively spent 93 % and 82 % of their solar thermal R&D budgets on CSP. Germany has been very active in CSP as well. For instance, the German Aerospace Center (DLR) has been part of the Plataforma Solar de Almería since 1987, one of the major infrastructures on CSP in the world. Other important players in CSP include the German research institute Fraunhofer ISE.

Large funders for solar heating and cooling include several countries with less solar irradiation, such as the United Kingdom, Germany and Austria. The United Kingdom and Austria spent nearly all of their solar thermal R&D budgets on heating and cooling (H&C), whereas Germany and France show a more equal allocation between the two technologies. Austria has several important research institutes, universities and an active industry in solar H&C. It also has a large installed capacity of solar thermal collectors (see section 5.1).

Italy provided more funding to R&D on CSP technologies than Spain, but did not install any CSP plants (see section 5.1). This illustrates that MS-funded R&D in solar thermal technologies is not the only driver for sector development. The main drivers for CSP installations in Spain were national policies and feed-in tariffs, which aided the development of the industry (see also section 5.1). In Italy there are no important industrial players, but it has research institutions and universities that publish a significant amount of research papers on CSP (see section 3.2).

Figure 2.5 Solar thermal R&D budgets of the Member States with the largest R&D budgets for solar thermal (1996-2015) and the EC (1998-2017)

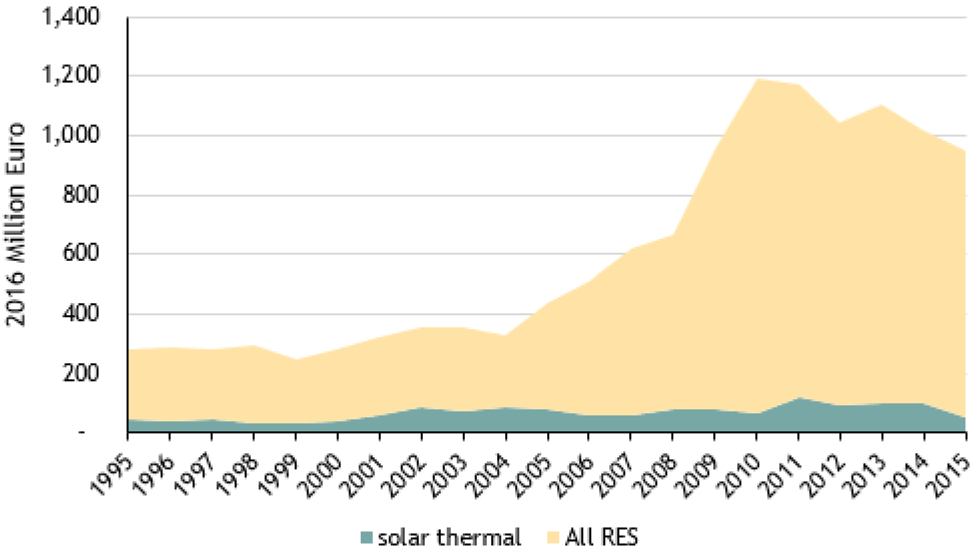


Source: Own elaboration based on data from OECD library and CORDIS (2018). Data for Italy was not available for 2010 and 2015, and data for the UK was not available for 2008.
Note: Time window of comparison between MS and EC funding is shifted 2 years due to data availability of MS budgets for the scope of analysis (FP5-H2020).

2.2.3 Share of total RE technology funding

In the period 1995 to 2015, MS allocated 12.7 % of their national research, development and demonstration (RD&D) funding for renewable energy (RE) technologies to solar thermal. In 1995, the share of solar thermal funding was 20.6 %. This share oscillated over the following years until it reached its peak from 2002 until 2004, with a share of approximately 30 %. From 2005 to 2010, the total funding for RE technologies increased, while for solar thermal the opposite happened; leading to a much lower share of all national R&D funding available for RE (+/- 10 %). After 2010, total funding for RE technologies started a decreasing trend. During this period solar thermal's share of funding remained relatively stable, oscillating around 10 %. Overall, it can be observed that solar thermal has become a lower priority for MS compared to other RE technologies, but that the technology still receives a significant share of the total MS R&D budgets.

Figure 2.6 Share of national R&D funding for solar thermal in proportion to the overall funding for all RE technologies



Source: Based on data from OECD/IEA (2018).
Note: Data for 20 EU countries was available in this source: The EU15 plus Czech Republic, Estonia, Hungary, Poland, Slovakia from the New Member States (NMS-13). Data for Italy was not available for 2010 and 2015, and data for the UK was not available for 2008.

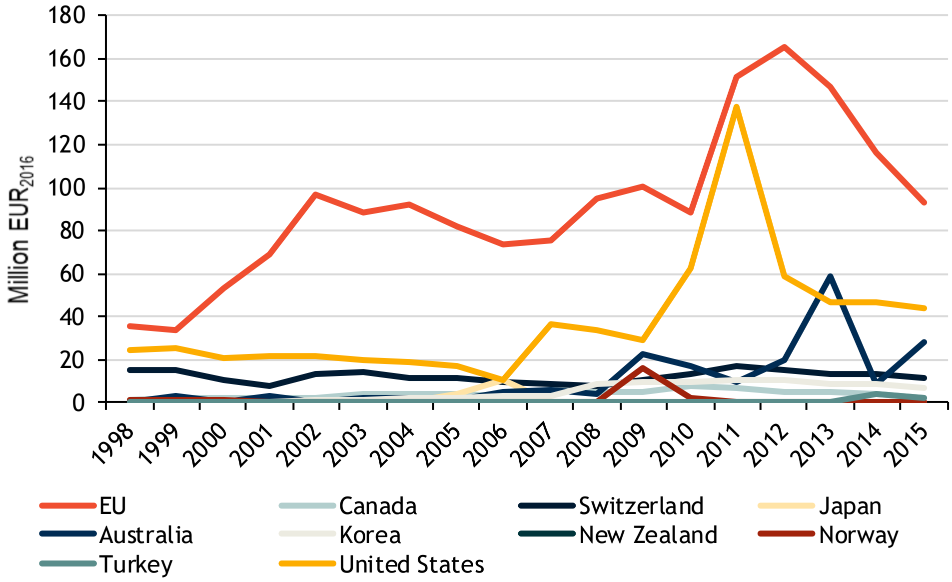
2.3 Private and international R&D funding

2.3.1 International public R&D funding

R&D funding for solar thermal technologies from the EU and MS combined is larger than in other countries, spending on average EUR 92 million per year between 1998 and 2015 (see Figure 2.7). The United States of America (USA) provided EUR 37 million per year on average between 1995 and 2015, of which nearly all went to CSP technologies. Its SUNSHOT programme had clearly defined objectives for the technologies to be developed, as well as cost reduction objectives. Together with Spain, it is the global leader in CSP installations and has been driving technology development in the sector over the last decade.

Switzerland is the next largest funder with EUR 13 million per year on solar thermal R&D funding on average, with an equal allocation between CSP and H&C. Australia also had significant budgets for both technologies, with average spending of EUR 9 million a year. Other countries with significant R&D budgets for solar thermal are Korea and Canada.

Figure 2.7 Comparison of international R&D funding for solar thermal



Source: OECD/IEA (2018).
Note: EU: European Commission and Member State budgets combined.
National budgets for 2016 were excluded from the analysis because they are early estimates and lack reliability/coverage. Data covers 20 EU countries: the EU15 and Czech Republic, Estonia, Hungary, Poland, Slovakia and the European funding programmes FP5, FP6, FP7 and H2020 (starting in 1998). For countries outside the EU, national budgets were available for Australia, Canada, Japan, Korea, New Zealand, Norway, Switzerland, Turkey and the USA. Data for Italy was not available for 2010 and 2015, and data for the UK was not available for 2008.

2.3.2 Private R&D funding

There is no data available on private R&D funding for solar thermal. The only data source that includes solar thermal in its statistics provides an aggregate number for solar PV and solar thermal together. As solar thermal private R&D is estimated to be a small share of the total solar R&D budgets, no reliable estimate on the magnitude of private R&D funding could be provided.

2.4 Conclusions

EU funding for solar thermal research was modest in the earlier years (FP5 and FP6) but has increased to considerable research budgets in FP7 and H2020. Compared to other RE technologies, solar thermal receives moderate support with a share of about 11 %. In terms of technologies, CSP received most of the funding, about twice as much as solar heating and cooling. The projects cover a wide range of technologies and applications, including the integration of energy storage technology.

The main recipients of EU funding include the leading research institutions on the topic as well as several industrial players. In terms of countries, Spain, Germany and Italy have received most EU funding, which coincides with the leading national research budgets that these countries have for solar thermal technologies. The MS research budgets increased significantly in the early 2000s, preceding the increase of EU solar thermal funding from 2007 onwards. Since then, MS research budgets have remained relatively stable in absolute terms. Their share of the overall MS RE technology research budgets has decreased considerably however, showing that the technology has been less popular in recent years. Still, the combined EU and MS R&D budgets for solar thermal are leading internationally.

3 Research effectiveness

R&D projects can lead to patents, publications, spin-offs and several other, less concrete but potentially important direct outputs such as standardisation and knowledge exchange. Such impacts are the most direct impacts of R&D funding and therefore provide the cleanest view on the effectiveness of research budgets spent. In this section we discuss patents, publications, spin-offs and other direct research outputs, and their relation to R&D funding for the solar thermal sector.

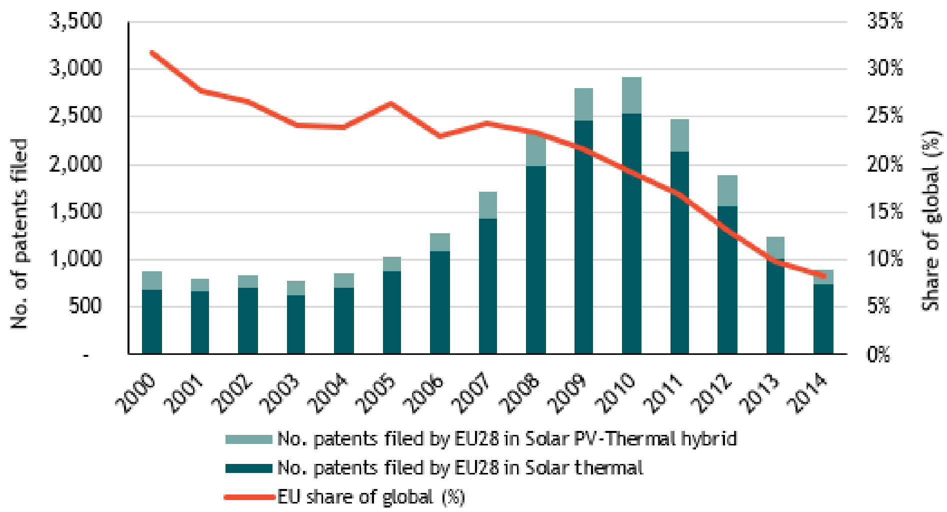
3.1 Patents

Patents are a commonly used indicator to measure the output of R&D funding as they provide a direct measurement of the impact in terms of novel knowledge generated. Furthermore, patent data are readily available, in a standardised form. However, some limitations have to be taken into account, such as the fact that filing a patent is not an objective of all research projects and that the economic value of patents varies significantly.

3.1.1 Evolution over time

Figure 3.1 shows the pattern of patents filed for solar thermal technologies by EU organisations and their share of the patents filed globally. The number of EU patents filed increased up to 2010, after which it decreased again to pre-2005 levels.

Figure 3.1 Evolution of solar thermal patents filed by EU countries



Source: IRENA INSPIRE (2017)

There is a downward trend in EU's share of global patents filed for solar thermal technologies, decreasing from nearly half of all global patents in 2000 to only 10 % in 2014. The share dropped even in years that the absolute number of EU patents increased. This is largely caused by a sharp increase in patents filed by China, growing from 500 patents/year in the early 2000s to more than 5000 patents/year from 2012 onwards. At the same time, EU companies have started to question the benefits of patenting and are increasingly choosing to move fast to reap the benefits of their inventions, rather than patenting.

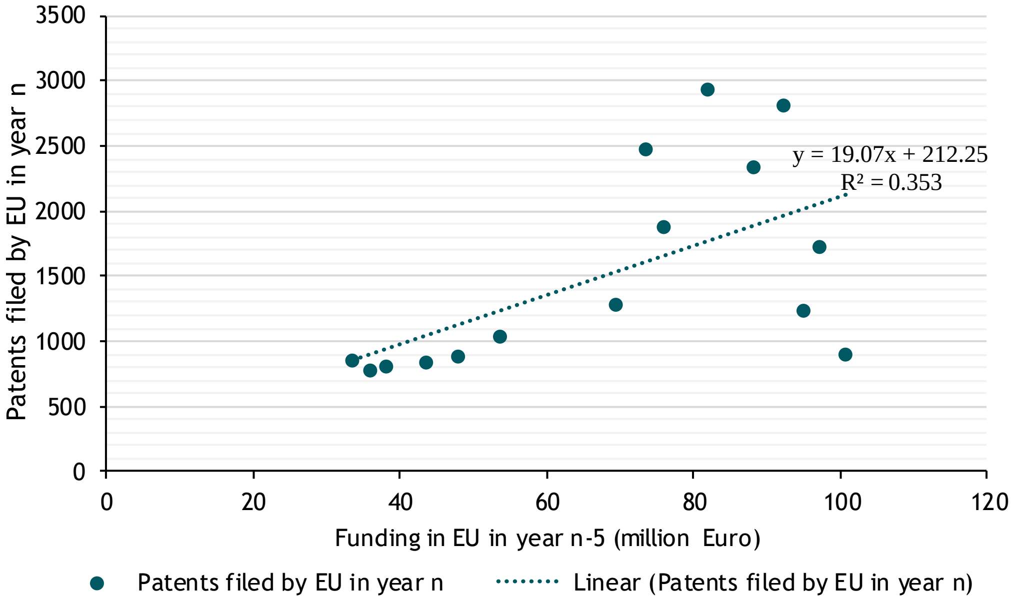
From 2002 to 2014, more than 8 000 patents were filed in Germany, which made it the MS where most EU patents were filed (42 % of the total number), followed by Spain (14 %), France (11 %), United Kingdom (5 %), Austria (5 %) and Italy (5 %). These are the same MS that provided the largest funding, although Italy provided the most funding but is surpassed by five other MS in terms of patents.

3.1.2 Effectiveness of R&D funding in producing new patents

In theory, higher R&D budgets in a region are expected to lead to an increase in the number of patents filed from that region. The extent to which this relation exists in the sector provides insight into the objectives of the research (is it targeted at technology development, so more likely to result to a patent application?) and the effectiveness of the research (was it successful in developing the technology so resulting in a patent application?).

Figure 3.2 compares the total amount of patents filed to the amount of EU R&D funding (MS + EU combined), accounting for a time lag between the moment of funding and the patent application. The highest correlation is visible with a time lag of 5 years. Even then, there is no clear correlation between the number of patents and the amount of EU funding; the funding levels do not explain the number of patents filed. This is in line with the findings for other RE sectors and underlines that patent applications are generally not a primary objective of a research project.

Figure 3.2 Patent effectiveness



Notes: We tested a delay of 0, 1, 2, 3, 4 and 5 years for the patents filed from year 2000-2014.
2015 data of patents was excluded because the source (IRENA) mentioned it is common to have delays of 3 years from a patent application and the year is reflected in the database. The correlation went up when 2015 data was excluded. A delay of 5 years between funding year and patents filed showed the highest correlation (R^2 = 0.353).

3.1.3 Contribution of EU funding

To help capture more directly the impact of EU-funding through the Framework Programmes (FP5 to H2020) a questionnaire was sent out to all project coordinators involved in research to develop the solar thermal energy technology sector. 168 Framework Programme projects in solar thermal energy were identified for this study. Out of these, it was not possible to contact all project coordinators (due to missing contact links on CORDIS). 124 project coordinators were contacted with a request to participate in the questionnaire. The overall response rate was 27 % (33 out of 124 projects). Project coordinators of FP7 and H2020 programmes constituted the large majority of responses.

Even though patent applications are often not a primary objective of research projects, several EU-funded projects have led to a patent application. Out of the 33 questionnaires that have been completed by solar thermal projects, 4 reported a patent application as one of their outputs.

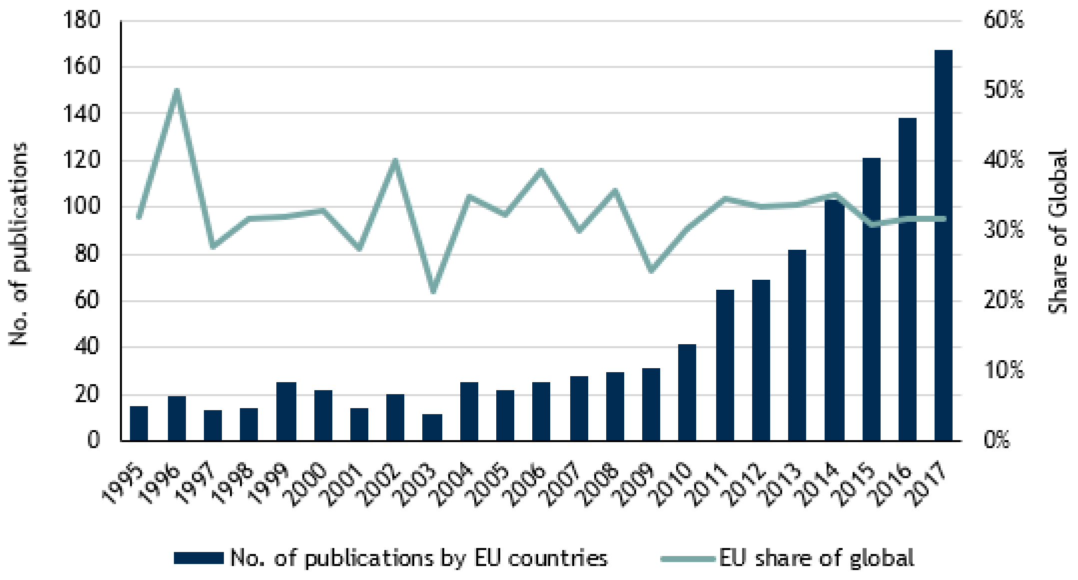
3.2 Publications

Publications of research papers are a useful indicator to measure the output of R&D funding, as there is enough data available to make a comparison between the EU's performance and the rest of the world. Moreover, publications have a close relation with public R&D funding, allowing us to differentiate the effect of public R&D funding from private R&D funding. Publications are categorised by country on the basis of the address of the author. If it has authors from different regions, the publication is counted for both regions.

3.2.1 *Evolution over time*

Figure 3.3 shows the pattern of solar thermal publications by EU-based authors over the years. The number of publications on solar thermal energy increased over the years. EU-based authors were involved in a third of the global publications between 1995-2017, making it the global leader. Outside of the EU, the largest number of publications had authors from China, the USA, and Canada. Combined, these authors were also involved in a third of the global publications between 1995-2017. Particularly in recent years, China has authored a large number of publications (20 % to 25 %), but this is still less than publications by EU authors. Within the EU, Germany has authored the most publications (202), followed by Spain (200), France (157), UK (153), and Italy (139). These five MS are also the five largest R&D funders, which seems to indicate a correlation between R&D funding and publications.

Figure 3.3 Evolution of solar thermal publications by EU countries



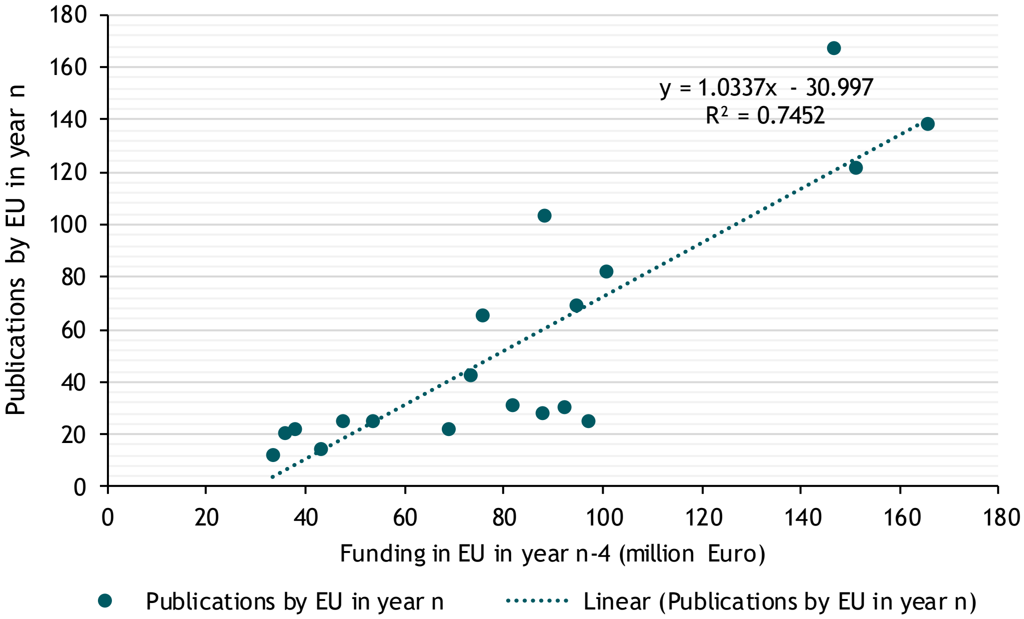
Source: Web of Science (2018)
Notes: keywords used are: 'solar heating' or 'concentrating solar' in the title, topics and abstract of articles between 1995-2017. The share of global refers only to those publications with an address listed. 1 % of the global publications had no address listed in that period of time. One article can have multiple authors (therefore, also multiple countries). The count is the number of articles in which at least one author listed a EU MS as their address.

3.2.2 R&D funding effectiveness in producing publications

In theory, higher R&D budgets in a region are expected to lead to an increase in the number of publications from that region. The extent to which this relation exists in the solar thermal energy sector provides insight into the objectives of the research (does it aim for a publication?) and the effectiveness of the research (is it successful in realising a publication?).

Figure 3.4 compares the total amount of EU publications to the amount of EU R&D funding (MS + EU combined), accounting for a time lag between the moment of funding and the publication. The number of publications correlates more closely to R&D funding than the number of patents does, indicating that publicly funded R&D projects in the solar thermal energy sector have a higher focus on publishing and/or are more effective at publishing. This is in line with the findings for other RE sectors and underlines that publishing is often one of the primary objectives of a research project.

Figure 3.4 Publication effectiveness



Note: We tested the publication effectiveness of R&D funding for the period 1995-2017. Funding in EU includes EU funding and MS funding. We tested different delays (0, 1, 2, 3, 4 and 5 years) to evaluate which one had the highest correlation. After two years of delay, for each year of delay, the sample size was reduced by one number (e.g. with 0, 1 and 2 years of delay the sample size was 21 years, with 3 delay the sample size was 20 years, etc.)
With no delays (n-0), the R^2 is the lowest of all the ones tested (0.4046). The highest R^2 was found using 4 years of delay (0.7452).

3.2.3 Contribution of EU funding

The correlation between R&D funding in the EU and publications by EU authors shows that there is a clear relation between the amount of funding and the number of publications. To what extent the funding through the European Commission contributed to these publications is the topic of this section.

Between 2008-2017, 153 publications explicitly reported benefitting from EU funding sources[4], which equates to 18 % of the total number of EU publications in those years. Not all publications report all sources of funding that they benefitted from, therefore it is likely that the real figure is higher.

[4] The EU funding sources are not always specified and may therefore include funding from other instruments than the Framework Programmes, such as funding from the EIB. The majority (82 %) did specify an FP explicitly however, so the inaccuracy resulting from a potential inclusion of publications that benefitted from other EU funding programmes is limited.

The high number of European publications that benefitted from EU funding is further confirmed by the questionnaire responses. More than 35 % of the respondents reported one or more publications as one of the outputs of the project. The Framework Programmes clearly play an important role in maintaining the EU's leading academic position in solar thermal.

The top EU organisations in terms of publications are listed in Table 3-1. It shows that the top 3 organisations in terms of EU funding are also among the top publishing organisations in the EU, confirming that the EU framework programmes support the academic leadership of the EU.

Table 3-1 Top organisations in the EU contributing to solar thermal publications (1995-2017)

Rank	Institutions	Country	No. Publications	EU funding rank
1	Centre National de la Recherche Scientifique CNRS	France	101	3
2	Helmholtz Association	Germany	75	30+
3	German Aerospace Centre DLR	Germany	65	1
4	University of Nottingham	UK	35	30+
5	Ulster University	UK	34	30+
6	Consejo Superior de Investigaciones Cientificas CSIC	Spain	24	30+
7	Polytechnic University of Madrid	Spain	22	30+
8	Universidade de Lisboa	Portugal	22	30+
9	CIEMAT	Spain	21	2
10	Technical University of Denmark	Denmark	21	30+

Source: Web of Science (2018)
Note: The count is the number of articles in which at least one author listed the European organisation as their address.

3.3 Start-ups and spin-offs

The creation of start-ups and spin-offs is another potential impact of research projects, which can function as an important link between research and the development of a European industry. Start-ups and spin-offs are not reported consistently, however. Therefore, questionnaire results are used to provide insight into these impacts.

While only 1 of the 33 projects that completed the questionnaire for this study reported a spin-off or start-up as one of the outputs of their project, EU funding has been clearly supportive for the EU solar thermal start-up community. 21 SMEs received funding through the SME instrument which aims to support ground-breaking innovative ideas developed by small and medium-sized companies and is part of the Framework Programmes. This way, the start-ups that emerge across the EU are supported in the development of their technology. Examples include:

1. SUN GEN: an Italian SME that has developed innovative optics to concentrate sunlight which is supported through the Focalstream project;
2. SunOyster System: A German SME, founded in 2011, that is developing and commercialising a highly efficient solar collector and is supported through the SOcool project (see project spotlight box below and case study in Annex A);
3. Fresnex: a German SME, founded in 2012, that has introduced a solar steam generation system for industrial applications to the market and is supported through the helioSTEAM project.

Project spotlight: Novel heating and cooling system - SOcool

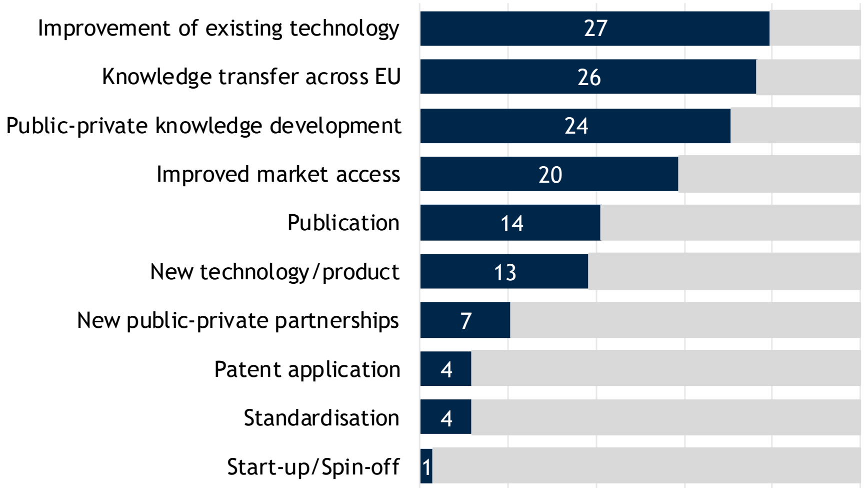
The SOcool project (SunOyster Cooling; H2020-SMEINST-2-2016-2017; September 2017 to August 2018; EU funding: EUR 1.4 million; Coordinator: SunOyster) is based on a patented innovation of concentrating photovoltaic/thermal (CPVT) system combined with chillers to provide cost-efficient solar energy in forms of electricity, heat and cold. SunOyster is building-up a production pilot line, testing and certifying three product packages, carrying-out a demonstration project, and launching large-scale commercialisation with the help of an SME-Instrument grant.

See annex A for a detailed case study on the SOcool project.

3.4 Other research outputs

While patents, publications and start-ups/spin-offs are often the most tangible and easily quantifiable outputs of EU-funded research of RE technologies, there are many other outputs that contribute to the development of a leading sector. To get a better understanding of these other impacts, a questionnaire was sent out to project coordinators of EU-funded R&D projects. The results of the questionnaire are presented in Figure 3.5.

Figure 3.5: Impacts of EU-funding based on questionnaire results (out of 34 responses in total)



Note: The impacts were determined from the description of the projects and their reports on results available on Cordis as well as the information they provided in the open questions of the questionnaires and during the interviews where applicable.

The most commonly reported impact is the improvement of existing technologies (27 out of 33). This shows that EU-funded R&D contributes to the continuous improvement of solar thermal technologies, which is of particular relevance for continuity in periods of limited new installed capacities such as currently for CSP (discussed in more detail in chapter 0).

Knowledge transfer across the EU (26 out of 33) and public-private knowledge development (24 out of 33) are also common outputs of EU-funded R&D projects. These outputs result from collaboration between different organisations across the EU within the EU-funded projects, including joint R&D between public research institutes and private companies. This way, the FPs play an important role for increasing collaboration and aligning R&D priorities across the EU and thereby sustaining academic leadership. The ECOSTAR (FP6) and STAGE-STE (FP7) projects are examples of EU-funded projects that brought many stakeholders in the solar thermal energy sector together and thereby contributed to increased knowledge transfer and public-private knowledge development for solar CSP (see also STAGE-STE project spotlight box below).

Finally, improved market access is a commonly reported output of EU-funded R&D projects. This illustrates that several solar thermal technologies are ready for market uptake and that the FPs contribute to this (for instance the EUROSUNMED project which provided access to new markets around the Mediterranean for its consortium members, which is described in the project spotlight box below). Related to this, is the contribution of EU-funded projects to the development of new business models which may open up new markets, such as illustrated by the PIME's project which delivered new Energy Service Company business models (see project spotlight box below).

Apart from these outputs, sector experts describe the role of EU funding as essential for the early development of the CSP sector in the 2000s by supporting various commercial-scale demonstration projects (discussed in more detail in section 5.1). For solar heating and cooling, comparable contributions have been made by supporting demonstrations of integrating the technology into buildings (discussed in section 4.3), integrating solar heating in district heating systems, and applying the technology for industrial process heat generation (discussed in section 5.1).

Project spotlight: STAGE-STE

STAGE-STE (Scientific and Technological Alliance for Guaranteeing the European Excellence in Concentrating Solar Thermal Energy; FP7-ENERGY-2013-IRP/CP-CSA; February 2014 to January 2018; EU funding: EUR 10 million; Coordinator: CIEMAT, Spain) contributed significantly to bringing European CSP research institutes and industry together to set a common research and technology agenda, and align the EU and national level policies in CSP field. The cooperation during the project period contributed to opening-up new markets for the European industry, and has led to many further opportunities to launch new initiatives on a bilateral basis. The project also resulted to over 200 joint publications, more than 4 000 tests carried out at the facilities of the project participants out of which more than 200 were joint tests involving two or more project participants, a web-repository including a description of more than 200 intellectual property assets and more than 100 researchers involved in mobility and exchange programmes.

See annex A for a detailed case study on the STAGE-STE project.

Project spotlight: PIME's

The PIME's project (CONCERTO communities towards optimal thermal and electrical efficiency of buildings and districts, based on microgrids; FP7-ENERGY-2008-TREN-1 – CP; January 2009 to November 2015; EC funding: EUR 10.8 million; Coordinator: Rogaland Fylkeskommune, Norway) was about piloting energy efficient communities. The project is a prime example of a project with a wide range of objectives that are relevant to the sector but that does not lend itself for capturing in concrete statistics. The project contributed to technology advances related to the implementation of large-scale solar thermal generation with associated heat storage, among several other technologies. The concepts were demonstrated at demonstration sites in Hungary and Spain and the project fed into several follow-up projects. Furthermore, several partnerships between the consortium members were created or strengthened, including partnerships with the private sector, and new Energy Service Company (ESCO) models were developed.

Source: EC, 2018, Community Research and Development Information Service; and interviews of the project coordinators.

Project spotlight: EUROSUNMED

The EUROSUNMED project is another example of a project with a wide range of objectives that are relevant to the sector but do not lend itself for capturing in concrete statistics. Apart from 3 patent applications, key outputs of the project include access to new markets around the Mediterranean for several of their consortium members, the development of various optical coatings, an absorber and thermal energy storage materials for use with CSP technology, as well as a several models and algorithms.

Source: project website (http://eurosunmed.cnrs.fr/).

3.5 Conclusions

The significant MS and EU budgets for solar thermal have been effective in establishing and maintaining a leading academic position globally. The EU is number 1 in terms of publications and has been able to preserve this leading position irrespective of the strong growth in publications from China. The specific contribution of EU funds is also clearly visible with a contribution to at least 18 % of the EU publications and possible many more.

The conversion of R&D budgets to patents has been less successful with a consistently declining share of the global patents and in recent years also a decline in the absolute number of patents from the EU. This can be partly attributed to the growth in patent applications from China and partly to EU companies making a conscious decision not to patent anymore due to the lack of clear benefits.

Start-ups are a less common direct output of EU-funded research projects. Nevertheless, EU funding supports numerous start-ups through their SME instrument, playing an important role in the development of these start-ups.

Further important outputs of EU-funded R&D include the improvement of technologies, alignment of R&D activities, and increasing knowledge transfer and collaboration across the EU. Moreover, EU-funded R&D contributed to improving market access for EU companies and stimulated market formation by financing the demonstration of various solar thermal technologies.

4 Technology development

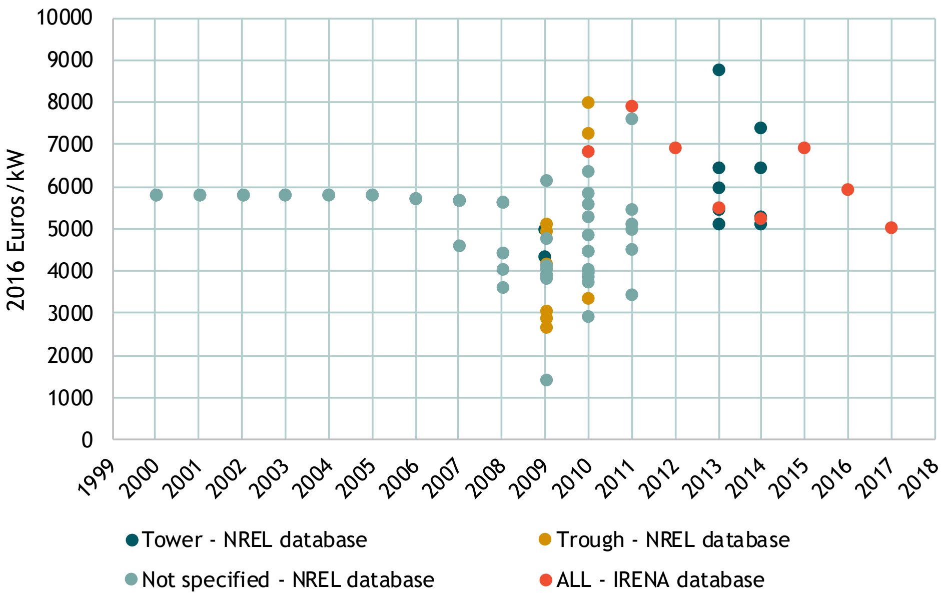
One of the core objectives of R&D funding on RE technologies is to contribute to the development of the technology to make it cost competitive and allow for increased uptake of the technology. The impacts on technology development can be assessed technologically, or from an economic point of view, looking at the costs, performance and competitiveness of the technology. This section focuses on key indicators that assess technology development from an economic point of view: capex, opex and Levelised Cost of Energy (LCOE).

4.1 Capex

Capex (capital expenditure) refers to the initial investment costs of the solar thermal projects. Cost-reducing innovations can contribute to a downward trend in capex, which in turn can make the sector more cost competitive and allow for increased uptake of the technology. One of the main limitations of this indicator is that capex is highly location- and technology-specific, and will therefore vary between projects. To be able to provide an overview of the evolution of the capex over time, we consider global historical estimations of capex, including the estimations of regions outside the EU.

The capex for solar thermal capacities varies greatly for both electricity and heat generation. For CSP, capex for solar tower plants ranges from EUR 4 358/kW to EUR 8 759/kW, while plants based on the older parabolic trough design range from EUR 2 700/kW to EUR 8 012/kW (see Figure 4.1). No clear trend can be discerned from the data, which is due to the costs being location-specific and the lack of a standard design that can be gradually improved. Instead, each plant requires a lot of specific design which adds to the costs. Furthermore, the functionality of each plant differs considerably.

Figure 4.1 Evolution of capex for electricity generation (CSP - Global estimates)

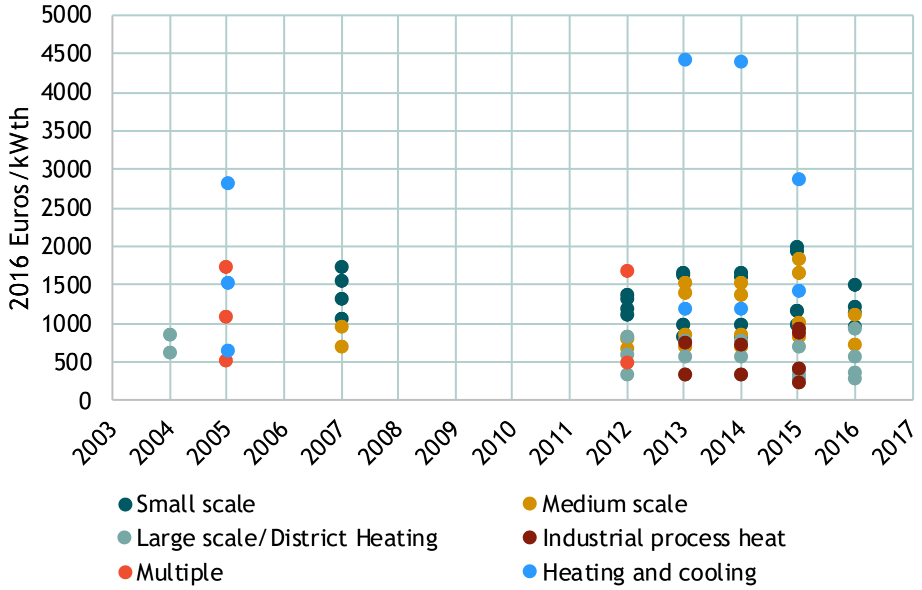


Note: All figures are global, unless specified otherwise.
For electricity generation, data was taken from NREL database and from IRENA database. IRENA's data is the 'Global weighted average' based on their database with ~15 000 real projects.

Also, the capex for heat generation capacities shows a wide range (see Figure 4.2). Capex for small-scale installations for households can have a capex as low as EUR 100/kW. These are used for hot water and/or heating of buildings. Capex for district heating is higher and ranges from EUR 300/kW to EUR 958/kW with the more expensive installations including seasonal storage. Solar thermal systems for industrial process heat have the largest range, from EUR 239/kW to EUR 1 626/kW. Generally, solar thermal plants used for cooling have the highest capex, ranging from EUR 657/kW to EUR 4 439/kW.

The trends in the capex of solar thermal heat applications are hard to evaluate. The data points with the lowest capex per sub-technology definitely point to reducing capex, for instance visible for large-scale district heating. However, there are also data points that show a higher capex in recent years.

Figure 4.2 Evolution of capex for heat generation (global estimates)



Note: All figures are global, unless specified otherwise.
For electricity generation, data was taken from NREL database and from IRENA database. IRENA's data is the 'Global weighted average' based on their database with ~15 000 real projects.
For heat generation, data was collected through a desk research. The main sources were REN21 reports (2005, 2007, 2010-2015), OECD/IEA (2007), Solar Thermal World (2016) and Gudmundsson et al (2013). The estimates found for heat were grouped in five categories: Small scale (single-family systems or installed capacity from 0-20 m² for hot water only and combi-systems), Medium scale (multi-family systems or installed capacity from 20-100 m² for hot water only and combi-systems), Large scale (district heating, block heating systems or installed capacity larger than 100 m² for hot water only and combi-systems), Industrial process heat (heat from 50 °C to 400 °C), Heating and cooling (heating and cooling systems, adsorption chillers) and Multiple (solar collectors of unspecified capacity, or with a wide range of capacity).

4.2 Opex

Opex (operational expenditure) includes fixed and variable costs for operation and maintenance (O&M) of the plants. Similar to capex, cost-reducing innovations can contribute to a downward trend in opex, which in turn can make the sector more cost competitive. Opex is less location-specific than capex, but can show large variations between sub-technologies. Only global figures were available for the opex.

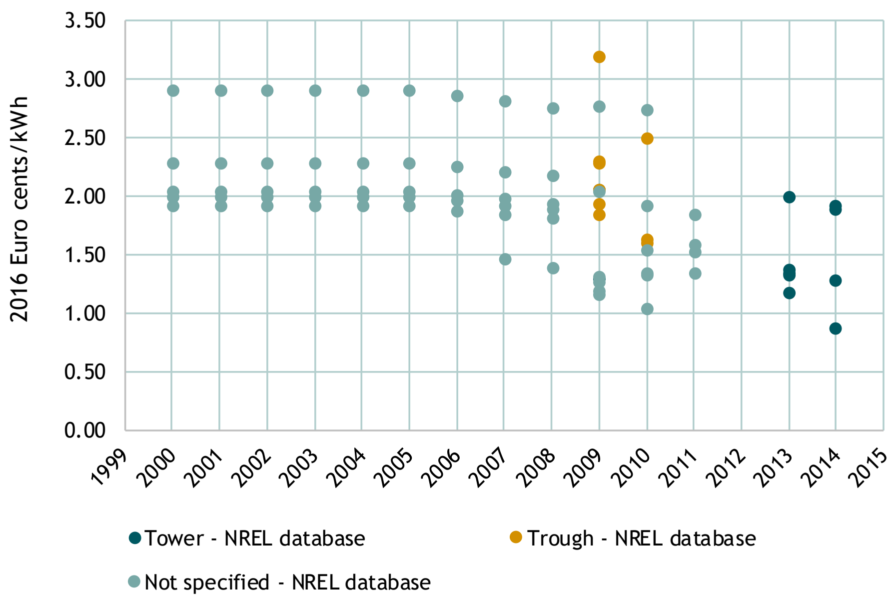
Figure 4.3 shows the development of the opex for solar thermal electricity generation. The majority of the historical O&M costs do not specify a sub-technology, however by 2014 about 85 % of the global cumulative installed capacity were trough plants.[5] The range of opex for trough plants ranges from 1.401 to 3.201 EURct/kWh. Opex for tower CSP plants has a generally lower range, from 0.861 to 2.047

[5] IRENA (2015) https://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Power_Costs_2014_report.pdf

EURct/kWh. The lowest value for tower CSP plants corresponds to a plant with 18 hours of storage, and a capacity factor of 80 %.

Recent CSP plants built in Spain have lower O&M costs than in the early 1990s. One of the main causes for O&M expenditures is still glass breakage and plant maintenance. Glass breakage requires the replacement of receivers and mirrors, while plant maintenance involves mirror washing (which includes water costs). Advances in materials, design and increased automation of CSP plants have reduced the opex over the last twenty years, but plant insurance (between 0.5 % to 1 % of total capital costs per year) and other potential costs remain significant components in the opex of solar thermal electricity generation.

Figure 4.3 Evolution of opex for electricity generation (CSP - global estimates)



Opex for solar thermal heating generation varies greatly depending on the scale and the type of system. In 2005, opex for direct hot water (DHW), thermo-syphon and combi-systems ranged from 1.21 to 4.53 EURct/kWh. In contrast, solar thermal heating with additional cooling equipment has considerably higher opex, ranging from 1.61 to 7.41 EURct/kWh[6].

In 2016, small-scale installations generating hot water and space heating had an average opex of 2.21 EURct/kWh, medium scale systems had an average opex of 1.73 EURct/kWh, and large-scale systems had an opex of 1.24 to 1.26 EURct/kWh.

[6] *OECD/IEA (2007) Renewables for heating and cooling. Untapped potential. IEA publications. Pg. 125*

4.3 LCOE

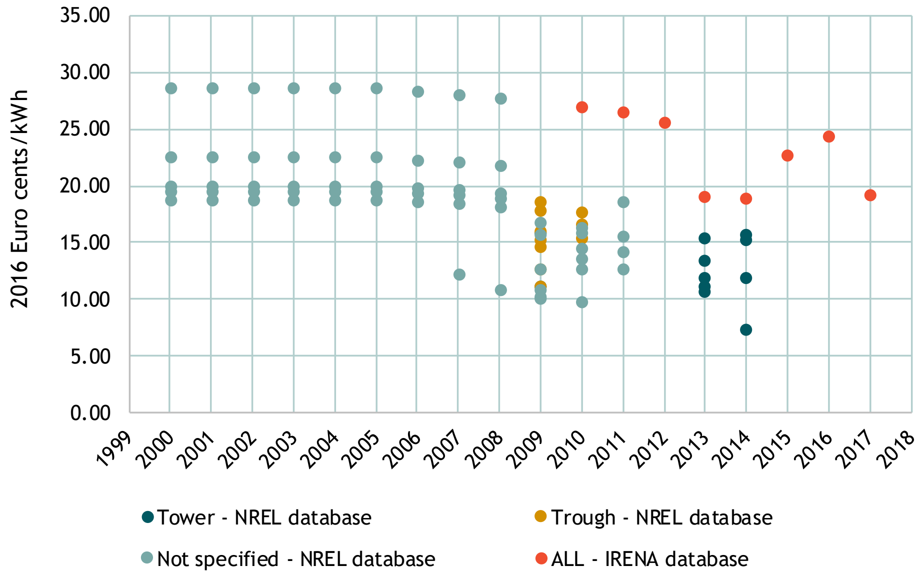
The Levelised Cost of Energy (LCOE) is an indicator to compare the project costs of different energy generation technologies.[7] LCOE is most commonly used in the context of electricity generation, with the 'E' denoting electricity. LCOE can however also be applied to heat generating technologies, sometimes then denoted as Levelised Cost Of Heat. In this document we use LCOE as Levelised Cost Of Energy, specifying per case if this concerns electricity or heat.

Similar to capex and opex, cost-reducing innovations can contribute to a downward trend in LCOE, which in turn can make the technology more cost competitive. While LCOE is a relatively comprehensive measure of the technology's costs, it does not include all the costs for delivering energy, such as ancillary services and transmission and distribution costs.

Figure 4.4 shows the evolution of the LCOE for solar thermal electricity. The LCOE ranges from 7.2 to 28.6 EURct/kWh. The minimum value represents a Tower CSP system with 18 hr storage and a capacity factor of 80 % and the maximum value is an estimate from an unspecified plant in the NREL database for years 2000 to 2005. On average, estimates from the NREL database have been stable between 2000 and 2006, and show a downward trend afterwards.

The IRENA database also shows a decreasing trend between 2012 and 2014. According to IRENA (2018), the global LCOE range in 2012 widened due to the mix of new projects in Spain, and the commissioning of more competitive plants. On average, the LCOE between 2013 and 2014 was about 20 % lower than between 2009 and 2012. According to IRENA, the main factor behind the downward trend during that period was probably the higher levels of Direct Normal Irradiance (DNI) at the sites of the newly installed plants.

Figure 4.4 Evolution of LCOE for solar thermal electricity generation (CSP - Global estimates)



Note: For electricity LCOE was calculated for the NREL database values using the market values of NREL (43 % average capacity factor, and 30 years of plant lifetime) when these values were not provided by the original source. A discount rate of 7.5 % was used, taken from IRENA's methodology, and the capex was annualized using the Capital Recovery Factor Method. LCOE from IRENA was taken directly from the database and converted to EUR_{2016}.

[7] There are different ways of calculating the LCOE; the method applied here is explained in the methodology document: Trinomics (2018) - Study on impacts of EU actions supporting the development of renewable energy technologies – Literature review and methodology (Deliverables D1.1 and D1.2)

EU-funded R&D projects contribute to important improvements and cost reductions in different CSP components (receiver, collector, heliostat design, turbines etc.), plant construction and operations. Furthermore, EU projects contribute to advances in areas such as heat transfer fluids, thermal energy storage, water consumption management, and hybrid CSP plant solutions have driven the costs of CSP technology further down. Examples include the MACCSOL and WASCOP projects, both of which developed technologies that reduce water consumption and the HYSOL project that demonstrated a solar-biogas hybrid CSP plant (see project spotlight boxes below).

Project spotlight: Air-cooling for CSP plants - MACCSOL

The MACCSOL project (The development and verification of a novel modular air-cooled condenser for enhanced concentrated solar power generation; FP7-ENERGY-2010-1/CP; September 2010 to February 2015; EC funding: EUR 5.1 million; Coordinator: University of Limerick, Ireland) developed, tested and demonstrated a dry cooling technology called Modular Air-Cooled Condenser (MACC) for CSP plants. CSP plants require cooling to condense steam during the power generation cycle. Water is typically used for cooling but as the CSP plants are placed in in high solar radiation areas, water supplies are scarce. The MACC technology developed provides a cost-efficient dry cooling technology based alternative. The modular air-cooled condenser is equipped with speed-controlled fans controlled by sensors that enable the condenser to maintain optimum pressure and temperature regardless of ambient conditions (e.g. temperature, wind). The system enables more efficient condenser unit performance. Based on theoretical models, simulation studies and lab-scale prototypes, the project built an industrial scale prototype installed at a 6 MW CSP plant constructed in Jemalong, New South Wales, Australia. The results showed that the technology enables up to 4 % increase in power plant efficiency, when compared to conventional dry cooling methodologies.

Source: Source: EC, 2018, Community Research and Development Information Service

Project spotlight: Water saving of CSP plants - WASCOP

H2020 project WASCOP (Water Saving for Solar Concentrated Power; H2020-LCE-2015/RIA - Research and Innovation action; January 2016 to December 2019; EC Funding: EUR 5.9 million; Coordinator: CEA, France) focuses on a holistic approach to CSP plants water consumption management. One of the main challenges of CSP is related to elevated water consumption. The CSP plants are typically located to areas with high solar radiation, which in turn often means that these areas suffer from water scarcity. The project is still on-going and develops an effective combination of technologies allowing a significant reduction in water consumption (up to 90 %), and a significant improvement in the water management of CSP plants. This is done e.g. by utilising anti-foiling coatings and dust barriers to avoid the dust to reach and stick in the mirrors, specific foiling sensor systems to clean the CSP plants only when necessary, and cleaning systems using very sour water limiting the water use. The project is also working towards an approach for cold thermal energy storage, with the basic idea to store cool air during the night to be used during the day to assist the cooling system and ease the work of the tanks. The project has led to a follow-up project called SOLWATT (H2020), which aims to demonstrate the water management technology developed during the WASCOP project in commercial CSP plants and it is expected to lead to direct commercialisation of the technology.

Source: EC, 2018, Community Research and Development Information Service; and interview of the project coordinator.

Project spotlight: 100 % renewables based hybrid CSP plant - HYSOL

The HYSOL project (Innovative Configuration for a Fully Renewable Hybrid CSP Plant; FP7-ENERGY-2012-1-2STAGE/CP; May 2013 to July 2016; EC funding: EUR 6.2 million; Coordinator: Cobra Instalaciones y Servicios S.A) developed a commercial scale CSP hybridisation system that combines solar power with biogas in a flexible configuration to ensure reliable energy supply. The system allows optimal electrical production with higher share of solar energy, high conversion efficiency and an excellent flexibility, and energy generation from fully renewable sources. The HYSOL technology integrates the biogas with a CSP system by means of an aeroderivative gas turbine, and the thermal energy from the gas turbine exhaust gases is stored into the molten salts of the CSP storage system. The molten salts heated by the exhaust gases can be used to either generate steam directly or be stored for later use, and the CSP plant achieves electrical generation efficiency similar to combined cycles. The HYSOL demonstrator was installed at the ACS/Cobra power plant in Alcazar de San Juan, Spain, and demonstrated that 100 % renewables based CSP plant is feasible.

Source: Source: EC, 2018, Community Research and Development Information Service; and HYSOL webpage (Available: https://www.hysolproject.eu/)

Technology improvements and learning effects still have significant reduction potentials in CSP. A reduction in electricity generation costs is expected in the coming years, aided by growing markets outside of the EU (see also section 5.1). Particularly when taking into account that the global cumulative capacity of CSP is still limited (+/- 5 GW), and that other technologies such as PV were much more expensive at this point in their development, the sector is optimistic about the possibilities for further cost reductions. EU R&D funding contributes to grasping these opportunities through projects such as NEXT-CSP which aims to make cost reductions up to 25 % and CAPTURE which aims for efficiency improvements of between 5 % and 8 %, and lower costs of electricity generated (see project spotlight boxes below).

The most recent prices offered underline these opportunities for cost reductions. In 2018, for instance, ACWA Power signed an Engineering, Procurement, and Construction (EPC) contract with Shanghai Electric, a major Chinese power company, to install the 700 MW DEWA CSP project in Dubai, Saudi Arabia. The project will consist of three 200 MW parabolic trough systems and a 100 MW central tower plant, summing to a total investment of USD[8] 3.9 billion. The project was awarded at a tariff price of USD 73/MWh (+/- 6.2 EURct/kWh) and includes up to 15 hours of energy storage capacity. Abengoa (Spain) and BrightSource (US) are the respective technology providers for the parabolic trough and central tower plants.[9]

Project spotlight: NEXT-CSP

NEXT-CSP is a project funded under H2020 (LCE-07-2016-2017) and aims to make cost reductions up to 25 % compared to the current CSP plants possible, underlining the significant possibilities for improvement of the technology. The project aims to achieve this by developing the fluidised particle-in-tube concept which is used to achieve higher temperature heat transfer fluids. The technology is currently at technology readiness level (TRL) 4 and the project aims to develop it to TRL 5. The project team estimates that at least 10 more years of development are needed before introducing the technology to the market and consider the EU funding essential for being able to conduct this research.

Source: EC, 2018, Community Research and Development Information Service; and interview with the project coordinator.

[8] Where USD is the US dollar
[9] http://analysis.newenergyupdate.com/csp-today/china-backed-4bn-csp-project-set-financial-close-august

Project spotlight: Combined cycle technology solar thermal power towers - CAPTURE

The CAPTure project (Competitive SolAr Power Towers; H2020-LCE-2014-1/RIA; May 2015 to December 2019; EC funding: EUR 6.1 million; Coordinator: CENER, Spain) aims to introduce the combined cycle technology into solar thermal power towers. The technology presents a clear advance compared to state-of-the-art, in terms of conversion efficiencies but it has not yet been implemented to solar thermal power plants because of complexities related to design and operation. The project develops and tests prototypes of all the key components and so far the main achievement is the development of a solar-driven gas turbine, which can be operated with a solar receiver without using fossil-fuels. The technology is expected to yield much higher efficiency-levels than the current state-of-the-art CSP plants and lower costs of electricity. The project is currently working in the final optimisation of the plant concept and the technology is estimated to yield 5-8 % efficiency increase compared to current state-of-the-art CSP tower plants.

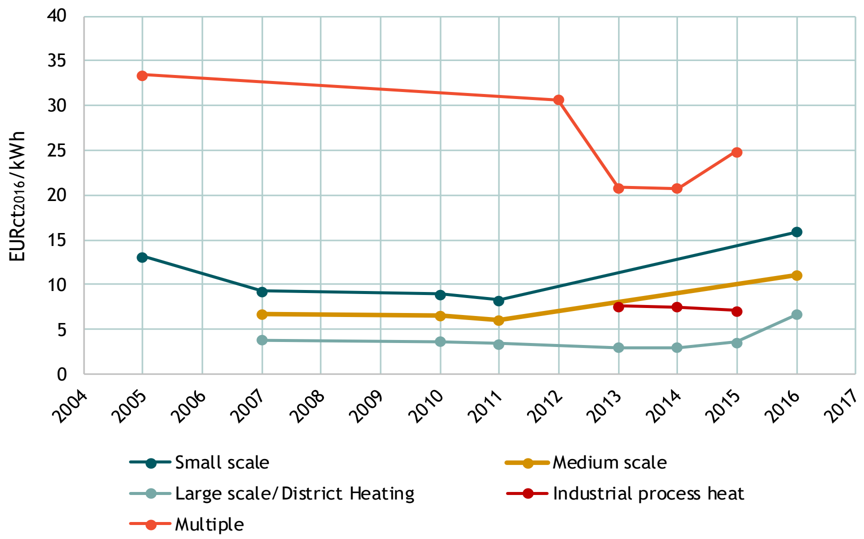
Source: EC, 2018, Community Research and Development Information Service; and interview of the project coordinator.

The development of the LCOE for solar thermal heating and cooling generation can be observed in Figure 4.5. Depending on system size, small-scale solar hot water and heating LCOE ranges from 1.50 to 68.68 EURct/kWh, medium scale from 0.75 to 13.4 EURct/kWh and large scale from 0.75 to 11.2 EURct/kWh.

The LCOE for industrial process heat ranges from 2.4 to 14.5 EURct/kWh, while applications offering both heating and cooling can go from 4.79 up to 134 EURct/kWh.

District heating in Austria, Germany and Denmark, are good examples of the potential for cost reductions thanks to economies of scale. In these regions, the LCOE of a small-scale solar thermal system varies between 13.7 and 18.1 EURct/kWh, and a medium system from 8.9 to 13.4 EURct/kWh. In contrast, the LCOE for a large district heating system is significantly lower, from 3.7 to 4.6 EURct/kWh.

Figure 4.5 Development of LCOE for solar thermal heating and cooling generation (global estimates)



Note: All figures are global, unless specified otherwise.
For heat generation, data was collected through a desk research. The main sources were REN21 reports (2005, 2007, 2010-2015), OECD/IEA (2007) and Solar Thermal World (2016). The estimates found for heat were grouped in five categories: Small-scale (single-family systems or installed capacity from 0-20 m² for hot water only and combi-systems), Medium scale (multi-family systems or installed capacity from 20-100 m² for hot water only and combi-systems), Large scale (district heating, block heating systems or installed capacity larger than 100 m² for hot water only and combi-systems), Industrial process heat (heat from 50 °C to 400 °C), Heating and cooling (Heating and cooling systems, Adsorption chillers) and Multiple ((solar collectors of unspecified capacity, or with a wide range of capacity).
LCOE for heat generation was taken directly from the desk research data sources and converted to EUR_{2016}.

In Europe the industry is focused on reducing the LCOE of solar heating by technology improvements, facilitating the system installations, and extending the lifetime of the solar thermal collectors (REN21, 2015). EU-funded R&D supports the technology development for instance through demonstration of direct integration of solar systems in residential and non-residential buildings (see project spotlight box on EINSTEIN and CHESS-SETUP below). Such projects have explored new or improved materials and manufacturing processes for solar collectors, sought for novel solutions to reduce complexity and costs of the installation, and advanced the potential for solar hybrid generation and seasonal energy storage solutions. Thanks to the EU FP funding, innovative building-integrated solar thermal (BIST) solutions also have been developed (see project spotlight box on FLUIDGLASS below).

Projects spotlight: Demonstration of solar thermal heating and cooling in buildings
EINSTEIN and CHESS-SETUP

The EINSTEIN project (Effective integration of seasonal thermal energy storage systems in existing buildings; FP7-2011-NMP-ENV-ENERGY-ICT-EeB/CP-IP; January 2012 to December 2015; EC funding: EUR 6.2 million; Coordinator: Tecnalia, Spain) demonstrated how low energy heating systems based on solar thermal energy combined with Seasonal Thermal Energy Storage (STES) - concept, coupled with heat pumps and conventional natural gas boilers, are a feasible solution from a technical and economic point of view. The project developed two full-scale pilot plants: hospital building in Ząbki (Poland) and a cultural centre in Bilbao (Spain).

The CHESS SETUP project (Combined heat system by using solar energy and heat pumps project; H2020-EE-02-2015; June 2016 to May 2019; EC funding: EUR 3.4 million; Coordinator: Agència d'ecologia urbana de Barcelona) was created to respond to the increasing heating and domestic hot water demand in the building sector. The project aim is to design, implement and promote a reliable, efficient and profitable system able to supply heating and hot water in buildings based on an optimal combination of existing technologies such as hybrid photovoltaic-thermal solar panels (PVT), heat pumps and long-term heat storage tanks. The proposed solution is being tested in three pilots: an office block in Manlleu (Spain), 47 new residential houses located in Corby (United Kingdom), and a new sport centre located in Sant Cugat (Spain). All the pilots are expected to be completed by December 2018.
Source: EC, 2018, Community Research and Development Information Service; and interviews with the project coordinators.

Project spotlight: Solar thermal facades - FLUIDGLASS

The FLUIDGLASS project (FP7-ENERGY-2013-1/CP; September 2013 – August 2017; EU funding: EUR 3.7 million; Coordinator: University Liechtenstein) developed an innovative concept of solar thermal façades for use at building and district level, increasing flexibility and energy efficiency. The concept is based on turning glass facades to transparent solar collectors and integrating those to the heating, ventilation and air conditioning system of the building. Testing of the concept was carried out in two locations: Cyprus and Liechtenstein. The project brought a significant cost advantage by increasing the thermal performance of the whole building resulting in an energy savings potential of between 50 % and 70 % for retrofitting, and 20 % and 30 % for new low energy buildings while increasing the comfort for the user, and taking into account the aesthetics of the building.
Source: EC, 2018, Community Research and Development Information Service; Final Report of the project.

4.4 Conclusions

The technology development of Concentrated Solar Power has led to clear cost reductions as shown by the downward trend in LCOE. EU-funded R&D has played an important role in enabling these cost reductions by financing research on many components of CSP technology. When interpreting the cost estimates, it is important to keep in mind that the installed capacities have been limited, which has led to limited opportunities for learning-by-doing and economies of scale. As a result, the LCOE is currently at a higher level than wind energy and solar PV, which poses a challenge to the sector. Nevertheless, the sector sees plenty of opportunities to improve the technology and reduce its costs. EU funding continues to play an important role in these developments by offering the necessary funding for promising technologies that are at present still too costly.

The technology development of solar heating and cooling technologies in terms of cost reductions is hard to evaluate due to the large variety of technologies and applications. Still, a downward trend in the capex of the lowest cost installations can be observed and the benefits of economies of scale are clearly visible in district heating applications.

5 Social, economic and environmental impacts

Public R&D funding for RE technologies is justified by several social, economic and environmental impacts. In this section we evaluate a range of indicators that provide insight into these impacts: installed capacity, annual generation, industry turnover, imports/exports, jobs and share of energy consumption.

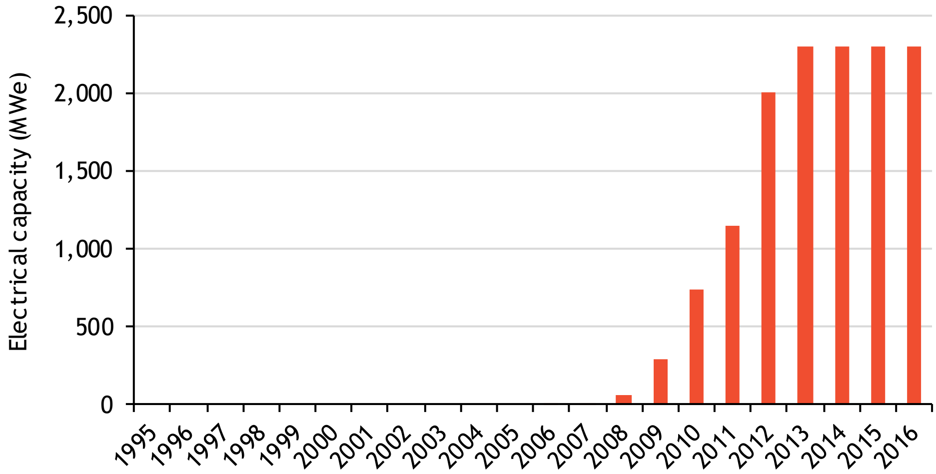
A direct link between these indicators and R&D funding is hard to establish, as the impact of R&D funding is confluent with numerous other factors that drive or prevent deployment. Still, the indicators presented in this section are relevant indicators to assess the evolution of the solar thermal energy sector over time.

5.1 Installed capacity

As installed capacities for RE technologies provide (near) carbon free energy that prevents the need for fossil fuel-based energy, they contribute to reducing greenhouse gas emissions and can be considered a measure of the environmental impacts. Installed capacity refers to the maximum installed generation capacity. This is expressed in MWe for electricity and MWth for heat production.

With 2 302 MWe installed by 2016 (see Figure 5.1), CSP is one of the smallest RE sources that produce electricity in the EU. The USA and Spain have been driving technology development and market formation in the CSP sector in the last decade. In the EU, CSP is installed in Spain (2 300 MW) and Germany (2 MW). Two prototype projects exist in France (1 MW) and Italy (5 MW), which are not listed in the Eurostat database. The German plant is built by the German Aerospace Center (DLR) and is only used for research purposes, which makes Spain the only country in the EU with CSP plants at a commercial scale.

Figure 5.1 Installed capacity of CSP plants in the EU



Source: Eurostat (2018)

In 2004, Spain created a policy framework that enabled the construction of CSP plants at a commercial scale. The first plants went into operation in 2007 and the market grew rapidly to 50 plants with a total capacity of 2 300 MW in 2013. The market was aided not only by strong R&D efforts and an abundance of solar radiation, but also by premium feed-in tariffs and the requirement to use renewables. The expansion stopped after 2013 due to amendments to the Spanish remuneration scheme for renewables that were introduced in that year. The measure was retroactive and stopped any new plant development in the country. The technological leadership of several small, but important companies was affected, although the biggest players managed to maintain their position thanks to the development of CSP plants in other regions around the world. Recently, the Spanish Government lost the first ICSID (International Centre for the Settlement of Investment Disputes) arbitration claim over the applied retroactive measures against CSP. There is no indication of new CSP plants being built in the EU in the near future.

EU funding through its FPs is recognised by industry experts as the other main driver of the CSP market development in the EU. The EU supported several demonstration projects in the EU, such as the PS10, Andasol and SOLAR TRES projects in Spain, allowing the technology to be tested at scale (see project spotlight box below). More recently, EU funding also supported demonstration projects outside of the EU such as the MATS and ORC-PLUS projects (see second project spotlight box below), enabling further development of the technology, as well as improving access to foreign markets for EU companies.

As a result of the current lack of policy support in Spain, the evolution of CSP will certainly be different in the next years. Other regions and countries such as China, Morocco, South Africa, Middle East, and India are expected to be the next biggest markets for the sector and predicted installed capacities are very high (IEA, 230GW for 2030). This expected evolution will be linked to the achieved reduction in electricity generation costs in the next years (see section 4.3).

While the lack of policy support in Spain in particular and the EU in general is an important challenge for the European CSP sector, the European industry remains active in projects all around the world thanks to its clear technological leadership. As such, it can be expected to benefit from the anticipated investments in CSP worldwide.

Projects spotlight: CSP demonstration projects PS10, ANDASOL and SOLAR TRES

During the 5th Research and Technological Development (RTD) Framework Programme (1998-2002), the EC supported three major CSP projects, each project receiving an EUR 5 million grant. All the three demonstrations were carried out in South of Spain due to two main reasons: favourable solar radiation conditions and at that time very supportive national policy scheme including feed-in tariffs for electricity produced by the solar thermal power plants. The demonstration projects were aimed to show technological and economic feasibility of the technology.

- PS10 (10 MW solar thermal power plant in Southern Spain) demonstrated the commercial viability of a 10 MW electric generation plant using the central tower receiver approach. The project was led by Abengoa Solar (Spain). The PS10 plant was constructed at Sanlucar la Mayor near Seville and became operational in 2007. The PS10 technology was further used in PS20 plant next to it (20 MWe, operational since 2009).
- ANDASOL (Andasol 50MWe Eurotrough solar thermal plant with thermal storage in the Marquesado Valley) consists of a 50 MW electric generation plant adopting the parabolic trough approach coupled with a molten-salt based storage system. The project was led by Cobra ACS (Spain) and Solar Millenium (Germany). The Andasol 1 was connected to grid in 2009 and was followed by two other plants (Andasol 2 and Andasol 3).
- SOLAR TRES (Molten salt solar thermal power 15MWe demonstration plant) demonstrated the feasibility of the world's first commercial scale central tower technology plant that utilises a molten salt thermal energy storage system. The Project was led by SENER Ingeneria y Sistemas (Spain). The Gemasolar CSP plant has been operative since 2011 in the Seville province, South Spain, and the technology is further applied in the Noor III plant currently under construction in Morocco *(See also the Case study in Annex A)*.

Source: EC, 2018, Community Research and Development Information Service; and interview with the SOLAR TRES project coordinator.

Projects spotlight: ENEA (IT) builds CSP demonstration plants in Egypt and Morocco (FP7-MATS and H2020-ORC-PLUS)

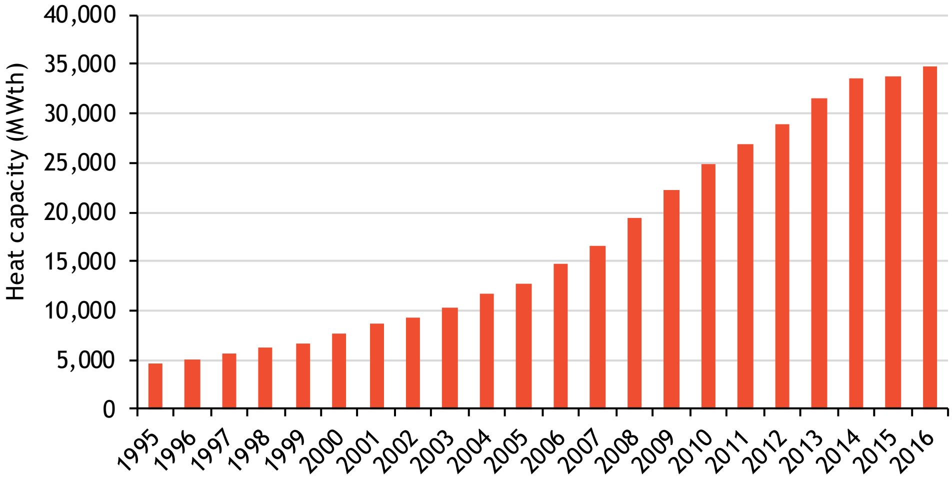
The FP7 project MATS (Multipurpose Applications by Thermodynamic Solar; FP7-ENERGY-2010-2/CP; December 2015 to July 2018; EC funding: EUR 12.5 million; Coordinator: ENEA, Italy) built a CSP demonstration plant in Egypt to demonstrate the potential of CSP technology to dispatch the energy on demand, and how the technology can be applied in small and medium-scale. The plant demonstrates co-generation of electricity and desalinated water to provide fresh water in desert environment. Egypt was chosen as a test location because of optimal radiation condition and being a promising market for European companies. At the moment, the plant is running and each unit is being tested individually.

The focus of the H2020 project ORC-PLUS (Organic rankine cycle - prototype link to unit storage; H2020-LCE-2014-2/IA; May 2015 to April 2019; EC funding: EUR 6.2 million: Coordinator: ENEA, Italy) is to develop a thermal energy storage (TES) system for a small to medium-scale (1-5 MWe) CSP plant. The plan is to couple Fresnel solar collectors, a TES system and an organic rankine cycle (ORC) turbine. The project will be the first thermocline TES system on industrial scale and a demonstration plant is being installed in Ben Guerir (Morocco) and will be completed by end of 2018.

Source: EC, 2018, Community Research and Development Information Service; and interviews of the project coordinators.

Installed capacity for heating and cooling shows a clear upward trend, rising from 5 000 MWth in 1995 to 35 000 MWth in 2016. Germany has the most capacity, accounting for 38 % of the total EU capacity, followed by Austria, Greece, Italy and Spain. Together, these MS account for 73 % of the total installed capacity in the EU.

Figure 5.2 Installed capacity of solar collectors in the EU



Source: Eurostat (2018)

EU-funded R&D contributes to the continued growth of installed capacities in many ways. Noteworthy examples are the development of the district heating and solar process heat sectors, for which the barriers to uptake are not necessarily technological but mainly commercial (payback period) and due to general inertia. The EU has been successful in pushing these markets ahead and is a global leader in district heating enabled by solar thermal technology (Denmark in particular). EU-funded projects that contributed to this leading position in district heating include the three SDH projects (described in the project spotlight box below) and SUNSTORE2 (FP5) which realised additional heat storage and solar collector (greater than 8 000 m^2) capacities in Denmark and improved the efficiency of solar collectors[10]. For solar process heat, EU-funded projects such as SOLARBREW (see project spotlight box below) provide important examples of the application of solar heat in industry and can serve as an example for other companies on how to apply solar process heat, thereby contributing to further growth in installed capacities. The current INSHIP project further underlines the important role that EU funding plays in developing the solar process heat sector (see project spotlight box below).

[10] http://sunstore4.eu/understand/example-of-sunstore2/

Projects spotlight: Advances in Solar District Heating market
SDHp2m, SDHplus and SDHtake-off
H2020 project SDHp2m (Solar District Heating from policy to market; H2020-LCE-2015-3; January 2016 to December 2018; EU funding: EUR 1.9 million; Coordinator: Steinbeis Innovation, Germany) has the aim to develop, improve and implement advanced policies and support measures for SDH in 9 participating EU regions. The project activities aim at a direct mobilisation of investments in SDH and hence a significant market rollout. It focuses on Denmark and Sweden, with their advanced district heating and cooling systems, as models. The project builds on the results of the SDHplus and SDHtake-off projects funded through the Intelligent Energy Europe Programme, which resulted in new business models, marketing strategies for SDH and a detailed analysis of market barriers and recommendations for regulations, support schemes, and policy.
Source: EC, 2018, Community Research and Development Information Service; Project webpage (Available: www.solar-district-heating.eu)

Project spotlight: SOLARBREW
The SOLARBREW project (Solar brewing the future; FP7-ENERGY-2011-2/CP; February 2012 to January 2016; EC funding: EUR 2.6 million, Coordinator AEE INTEC, Austria) designed three solar thermal systems (more than 1 MW each) for the use of solar process heat at different production sites of one of the world-leading brewing companies, Heineken Group. The project has made a significant contribution to the solar heating capacities in the EU by designing over 7 000 m^2 of solar heating capacity of which 1 375 m^2 is already realised. Compared to overall solar heating capacities in the EU of approximately 50 000 m^2, the contribution of SOLARBREW is significant.

The project aimed to develop the use of large-scale solar process heat for the brewing industry in collaboration with the world-leading brewer Heineken. Apart from the planned and installed capacities, the project led to significant improvements in terms of solar process heat integration and technological and economic development of solar thermal systems. Furthermore, the demonstration of a solar process heating technology at a multinational company like Heineken was important for building awareness and further uptake of the industry.
For a detailed case study on the SOLARBREW project, see annex A.

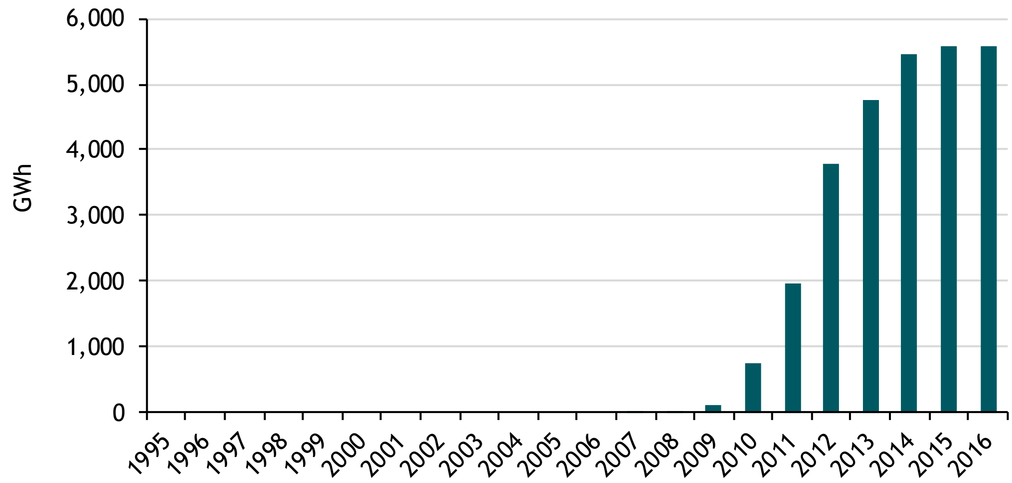
Project spotlight: Towards a common research agenda in solar heat for industrial processes (INSHIP)
The INSHIP project (Integrating National Research Agendas on Solar Heat for Industrial Processes; H2020-LCE-2016-ERA/RIA; January 2017 to December 2020; EC funding: EUR 2.9 million; Coordinator: Fraunhofer, Germany) unifies the key EU actors in the field of solar heat application to industrial processes to arrive with a common research agenda for upcoming years. The project conducts R&I activities such as enhanced integration of solar thermal technologies to different industry requirements, overcoming the barriers related to high temperature solar processes and increasing the connections between industrial parks through centralised distribution networks and the connection with district heating systems and the electricity grid.
Source: EC, 2018, Community Research and Development Information Service; and INSHIP webpage (Available: www.inship.eu)

5.2 Annual generation

While installed capacity is a commonly used indicator to measure the progress in deploying RE technologies, it can be somewhat misleading due to differences in capacity factors. Annual generation includes the effects of these differences and is therefore a valuable indicator to complement the statistics on installed capacities.

Only Spain had electricity generation from CSP plants for commercial use (the German solar thermal power plant is only for research purposes, which is why no electricity is sold). With the 2 300 MW installed capacity, it generates 5 500 GWh per year.

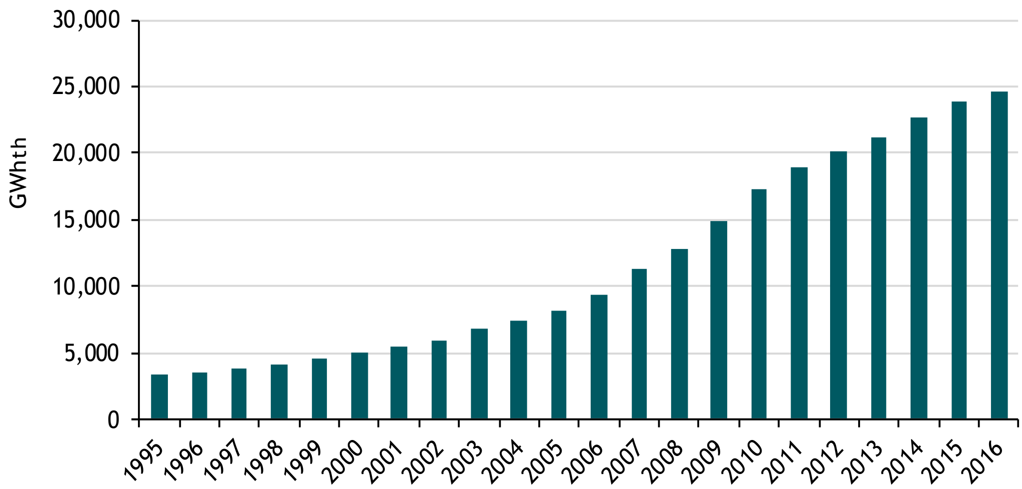
Figure 5.3 Annual electricity generation in the EU from solar thermal (CSP)



Source: Eurostat (2018)

Generation from solar H&C shows an upward trend, similar to its increase in capacity over the years. With 35 000 MWth currently installed, it generates close to 25 000 GWhth per year.

Figure 5.4 Annual heat generation in the EU from solar thermal (solar heating and cooling)



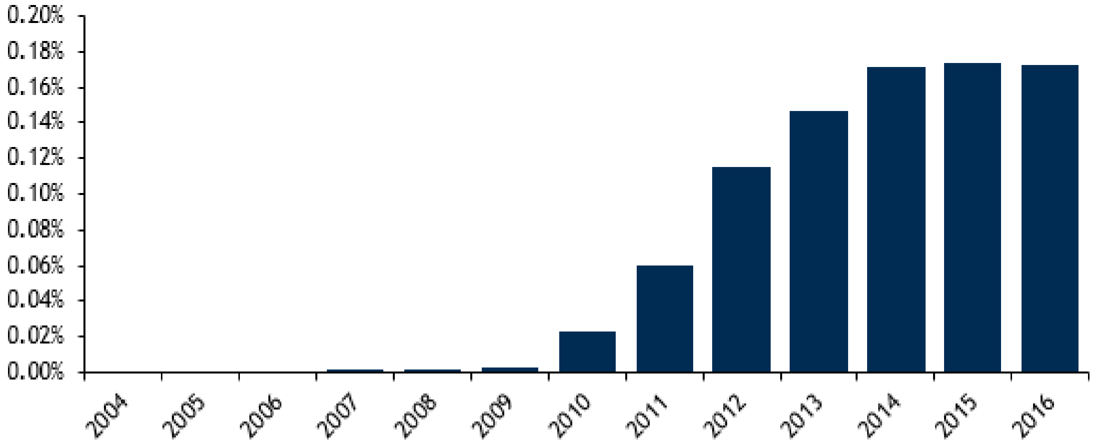
Source: Eurostat (2018)

5.3 Share of energy consumption

Share of energy consumption refers to the participation of solar thermal energy in the gross final energy consumed in each market sector (electricity, heating and cooling, and transport). This indicator allows us to analyse the participation of the solar thermal sector in the overall target of increasing the share of energy from RES in the EU's gross final energy consumption.

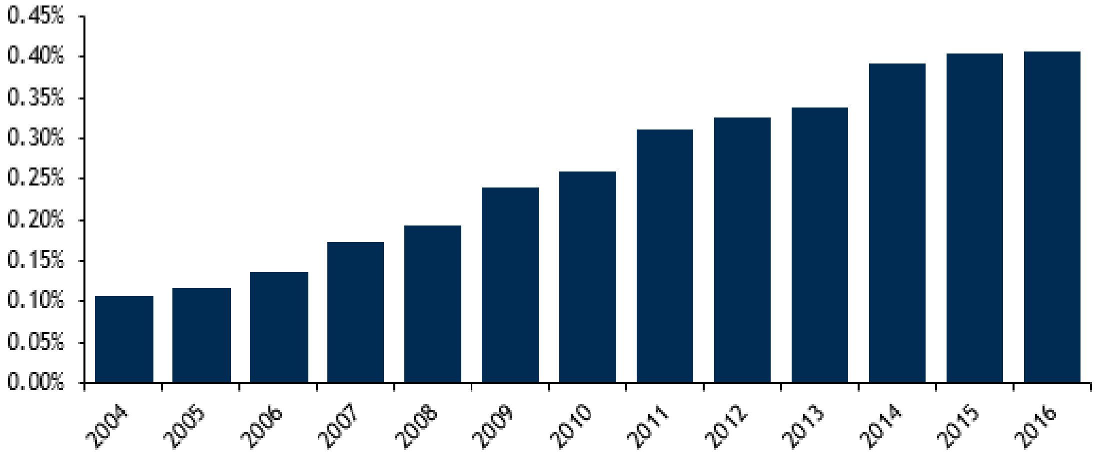
The shares of gross final electricity and heat consumption from solar thermal energy in the EU are 0.17 % and 0.40 % respectively. No new CSP plants are planned currently, therefore it is expected that the share of electricity will remain the same in the coming years. For heat, it is slowly increasing since 2004, which can be attributed to the increasing capacity and generation from solar heat in the EU. This trend is likely to continue.

Figure 5.5 Share of gross final electricity consumption from solar thermal in the EU



Source: Eurostat (2018)

Figure 5.6 Share of gross final heat consumption from solar thermal in the EU



Source: Eurostat (2018)

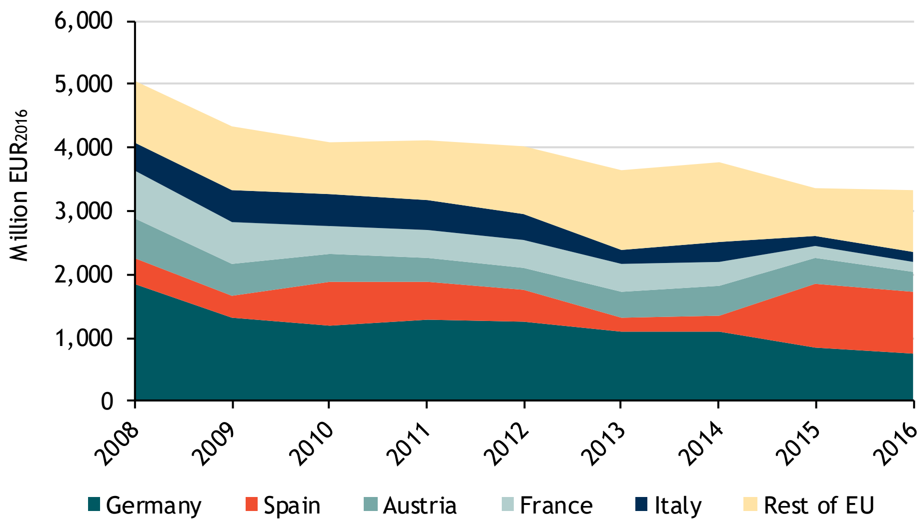
5.4 Industry turnover

Industry turnover is the total amount invoiced from the market sales of goods and/or services supplied to third parties by all sellers in the solar thermal sector. Following the definition in EurObserv'ER, it focuses on the main economic activities of the supply chain including manufacturing, installation of equipment and operation and maintenance (O&M). A growing turnover indicates a growing market.

Industry turnover in the solar thermal sector is estimated at EUR 3.4 billion in 2016. It has declined between 2008-2016, due to various reasons. Generally, the financial crisis and low oil prices affected the market, as well as increased competition from Asian manufacturers and heat pumps becoming an alternative for solar H&C systems.

Some countries such as Austria upheld stable rates, partially thanks to a growing export market for its manufacturers, but overall heating and cooling installations dropped due to stagnation in the building sector. In Italy, a 55 % tax reduction measure gave a boost to the sector in 2011, but the building sector was not able to maintain previous levels in 2012. Italy also implemented a heat feed-in-tariff in 2012, but this only had minor effects on installation rates. Germany also saw declining installation rates, which was offset slightly by large installation parks. Denmark is one of the few exceptions, where turnover grew from an estimated EUR 27 million in 2008 to EUR 521 million in 2016. This success can be ascribed to the installation of numerous solar district heating applications. Spain is the largest player in terms of turnover in recent years, thanks to its strong CSP industry that has retained technological leadership and is active in many global CSP projects.

Figure 5.7 Solar thermal industry turnover in the EU



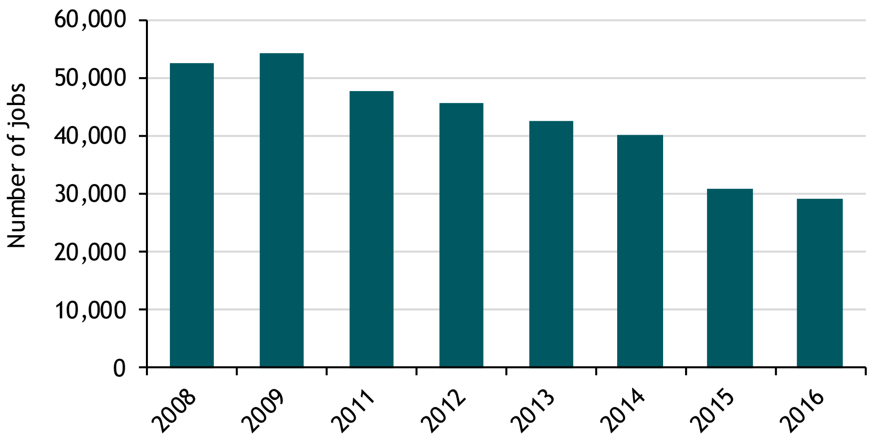
Source: EurObserv'ER reports 2010-2017.
Note: Data is missing for Croatia on years 2008-2011. It is assumed that the figures of all solar thermal industry turnover include data on the sub-technologies CSP as well as Heating and Cooling. This is explicitly stated in the EurObserv'ER reports from 2013, 2014, 2015 and 2017. It is loosely referred to in the 2011 and 2016 reports, but is not mentioned in 2010.

5.5 Jobs

Employment is an important indicator to understand the socio-economic impact of RE technology deployment. Linking jobs to R&D funding is difficult due to the number of confounding factors, but it is possible to make a connection between RE deployment and jobs. Different methods exist for estimating employment figures. A consistent time-series was only available for 2008-2016.

The solar thermal sector has an estimated 29 000 direct and indirect jobs in 2016. Like industry turnover, the amount of jobs in the solar thermal sector saw a decline from 2008 to 2016. Spain is the largest employer, with an estimated workforce of 8 000 in 2016. A substantial part of this labour force is dedicated to O&M of the existing CSP plants and the development of new CSP plants outside of the EU.

Figure 5.8 Evolution of EU jobs in solar thermal



Source: EurObserv'ER (2010-2017).
Note: Data from Croatia is missing for years 2008-2011. Accounts for direct and indirect jobs in solar thermal (aggregating CSP and solar heating and cooling sub-technologies) in the EU MS. It is assumed that the figures of all solar thermal jobs include data on the sub-technologies CSP as well as Heating and Cooling. This is explicitly stated in the EurObserv'ER reports from 2013, 2014, 2015 and 2017. It is loosely referred to in the 2011 and 2016 reports, but is not mentioned in 2010.

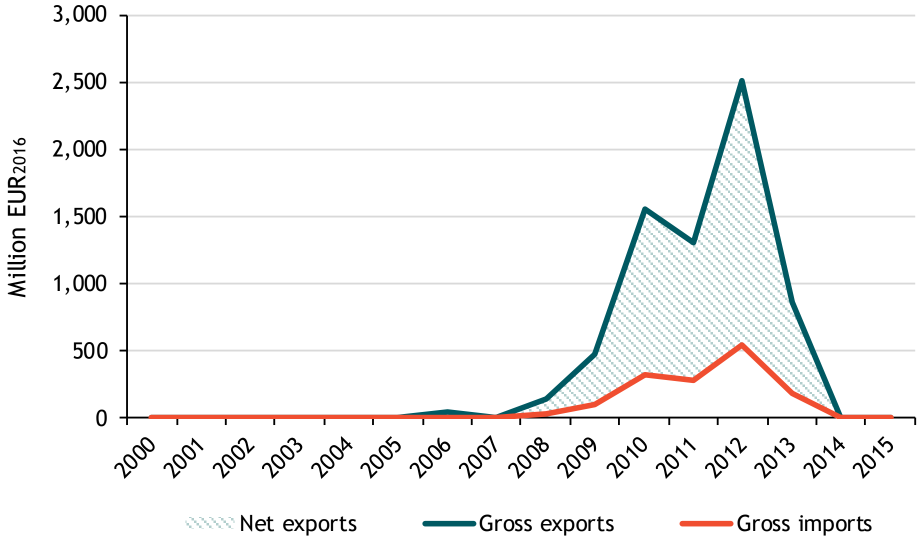
5.6 Imports/exports

International trade can provide a measure of the market uptake of solar thermal technologies and development of the solar thermal sector itself. It allows us to examine the extent of the external market for these goods, with increasing exports leading to increased growth of the domestic sector. Similarly, increased activity in the sector will lead to an increase in demand for intermediate goods used in the manufacture of RE technologies, a proportion of which may be imported. Increasing imports of these intermediate goods also provide an indication of the growth within the technology sectors.

Overall the EU exports more than what it imports. For the whole period from 2000 to 2015 taking into account CSP and solar heating and cooling, the total value of exports to non-EU countries was 3 times the total value of imports from non-EU countries.

The gross exports and imports for CSP are shown in Figure 5.9. Exports for CSP components are almost five times to the size of imports for CSP components, indicating that the EU CSP industry is competitive in the global market.

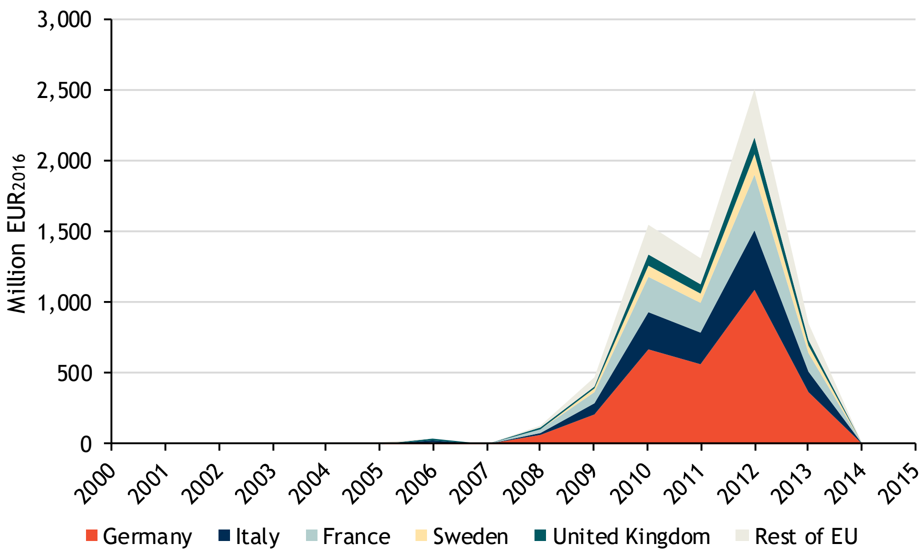
Figure 5.9 Trade balance for CSP



Source: Based on Comext (2018), Lako, P (2008), Eurostat (2018), Wind, I (2009), and Jha, V (2009).
Note: Data for 1999 and 2016 was 0 for all countries so it was excluded.
For an explanation of the methodology used, see Annex C.

The largest exporter to non-EU countries of CSP components is Germany (see Figure 5.10). Italy, France, Sweden, and the UK make up some of the other large exporters of CSP to non-EU countries. Germany leads the extra EU exports with EUR 2 983 million during the period 2000-2015. Italy and France follow with EUR 1 160 million and EUR 1 079 million each. Sweden has EUR 390 million while the United Kingdom has EUR 332 million. The participation of the rest of the EU MS is minimum, with only EUR 94 million. Important to note is that the import and export volumes only concerns components. Hence, the participation of EU companies as knowledge providers/project managers in international projects is not captured in these statistics, which explains why Spain is for instance not shown as a main exporter, while Spanish companies do export their knowledge.

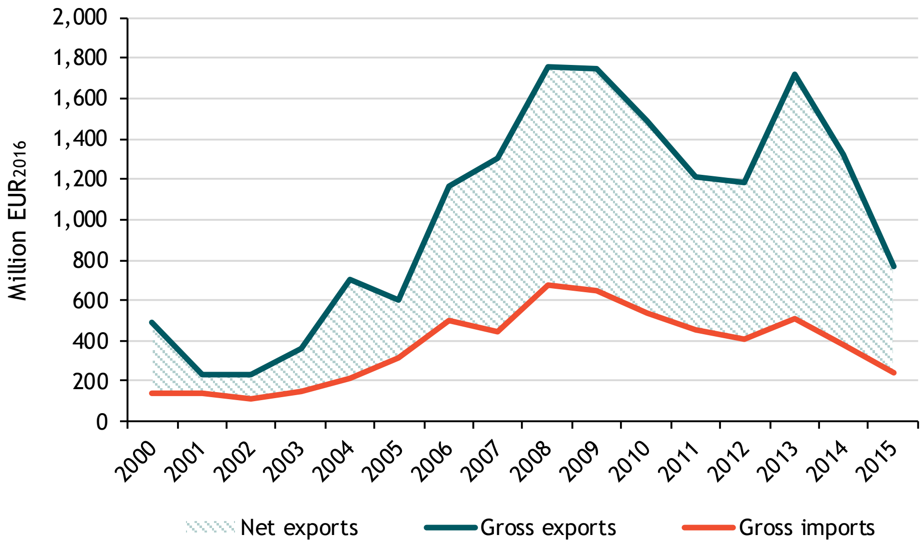
Figure 5.10 CSP exports - extra EU28



Source: Based on Comext (2018), Lako, P (2008), Eurostat (2018), Wind, I (2009), and Jha, V (2009).
Note: Values in 2007 are 0 for all MS. Data for 1999 and 2016 was 0 for all countries so it was excluded. For an explanation of the methodology used, see Annex C.

Also, for solar H&C, the EU maintained a trade surplus between 2000 and 2015 (see Figure 5.11). The total exports for solar H&C in this time period are more than double the CSP exports, thanks to the consistent demand for solar H&C components.

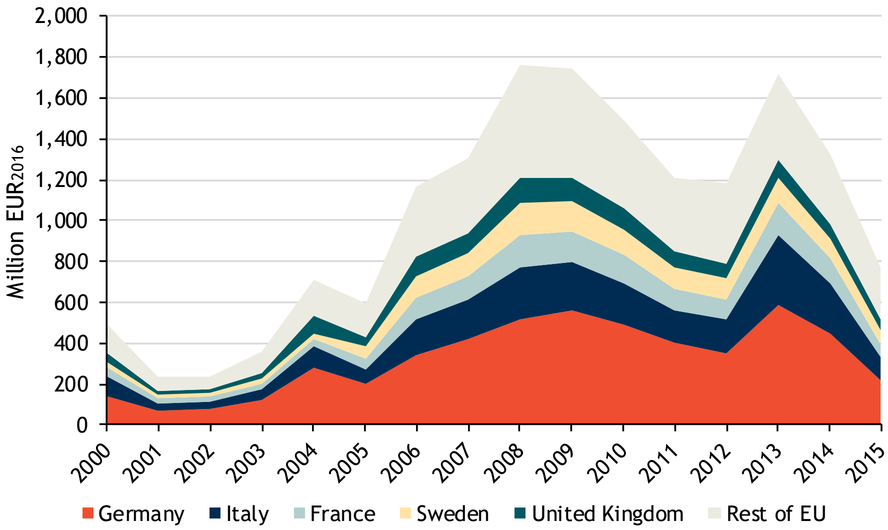
Figure 5.11 Trade balance for solar heating and cooling



Source: Based on Comext (2018), Lako, P (2008), Eurostat (2018), Wind, I (2009), and Jha, V (2009).
Note: Data for 1999 and 2016 was 0 for all countries so it was excluded. For an explanation of the methodology used, see Annex C.

The main MS exporting solar H&C outside of the EU are the same as those exporting CSP components. From these, Germany again is leading the exports – exporting EUR 5 232 million worth of components, over the period 2000 to 2015. Italy and France follow with EUR 2 465 million and EUR 1 419 million respectively.

Figure 5.12 Solar heating and cooling exports - extra EU28



Source: Based on Comext (2018), Lako, P (2008), Eurostat (2018), Wind, I (2009), and Jha, V (2009).
Notes:Data for 1999 and 2016 was 0 for all countries so it was excluded.
For an explanation of the methodology used, see Annex B.

5.7 Conclusions

The CSP sector experienced a significant growth in installed capacities from 2008 to 2013, growing from close to zero to more than 2 000 MW, leading to a share of total EU electricity consumption of 0.2 %. The growth has been enabled by the supportive policy framework in Spain as well as EU funding for demonstration projects. From 2013 onwards, no new capacities have been installed in the EU. Spain has been the only real market for CSP plants and the withdrawal of the Spanish support measures for CSP has caused the growth of the capacities to halt. In spite of the lack of a local market, the EU industry has managed to retain industrial leadership and is active in many CSP projects around the world.

The solar heating and cooling sector has experienced a much more gradual growth. In 2004 solar heating provided 0.1 % of EU heat consumption which has grown fourfold to 0.4 % in 2016. Noteworthy developments are the leading position that Denmark has achieved in the large-scale district heating sector, considered the only example of a mature and commercial solar district heating market, and the recent efforts to develop the industrial process heat market. EU funding has contributed to the development of these sectors through demonstration projects and addressing market barriers. The EU solar heating and cooling industry has a strong industrial position with a large trade surplus.

For the solar thermal sector overall, the industry turnover and number of jobs have been in steady decline since 2008, probably largely due to the downturn in CSP capacity additions. O&M to existing CSP capacities and manufacturing for exports still keep the industry alive but have not been able to prevent a steady decline.

6 Conclusions

Solar thermal energy technologies have received 11 % of EU R&D funds and 13 % of MS R&D funds for RE technologies over the past 20 years. Internationally, the EU has a strong academic position with leading R&D budgets and the number 1 position in terms of publications worldwide. The EU Framework Programmes made a clear contribution to the EU's academic leadership by funding projects that delivered many publications and stimulating collaboration and alignment of R&D agendas across the EU.

For Concentrated Solar Power (CSP), one of the key impacts of EU funding has been its contribution to the scale-up and market uptake of the technology, by funding several demonstration projects. Together with the policy support of Spain, this created strong growth in installed capacities and enabled the development of a globally leading EU industry. Furthermore, EU-funded R&D contributed to technology improvements and cost reductions for CSP technologies that facilitate the continued global competitiveness of the EU CSP industry.

The EU solar heating and cooling capacities have grown steadily over the past 20 years. EU-funded R&D has contributed to achieving cost reductions, improving technologies and facilitating market uptake. Noteworthy examples include the EU contribution to the development and demonstration of building-integrated solar heating and cooling technologies and the efforts to increase the uptake of solar process heat by the industry. Furthermore, EU-funded projects have contributed to the development of world-leading solar district heating infrastructures (Denmark in particular). Thanks to the efforts of the EU and MS, the EU solar heating and cooling industry has a strong global position with a significant trade surplus.

Annex 2A - Case studies

Case study: SOcool

Author:	Hanna Kuittinen Iñigo Iparraguirre	**Approver:**	Dr. Carsten Corino
Project title:	SunOyster cooling (SOcool)		
Lead partner:	SunOyster Systems GmbH Poststrasse 46 25469 Halstenbek Germany		
Project location*:	Germany		
Technology area/s:	Solar thermal		
Start and end date:**	Phase 1: August 2016 to January 2017 Phase 2: September 2017 to August 2019		
Project cost:	Phase 1: EUR 71 429 Phase 2: EUR 1 997 825	**EC funding:**	Phase 1: EUR 50 000 Phase 2: EUR 1 398 477.50
Other funding sources:	Private investments		
Quantifiable outputs and impacts:	The second phase of the project is still on-going and to be finalised in August 2019. The company has estimated that, by 2021, the SunOyster SoCool product could lead to: Annual installed capacity: 50 MW electric capacity + 75 MW thermal capacity Systems sold: 10 000 per year Turnover: EUR 66 million Job creation: 140		
Further information*:**	Project website General Manager (GM) – Dr Carsten Corino, SunOyster Systems GmbH. Visiting address, Poststrasse 46, 25469 Halstenbek, Germany. T +49 4101 80 87 67. E carsten.corino@sunoyster.com		

Project description

SunOyster Systems, the single beneficiary of the SOcool project, is a SME established in 2011, based in Halstenbek, near Hamburg, Germany. The company is focused on developing and commercialising concentrating solar technology, and has developed its own technology including a highly efficient solar collector, which produces simultaneously electricity and high-grade heat. Technologically it is based on a large parabolic mirror on one line (16 m^2) concentrating the solar energy on a receiver, which uses PV cells to covert the solar radiation directly into electricity. These cell assemblies also produce heat, and conduct the heat through a receiver tube into a thermal fluid, which is transporting the heat to storage or direct usage. This technology is highly efficient, achieving from serial production an electric efficiency of up to 30 % and a thermal efficiency of 45 %, both in relation to direct normal irradiance. In this system, heat is a cheap by-product of electricity generation. SunOyster has applied for three international patents for the company's main innovations related to the above-mentioned technology.

The objective of the SOcool project is to use a concentrating photovoltaic/thermal (CPVT) system combined with chillers to provide cost-efficient solar energy in forms of electricity, heat and cold. The project is based on the premise that cooling and refrigeration cause nowadays 7 % of the worldwide greenhouse gas (GHG) emissions, and their market demand is expected to increase during the next decade. As cooling is mainly required when the sun is shining, the basic idea of the SOcool project is to use solar energy to generate cooling. The proprietary technology of SunOyster can generate at the same time electricity and heat with a very high efficiency, and the idea of SOcool project is to combine this technology with thermal chillers, readily available on the market, and to offer integrated and standardised solar cooling packages. These can be directly used for the air-conditioning of residential or commercial buildings, cool storage or other industrial purposes. The SOcool project aims to develop the technology further, to easily scalable, adaptable and standardised solar cooling product packages for the supply of electricity, cooling and heat. This will be achieved by building-up a production pilot, testing and certifying the packages, carrying-out a demonstration project, and launching large-scale commercialisation. The focus is on three applications areas, which have demonstrated to have the highest market potential:

- SOcool Hotel: covering the large heating and cooling demands of hotels;
- SOcool Office: where the cooling demand corresponds well with the sunshine hours ;and
- SOcool Pool: for villas with a pool, where the pool is used as the heat sink for the SunOyster in spring and autumn, when the building needs less heating or cooling.

Outputs and impacts

Before the SOcool project started, the technology had already reached TRL 6-7, and SunOyster had applied for intellectual property (IP) rights protection (patents, utility model) in its main markets (USA, EU, India and China). The first phase of the SOcool project was successfully finalised in January 2017. It was focused on a feasibility study laying the foundations for the development of the SOcool packages, including a preliminary supply chain mapping, and a market analysis. The second phase of the project is still on-going and is planned to be finalised in August 2019. The project is advancing as scheduled, and so far, it has not encountered any major drawbacks or deviations from the planned schedule. The company has first prototypes and the first zero and pre-series machines installed, and is setting-up a pilot production plant in Germany and is looking forward to upscale the manufacturing in near future. The SOcool packages are in testing phase.

The company has estimated that, by 2021, the annual installation of SOcool is expected to rise to 50 MW electric and 75 MW thermal capacity, corresponding to 10 000 sold systems per year, generating EUR 66 million turnover and creating 140 green jobs in the EU. This will contribute to carbon dioxide (CO_2) emission reductions, and enhance the living standards of people suffering from hot climate.

Outlook and commercial application of the outputs

The technology has different advantages such as a larger energy generation capacity thanks to the hybridisation in relation to the occupied roof surface when compared to energy generation of conventional photovoltaics and low-medium temperature solar thermal collectors. The main challenge is related to production costs and the company is currently discussing with potential component suppliers to bring down costs.

The company considers China and India as its main markets, and especially Chinese market shows currently high potential. The company also sees market potential in EU countries, including in SunOyster System's home country Germany. European policies are considered to have been very focused on renewable electricity generation while they have neglected the role of heating and cooling. According to the SunOyster System CEO Dr. Carsten Corino 'Heat is the sleeping giant in Europe and to achieve the ambitious climate change targets, the sector should be better activated'.

The role of EU funding

The SOcool project received funding from the European Union's Horizon 2020 Programme for Research and Innovation (H2020). Horizon 2020 funds high-potential innovation developed by SMEs through a dedicated programme called SME Instrument, targeted to support close-to-market activities and boost the SMEs to reach global markets with their highly innovative ideas. The funding programme is organised in two phases: Phase 1 for feasibility assessment (lump sum of EUR 50 000, for a period of 6 months), and Phase 2 for innovation development and demonstration purposes (up to EUR 2.5 million grant with duration 1-2 years). SunOyster Systems successfully finalised the Phase 1 project and competed and received funding for the Phase 2 in 2017. The EU contribution for the Phase 1 SOcool project was EUR 50 000, whereas the Phase 2 grant is significantly larger EUR 1 398 477.50. For both phases, the EC contribution corresponds to 70 % of the projects' total costs. Winning the SME Instrument grant was an important milestone for SunOyster Systems, and it allowed the company to enlarge its personnel and consolidate activities. The company had accomplished a private investment prior to receiving the SME Instrument grant. The private investor was encouraged to increase its investment after SunOyster got the Phase 2 EU funding. The SME Instrument grants have contributed to an increased visibility of SunOyster Systems.

Full project participant list

Organisation	Country	Type
SunOyster Systems GmbH	Germany	Private company (SME)

The case study authors would like to express their acknowledgements to Dr. Carsten Corino, General Manager of SunOyster Systems, for his kind support and participation in a telephone interview on 14 May 2018.

Case study: SOLARBREW

Author:	Hanna Kuittinen Iñigo Iparraguirre	**Approver:**	Wolfgang Glatzl Christoph Brunner
Project title:	Solar brewing the future (SOLARBREW)		
Lead partner:	AEE - Institute for Sustainable Technologies (AEE INTEC) Feldgasse 19 8200 Gleisdorf Austria		
Project location:	Austria		
Technology area/s:	Solar thermal		
Start and end date:	February 2012 to January 2016		
Project cost:	EUR 4 894 032.80	**EC funding:**	EUR 2 628 572.00
Other funding sources:	-		
Quantifiable outputs and impacts:	Design of three large-scale solar thermal systems for three different brewing plants of the world-leading brewing company Heineken, with a total planned capacity of 5.08 MWth corresponding to a 7 270 m² solar collector area. One of the plants was built during the course of the project in Göss, Austria with a capacity 1 MWth, corresponding to 1 375 m² collector area.		
Further information:	Project website Project Manager - DI Christoph Brunner, Industrial Processess and Energy Systems, AEE - Institute for Sustainable Technologies (AEE INTEC) Visiting address, Feldgasse 19, A-8200 Gleisdorf. T +43 (0)3112-5886. E c.brunner@aee.at		

Project Description

The SOLARBREW project aimed at developing the use of solar process heat in the brewing industry by designing three large-scale solar thermal systems (more than 1 MW each) at different production sites of one of the world-leading brewing companies, Heineken Group. The coordinator of the project AEE INTEC had worked several years on so called green brewery concept together with a local Göss Brewery in Leoben. Göss Brewery is one of the largest and most-well known breweries in Austria, whose majority shareholder is the Dutch brewing company Heineken. As a result of this local collaboration, the Heineken Group became interested to explore further energy-efficiency applications in the brewing processes.

The objective of the project was to demonstrate the technical and economic feasibility of large-scale solar thermal system integration in the brewing industry for the first time. Enhanced utilisation of thermal energy available from heat recovery combined with integration of solar heat supply was expected to reduce exergy losses and fossil fuel based CO_2 emissions of the brewing process. Brewing industry processes are especially suitable to be supplied by solar thermal systems, since they require optimal temperature range (between 50 °C and 100 °C) for advanced medium temperature solar collectors. The project aimed at designing solar thermal systems in three demonstrations in Heineken Group plants located at Göss, Austria; Valencia, Spain; and Vialonga, Portugal. The project was an important milestone for brewing and solar thermal industry, by demonstrating in real-scale how solar thermal energy applications can be used in key-processes of brewing industry.

The project was coordinated by AEE INTEC, which is a non-university research institute located in Gleisdorf, Austria. AEE INTEC is specialising in thermal energy technologies and hybrid systems, building and renovation, as well as industrial processes and energy systems. The partners of the project involved one of the world-leading brewery companies Heineken Supply Chain BV from the Netherlands; GEA Brewery Systems GMBH, a brewery sector process engineering specialist from Germany, and Sunmark AS, a solar engineering company from Denmark.

Outputs and impacts

The project designed three demonstrator plants with a total planned solar thermal energy capacity of 5.08 MWth, corresponding to 7 270 m² of collector area. The three demonstrations involved different brewing industry processes (mashing, pasteurisation and drying malt), and different climatic zones (Austria, Spain and Portugal), in orto evaluate the performance of the plants under different solar radiation conditions. One of the three designed solar thermal plants was built during the course of project in Göss, Austria with a capacity 1 MWth, corresponding to 1.375 m² collector area. The solar thermal system Göss implies several innovative approaches: Two steam supplied vessels (mash tuns) were retrofitted by especially designed internal plate heat exchanger templates, which enabled a supply system based on hot water instead of steam. The new hot water supply is fed by waste heat from a nearby biomass CHP plant as well as by a large-scale ground mounted solar thermal system, which is hydraulically connected to a solar energy storage tank. As a result, approximately 20 % of the thermal process energy demand previously supplied by steam can be supplied by the solar thermal system, leading to reduced CO_2 emissions.

The project led to a significant improvement of solar process heat integration and a technological and economic development of solar thermal systems.

- Compared to the state of art, the most important technological results achieved included improved hydraulic concepts and stagnation behaviour control of large-scale solar thermal systems, and the development and application of advanced flat-plate collectors, utilising, among other features, a second transparent cover and advanced insulation, allowing more efficiency on higher temperature levels;
- The project also developed new solutions for the adaptation and optimisation of the machinery and processes involved in brewing and malting processes to solar energy supply (e.g. matching the time-dependency of the solar energy supply and the heat demand of the processes);
- In addition, the project enhanced the usage of the synergies of converting the heat supply system of the related processes from a steam based heat supply system to a hot water based supply system, enabling efficient integration of the solar thermal systems;
- The project resulted to one peer-reviewed journal article and to a number of conference presentations, press releases, newspaper and magazine articles;
- Most importantly, the project showcased how the large-scale application of solar thermal energy is a viable and economically feasible solution for brewing industry energy supply, even competitive compared to fossil fuels in short term. Present investment costs for solar thermal systems range from 400 to 500 €/m² (corresponding to 250-1 000 €/kW of thermal power) leading to average energy costs in Southern Europe from 2 to 5 cent/kWh for very low temperature applications and from 5 to 15 cent/kWh for medium temperature systems;

- Finally, the project developed a comprehensive 'Green Brewery' sector concept, including a guideline and calculation tool, which serves as basis for a broad European wide training and dissemination programme, and supports energy managers, solar thermal experts and consultants to reduce the fossil CO2 emissions in breweries and malting plants.

Outlook and commercial application of the outputs

The project was finalised in January 2016, but the work continues. The demonstrations carried-out in SOLARBREW project can be considered as best practice example for the brewing sector, and can act as a catalyser for the market uptake of the solar thermal energy in the whole food and drink industry resulting to important boost for the solar thermal industry and significant reductions of CO_2 emissions in the brewing industry. The results of the project are not only useful for the broad market deployment in the brewing industry, but they are also of high relevance for food and beverage industry in general, as many of the brewing industry processes (pasteurising, drying) are common also in the food and beverage industry.

The project results and the Green Brewery concept have been further developed by AEE INTEC in 5-6 new projects with Göss Brewery and other major breweries such as Carlsberg. They have also conducted an Intelligent Energy Europe co-funded project called GREENFOODS[11] aimed to lead the European food and beverage industry to high energy efficiency and reduction of fossil carbon emissions. Also, Heineken Group continues their efforts towards sustainability, and has announced goals to reduce CO_2 emissions of their production process by 40 % by 2020 (compared to 2008 level)[12]. The Göss Brewery where the demonstration plant was built, is fully carbon-neutral, and its energy supply is 100 % based on RE, including solar thermal energy[13].

The role of EU funding

The SOLARBREW project received funding from the European Union's Seventh Framework Programme for Research and Innovation (FP7). Energy was one of the thematic areas under the Cooperation programme, and provided project funding for collaborative research. The SOLARBREW project received the funding under the specific call topic: Low/Medium temperature solar thermal systems for industrial process heat, aimed at demonstrating large-scale integration of solar collectors into existing industrial process heat demand. The FP7 has since been replaced by the Horizon 2020 programme, which continues to fund near-to-market solutions for the use of solar heat in industrial processes (e.g. topic LCE-12-2017).

The EU contribution of the SOLARBREW project yield to 54 % of the project total cost, and the funding rates varied by participant types; research organisation AAE Intec and SME Sunmark had a higher funding rate 75 %, whereas the large companies, Heineken Group and GEA Brewery Systems, had a funding rate of 50 %. The project necessitated contractual changes and amendments due to a bankruptcy and later merger of project partner Sunmark in 2015.

According to the project coordinators, the EU support was essential for the project, and the demonstration would not have taken place without EU funding, not at least at the same scale or

[11] http://www.green-foods.eu/objectives/
[12] http://www.theheinekencompany.com/heinekens-view-on-renewable-energy
[13] http://www.theheinekencompany.com/media/features/goss-brewery-celebrates-becoming-carbon-neutral

timetable. In addition, the EU funding ensured significant visibility and enhanced the awareness of RE and sustainable brewing within the sector.

Full project participant list

Organisation	Country	Type
Arbeitsgemeinschaft - Erneuerbare Energie - Institut Fur Nachhaltige Technologien (AEE INTEC)	Austria	Research institute
Heineken Supply Chain B.V.	The Netherlands	Private company
GEA Brewery Systems GMBH	Germany	Private company
Sunmark AS (later Arcon-Sunmark)	Denmark	Private company (SME)

The case study authors would like to express their acknowledgements to Mr. Wolfgang Glatzl and Mr. Christoph Brunner from AEE-INTEC for their kind support and participation in a telephone interview on 14 May 2018.

Case study: STAGE-STE

Author:	Iñigo Iparraguirre Hanna Kuittinen	**Approver:**	Dr. Julián Blanco Galvez, Director, Almería Solar Platform, CIEMAT
Project title:	Scientific and Technological Alliance for Guaranteeing the European Excellence in Concentrating Solar Thermal Energy (STAGE-STE)		
Lead partner:	CIEMAT - Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas Avenida Complutense 40 28040 Madrid Spain		
Project location:	Spain		
Technology area/s:	Solar thermal		
Start and end date:	February 2014 to January 2018		
Project cost:	EUR 21 134 658.37	**EC funding:**	EUR 9 997 207.00
Other funding sources:	In-kind contributions		
Quantifiable outputs and impacts:	Selected key performance indicators (KPIs) of the project[14]: • More than 200 joint publications accepted/published in academic peer-reviewed journals during the project lifetime • More than 4 000 tests carried out at the facilities of the project participants out of which more than 200 were joint tests involving two or more project participants • A web-repository including a description of more than 200 IP assets • More than 100 researchers involved in mobility and exchange programmes		
Further information:	Project website Project Coordinator – Dr. Julián Blanco Gálvez, Director, Almería Solar Platform, CIEMAT. Avenida Complutense 40, 28040 Madrid, Spain. T +34 950387800. E julian.blanco@psa.es		

Project description

The Scientific and Technological Alliance for Guaranteeing the European Excellence in Concentrating Solar Thermal Energy (STAGE-STE) project started from three premises: 1) Solar energy offers the highest RE potential to our planet; 2) Solar thermal electricity (STE) can provide dispatchable power in a technically and economically viable way, by means of thermal energy storage and/or hybridisation, e.g. with biomass; 3) Significant research efforts are still needed to realise the full potential and benefits of the technology. Keeping this in mind, the STAGE-STE project was set to accomplish the following general objectives:

- Convert the consortium into a reference institution for concentrated solar power (CSP) research in Europe, creating a new entity with an effective governance structure;

14 The project has altogether 47 KPI to assess the progress made.

- Enhance the cooperation between European research institutions participating in the project to create European added value;
- Synchronise the different national research programmes to avoid duplication and to achieve better and faster results;
- Accelerate the transfer of knowledge to industry to maintain and strengthen the existing European industrial leadership in STE;
- Expand joint activities among research centres by offering researchers and industry a comprehensive portfolio of research capabilities, bringing added value to innovation and industry-driven technology;
- Establish the European reference association for promoting and coordinating international cooperation in solar thermal electricity research.

To achieve the above listed objectives, the project was organised into two modules:
- *Coordination and support*: Six groups of activities aimed to intensify the cooperation between institutes. The objective was to more efficiently coordinate, complement and reinforce the activities of the European research institutes active in the STE field;
- *Research and innovation*: Another set of six activities related to STE technology development (covering topics such as central receiver systems, line-focusing systems, thermal energy storage (TES), materials for solar receivers and STE components, solar thermochemical fuels, and CSP and desalination).

The STAGE-STE project joined forces of the leading European and international research centres (23 European and 9 international) in the CSP field together with industrial companies, including also the European Association of Solar Thermal Industries (ESTELA).

Outputs and impacts

The project made a considerable progress towards a benchmark institution for CSP/STE research in Europe. Although the project did not create a new legal entity, a concrete plan, endorsed by all the partners, was made to concentrate the efforts on further development of the EU-SOLARIS initiative[15]. The project enabled collaboration and mutual learning among the partners thanks to the intensive technical and scientific cooperation in research activities and the extensive staff exchange programme. STAGE-STE also achieved significant progresses in terms of alignment of national research programmes and EU programmes. The project engaged with key persons in the respective government ministries of participant countries (Spain, Portugal, France, Germany, Italy, Switzerland, United Kingdom, Cyprus and Turkey), and a roadmap was proposed to align national research programmes.

In respect to knowledge transfer to industry, the most relevant achievement of the project was the development of a web-based IP repository. The repository contains descriptions of more than 200 relevant IP assets (foreground and background), which can be used to share knowledge, foster alignment of research, and create a basis for new collaboration and knowledge exploitation opportunities[16]. The IP repository remains operational and in use within the European Energy Research Alliance CSP Joint Programme. The project also contributed towards the development of several

[15] EU-SOLARIS (http://eusolaris.eu/) initiative engages all the major European research institutes, with relevant activities on CSP/STE, into an integrated structure to ensure the continuation of the ongoing networking activities. EU-SOLARIS should be fully implemented and operative by 2019.
[16] A public showcase of the repository is available on the European Energy Research Alliance (EERA) webpage: https://www.eera-set.eu/eera-joint-programmes-jps/about-jps/ip-assets/

International Energy Committee (IEC) standards, created a publicly available database[17] on technical characteristics of line-focus solar collectors as well as guidelines for reflector measurement.

STAGE-STE was highly successful in establishing linkages between European and international CSP/STE communities. Relevant organisations from leading countries and regions (North Africa, Middle East, South Africa, Australia, China, India, Chile, Mexico and Brazil), were involved in the networking and research activities of STAGE-STE.

The project made advances in several different areas of research and the partners contributed to critical technological achievements that are reported in academic journal articles and conference presentations. Among others:

- Thermal energy storage (TES) for STE plants: New approaches for TES systems such as identification of barriers that may limit the commercial use of innovative heat exchangers, research on compatibility of solar salt with industrial waste, concrete fillers for thermocline tanks, and improved models of TES systems;
- Materials for solar receivers and STE components: development of three guidelines/standards characterising the aging behaviour of reflectors and new knowledge of the aging behaviour of several absorber materials. The developed methods and tools will help plant developers and investors to reduce the risk linked to the aging behaviour of materials;
- Solar fuels: Improvements of many solar thermochemical processes, e.g. improved design of solar reactors and basic studies of innovative solar fuel processes;
- STE and desalination: analysis of the feasibility of a solar thermal cogeneration scheme compared to the separate generation of electricity with a solar plant and the use of part of such electricity to drive a desalination process like reverse osmosis;
- CSP and tower technology: Development of test procedures for durability testing of key components, innovations in absorbers, heliostats and heliostat fields including analysis and testing of new receiver structures;
- Line-focus technologies: A new procedure to monitor the status of the vacuum level in linear receivers utilising infrared images, a system for off-line monitoring of thermal oil degradation and a dynamic solar field testing procedure for assessing solar collectors' performance in commercial plants.

Outlook and commercial application of the outputs

As a result of over a decade of supportive policies at European and national levels, the European industry has become a global leader in STE technologies. However, the competition has increased in recent years, and the countries traditionally strong in the STE technologies (e.g. the USA) but also emerging countries (e.g. China, India) are challenging the European leadership. STAGE-STE contributed significantly to bringing European research institutes and industry together to set a common research and technology agenda. 'This is essential for maintaining the competitiveness of the European STE industry', Julian Blanco, coordinator of the STAGE-STE project highlighted.

Despite the fact that Europe is at the forefront of STE research, industrial exploitation is currently rather limited. The future deployment of the technology will largely take place outside the EU. The STAGE-STE project successfully integrated partners from four continents – Australia, Latin-America

[17] The database is available at http://stage-ste.eu/keydocuments/solar_collectors/index.php/SolarCollectors

(Chile, Brazil, and Mexico), Asia (India, China), as well as countries from Middle East and North Africa (Libya, Morocco and Saudi Arabia). The cooperation during the project period contributed to opening-up new markets for the European industry, and has led to many further opportunities to launch new initiatives on a bilateral basis. 'While the STAGE-STE project provided a framework and initial boost for international cooperation, the network is now a well-established community with strong links between the research organisations, and drawing an increasing interest from industry due to the opportunities to access new international markets' Julian Blanco explained.

The role of EU funding

STAGE-STE project was supported by the European Union's Seventh Research and Innovation funding programme (FP7) that was in place in 2007-2013. The FP7 Energy programme launched Integrated Research Programmes (IRPs) as an instrument combining research and coordination and support actions. The aim of the instrument was to increase European coherence among national research operators through pooling of research resources in RE technologies, including CSP. The STAGE-STE project had a total budget of more than EUR 21 million, out of which 47 % came from the EU. The project started in February 2014 and ran for four years, celebrating the final conference in January 2018.

The project contributed significantly to future research and innovation policy in Europe. It acted as a 'nexus' between the research community, national authorities and funding agencies, the industry, and the European Commission. This collaboration and intensified knowledge flows supported the work of the SET Plan[18] temporary working group on CSP, and led to successful drafting of the SET Plan CSP Implementation Plan in 2017. 'EU funding has been essential for research and development in the field, especially in terms of facilitating collaborative research and innovation between the different European and international actors', Julian Blanco concluded.

Full project participant list

Organisation	Country	Type
Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas	Spain	Research institute
Deutsches Zentrum fuer Luft - und Raumfahrt EV	Germany	Research institute
Paul Scherrer Institut	Switzerland	Research institute
Centre National de la Recherche Scientifique	France	Research institute
Fraunhofer-Gesellschaft zur Foerderung der Angewandten Forschung E.V	Germany	Research institute
Agenzia Nazionale per le Nuove Tecnologie, L'energia e lo Sviluppo Economico Sostenibile	Italy	Research institute
Eidgenoessische Technische Hochschule Zurich	Switzerland	Academic institute
Commissariat à l'Energie Atomique et aux Energies Alternatives	France	Research institute
The Cyprus Institute Limited	Cyprus	Industry association
Laboratorio Nacional de Energia e Geologia I.P.	Portugal	Research institute
Fundacion Centro Tecnologico Avanzado de Energias Renovables de Andalucia	Spain	Research institute
Consiglio Nazionale delle Ricerche	Italy	Research institute
Fundacion Cener-Ciemat	Spain	Research institute

[18] Strategic Energy Technology Plan, https://ec.europa.eu/energy/en/topics/technology-and-innovation/strategic-energy-technology-plan

Organisation	Country	Type
Fundacion Tecnalia Research & Innovation	Spain	Research institute
Universidade de Evora	Portugal	Academic institute
Fundacion Imdea Energia	Spain	Academic institute
Cranfield University	United Kingdom	Academic institute
Fundacion Tekniker	Spain	Research institute
Universita Degli Studi di Palermo	Italy	Research institute
Centro di Ricerca, Sviluppo e Studi Superiori in Sardegna	Italy	Research institute
INESC ID - Instituto de Engenhariade Sistemas e Computadores, Investigacao e Desenvolvimento em Lisboa Associacao	Portugal	Research institute
Associacao do Instituto Superior Tecnico para a Investigacao e Desenvolvimento	Portugal	Research institute
Sener Ingenieria y Sistemas S.A.	Spain	Private company
HSE Hitit Solar Enerji AS	Turkey	Private company
Acciona Energia S.A.	Spain	Private company
Schott Solar CSP GmbH	Germany	Private company
Archimede Solar Energy SRL	Italy	Private company
European Solar Thermal Electricity Association	Belgium	
Abengoa Solar New Technologies SA	Spain	Private company
King Saud University	Saudi Arabia	Academic institute
Universidad Nacional Autonoma de Mexico	Mexico	Academic institute
Stellenbosch University	South Africa	Academic institute
Centre for Solar Energy Research and Studies	Libya	Research institute
Commonwealth Scientific and Industrial Research Organisation	Australia	Research institute
Fundacao de Apoio a Universidade De Sao Paulo	Brazil	Academic institute
Institute of Electrical Engineering Chinese Academy of Sciences	China	Research institute
Universidad de Chile	Chile	Academic institute
Universite Cadi Ayyad	Morocco	Academic institute
Fondazione Bruno Kessler	Italy	Research institute
Cobra Instalaciones y Servicios S.A	Spain	Private company
Suncnim	France	Private company
Universidad de Sevilla	Spain	Academic institute

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Case study: SOLAR TRES

Author:	Hanna Kuittinen Iñigo Iparraguirre	**Approver:**	Juan Ignacio Burgaleta, CSP Consultant, SOLAR TRES Project Coordinator, former CTO of Torresol Energy
Project title:	Molten salt solar thermal power 15MWe demonstration plant (SOLAR TRES)		
Lead partner:	SENER Ingenieria y Sistemas, S.A		
Project location:	Spain		
Technology area/s:	Solar thermal		
Start and end date:	December 2002 - December 2008		
Project cost:	EUR 15 343 220	**EC funding:**	EUR 5 000 000
Other funding sources:	Private investments		
Quantifiable outputs and impacts:	Gemasolar CSP plant, with a registered electrical power capacity of 19.9 MW, 80 GWh production per year, generating electrical power to supply 27 500 households and reducing CO_2 emissions by more than 28 000 tons per year.		
Further information:	Project website Project Coordinator – Sener Ingenieria y Sistemas, S.A., Avda. Zugazarte, 56 -Las Arenas, Getxo, Spain.		

Project description

The objective of the SOLAR TRES project was to demonstrate the technical and economic viability of the world's first commercial-scale concentrated solar power (CSP) plant that applies a central tower receiver technology combined with thermal storage including a single thermal fluid (molten salts). The demonstration project led to building of Gemasolar CSP plant in Fuentes de Andalucía, Seville, Spain. The project presented a milestone of the sector by building and demonstrating operations of a CSP plant with technology that allows dispatchable power generation.

The SOLAR TRES project was encouraged by the experience of the former Solar One and Solar Two demonstration projects, built in California, USA in the 1980s and 1990s with the support of Department of Energy (DOE)[19]. The Solar Two was a 10 MWe demonstration project operated from 1997 to 1999, successfully demonstrating advanced molten salt power technology and a storage system allowing solar energy to be collected during the sunlight hours and dispatched as high-value electric power at night or when demanded by the utility.

The SOLAR TRES project was led by SENER, an engineering company based in Getxo, Spain. Initially, the demonstration initiative following the Solar Two experience was promoted by Nexant (USA), Boeing (USA) and GHER (Spain)[20], and the group had carried-out preliminary design of the plant in 2000. SENER joined the team in 2001. Later on, for different reasons, Nexant and Boeing left the project in 2004,

[19] http://www.solaripedia.com/13/31/solar_one_and_two_(now_defunct).html
[20] Gould, W. et al. (2000) Solar Tres 10 MWe Central receiver Project. In Energy 2000: The Beginning of a New Millennium. P.394 - 399. Ed. Catania, P.

and SENER assumed the responsibility to lead the SOLAR TRES project in 2005, after renewed negotiations with the European Commission. SENER had made the decision to invest in CSP technology development, also due to favourable conditions imposed by the Spanish legislation of solar thermal power. Spain was the first European country to introduce a feed-in tariff funding system for solar thermal power in 2002[21]. The conditions related to these support mechanisms were changed in 2004, 2007 and 2008, and were finally withdrawn in 2012.

SENER developed its own state of the art solar thermoelectric facilities, allowing the company to carry-out commercial scale testing. SENER collaborated closely with the Spanish National Research Centre for Energy, Environment and Technology (CIEMAT - Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas) and CIEMAT's Solar Energy Platform (PSA - Plataforma Solar de Almería) to develop the plant concept and component design and signed an agreement for the development and evaluation of new heliostat and molten salt receiver concepts and a prototype with better thermal performance.

The European Union Fifth Framework Programme for Research (FP5) supported the SOLAR TRES project with a EUR 5 million grant for further development of the technology and carrying out a demonstration. Apart from SENER (coordinator of SOLAR TRES FP5 project) and CIEMAT, the project consortium was formed by Saint Gobain S.A, a French specialised material company responsible for the solar mirrors, Siemens, a German conglomerate, which developed the steam turbines and Gher, S.A., a Spanish research laboratory.

Outputs and impacts

The SOLAR TRES demonstration project led to the Gemasolar thermosolar power plant in Fuentes de Andalucía, Seville province in Spain. In 2007, after successful experimental validation of the prototype receiver and molten salt loop, and testing carried out at PSA, SENER decided to develop a CSP plant that is now called Gemasolar. SENER had already accomplished the needed permissions, environmental impact studies and financing necessary. In 2007, the detailed engineering of the main components was completed including: design of heliostats, receiver and thermal storage system; turbine selection; electrical tracing; instrumentation and plans for the civil engineering work; and selection of mirrors for the heliostats. As a result of development work carried out in the SOLAR TRES project, SENER applied for two patents for its proprietary central tower receiver technology. In 2008 Torresol Energy Investments was founded for constructing and operating the plant. Torresol Energy is a joint venture between SENER (60 %) and Masdar (40 %), a RE company located in Aby-Dhabi, United Arab Emirates. The plant construction took two years and the investment costs were approximately EUR 230 million[22]. The plant started its operations in 2011.

Gemasolar is a 19.9 MWe thermosolar power plant, which uses central tower receiver technology with a thermal energy storage system. The central receiver is surrounded by thousands of sun-tracking heliostats, forming a solar field of 310 000 m^2 mirror surface, which reflect the sun light directly to a receiver located on top of a 140 metres high tower. Within the tower receiver there is an innovative heat transfer system based on molten salts. The heat is collected by the molten salts, which can reach very high temperatures (over 500 C°), which flow through a heat exchanger to generate steam. The steam is directed to a turbine for producing electricity. The solar thermal energy collected and stored

[21] https://www.solarpaces.org/csp-technologies/csp-potential-solar-thermal-energy-by-member-nation/spain/
[22] https://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=40

in the molten salt tank allows for 15 hours of production and thus ensures dispatchable solar electricity generation.

Gemasolar typical net electricity output to the grid reaches 80 GWh per year and it has the capacity to produce electric power 24 hours a day as the thermal storage system allows for power generation autonomy for up to 15 hours without sunlight. The record for continuous operation is 36 days. The plant supplies energy to 27 500 households and reduces CO_2 emissions by more than 28 000 tonnes per year. After nearly seven years since its official opening, the plant has an excellent operational record and it has exceeded all the expectations. The Gemasolar plant is still a global benchmark in the CSP sector. Others have intended to build a plant with similar characteristics but without succeeding' Mr. Juan Ignacio Burgaleta, the Coordinator of the SOLAR TRES project, explained.

Outlook and commercial application of the outputs

The Gemasolar plant is still a landmark of the industry. It paved the way for building the first utility-scale CSP plant with molten salt storage in Tonopah, Nevada, USA, which started operations in 2015. SENER is currently building the Noor III plant in Morocco with a capacity of 150 MW. The Noor III project is based on the experiences and learning achieved in constructing and operating the Gemasolar plant. It features certain improvements, such as a larger receiver, improved heliostat reflective surfaces and a more precise solar tracker system. Noor III presents a step change also in terms of reduction of CAPEX, leading to a cost reduction of the electricity[23] of approximately 40 %. This is partially explained by economies of scale as Noor III has a 600 MW thermal receiver compared to the 120 MW receiver used in Gemasolar. In addition to the difference in scale, other factors such as continuous R&D activities of SENER, lessons learned with Gemasolar, efficiency gains and industrialisation of component manufacturing play also a key role. Although Noor III is SENER's 29th CSP project, it is only the second to feature a CSP tower plant with molten salts storage. In general, the central tower technology still presents a niche market within the CSP technology, parabolic through comprising 90 % of the CSP deployed. The CSP parabolic trough levelized cost of electricity (LCOE) has decreased considerably over the last decade through scale-up and enhanced efficiency. Although tower technology is still in its infancy, the last project auctions have showed remarkable cost reductions. 'There is still lot of potential for cost reductions in central tower technology, but this will be achieved only by constructing more plants', Mr. Burgaleta pointed out. The central tower technology combined with molten salts energy storage is seen as the future of CSP: 'Dispatchability is a large advantage and it is a great value added of CSP technology compared to other renewable energy technologies' Mr. Burgaleta concluded.

Thanks to Gemasolar plant, SENER has been awarded the European Business Awards (EBA) for Innovation in 2011[24] and the USA CSP Today awards in the categories of 'Engineering Firm of the year 2011' and 'Commercialized Technology Innovation of the year 2011', and 'Solutions for improving manageability capacity' in 2012, 2013 and 2015. The company was also awarded the DESERTEC Foundation 2014 Award for pioneering and replicable solutions for clean energy supply in deserted areas. The company represented Spain in the European Union campaign 'Together for the climate' in COP21, the Paris Conference on Climate Change in 2015[25].

[23] http://www.solarpaces.org/moroccos-noor-iii-solar-tower-csp-deliver-power-october/
[24] https://www.businessawardseurope.com/download/EBA_case_study_SENER_61.pdf
[25] http://www.engineeringandconstruction.sener/press-releases/gemasolar-is-the-project-that-represents-spain-in-the-european-campaign-together-for-the-climate-cop21

The role of EU funding

The SOLAR TRES project received funding from the European Union's Fifth Framework Programme for Research and Innovation (FP5). Under FP5, the EU contributed to research projects intended to develop CSP technologies, notably components, storage, solar-hybrid co-generation, and solar chemistry including hydrogen production. The activities included three major CSP demonstration projects that received a total EU contribution of EUR 15 million. These projects were aimed to validate the full-scale application of different technological approaches and their economic viability under market conditions. SOLAR TRES received EUR 5 million, while the total costs of the demonstration project were EUR 15 345 000. The EU support was only a modest fraction of the total costs of the construction of the Gemasolar plant. In the scope of the SOLAR TRES project, only the costs for the innovative parts of the project were eligible, and e.g. civil works and the turbine-electricity generation assembly were not eligible for EU funding. For the construction of the Gemasolar plant, Torresol Energy received financial support from the European Investment Bank with a EUR 80 million loan[26]. The EU support was important for the demonstration phase of the Gemasolar technology, and allowed SENER to build CSP central tower technology capacities and mitigate the risks of investing in early-phase technology. The demonstration and building of the plant would not have taken place in the same timetable without the EU support.

Full project participant list

Organisation	Country	Type
Sener Ingenieria y Sistemas, S.A.	Spain	Private company
Centro de Investigaciones Energeticas, Medioambientales Y Tecnologicas	Spain	Research institute
Compagnie de Saint Gobain S.A.	France	Private company
Gher, S.A.Spain	Spain	Private company
Siemens Aktiengesellschaft	Germany	Private company

The case study authors would like to express their acknowledgements to Juan Ignacio Burgaleta for his kind support, and participation to an interview in June 2018.

[26] http://europa.eu/rapid/press-release_BEI-09-224_en.htm

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Annex 2C - Methodological note on imports and exports

The value of the following components was assessed for solar thermal:

Table C-1 HS6 product codes relevant to the solar thermal sector

HS6 code	Brief product description
700991	Glass mirrors, unframed
700992	Glass mirrors, framed
711590	Other articles of precious metal or of metal clad with precious metals, other
732290	Radiators for central heating, air-heaters, hot air-distributors non-electric, other
830630	Photograph, picture or similar frames, mirrors; and parts thereof
841280	Other engines and motors
841919	Instantaneous or storage water heaters, nonelectric
841989	Other machines and mechanical appliances for the treatment of materials by a process involving a change of temperature: other
841990	Other machines and mechanical appliances for the treatment of materials by a process involving a change of temperature: parts
850239	Other generating sets: other
900190	Other (including lenses and mirrors)
900290	Other optical elements (including mirrors)
900580	Other instruments

Source: Comext database and Jha (2009)

Annex 2D - List of EU-funded projects

Table D-1 Solar thermal EU funded projects

Acronym	Rcn	Project title	EC funding (2016 EUR)	Programme	Topic
AIRCOOL	54437	Adsorption cooling of buildings with integrated pv/solar air heating facades ('AIRCOOL')	787328	FP5-EESD	1.1.4.-6.
ALONE	90321	Small Scale Solar Cooling Device	2565949	FP7-ENERGY	ENERGY-2007-4.1-02
ANDASOL	70424	Andasol 50 MWe Eurotrough Solar Thermal Plant with Thermal Storage in the Marquesado Valley (Granada, Spain)	6305350	FP5-EESD	1.1.4.-5.2.4
ANDASOL	86905	Andasol 50MWe Eurotrough solar thermal plant with thermal storage in the Marquesado Valley (Granada, Spain)	5919597	FP5-EESD	
ARCHETYPE SW550	103634	Demonstration of innovating parabolic solar trough using an alternative heat transfer fluid producing electricity and fresh water: ARChimede Hot Energy TYPology Enhanced Water Solar 550	30382871	FP7-ENERGY	ENERGY.2010.2.9-1
ARTISC	86865	Refrigeration, heating and air-conditioning using an absorption refrigeration system heated by transparent insulated solar collectors	507582	FP5-EESD	
ASFIC	60074	Advanced solar facades with integrated collectors-accumulators for domestic hot water and space heating applications (ASFIC)	547207	FP5-EESD	1.1.4.-6.
a-Si PVT-ORC	201177	A novel amorphous silicon cell-based solar cogeneration system using the coupled thermal storage/organic Rankine cycle as an alternative to battery	192158	H2020-EU.1.3.2.	MSCA-IF-2015-EF
ASODECO	57661	Advanced Solar Driven Desiccant Cooling Systems for Central European and Mediterranean Climates	925288	FP5-EESD	1.1.4.-6.1.3
BIONICOL	90331	Development of a bionic solar collector with aluminium roll-bond absorber	1182198	FP7-ENERGY	ENERGY-2007-4.1-01
BIOSTIRLING-4SKA	108900	A cost effective and efficient approach for a new generation of solar dish-Stirling plants based on storage and hybridization	3460027	FP7-ENERGY	ENERGY.2012.2.5.1
BIPV-PCM-COGEN	103335	A Novel BIPV-PCM Heat and Power Cogeneration System for Buildings	285238	FP7-PEOPLE	FP7-PEOPLE-2011-IIF
BRESAER	193471	Breakthrough solutions for adaptable envelopes for building refurbishment	5863730	H2020-EU.2.1.5.2.	EeB-02-2014
CAPTure	193759	Competitive SolAr Power Towers – CAPTure	6119293	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-02-2014
CESAR	101325	Cost-Effective Solar AiR conditioning	705751	FP7-SME	SME-2011-1
CHESS-SETUP	203231	Combined HEat SyStem by using Solar Energy and heaT pUmPs	3364315	H2020-EU.3.3.1.	EE-02-2015
COLOURFACE	61368	Coloured collector facades for solar heating systems and building insulation (COLOURFACE)	1020286	FP5-EESD	1.1.4.-6.
COMPACT	86995	Low-cost compact solar heaters made of plastic materials and composites	663206	FP5-EESD	
CompoSol	101548	Fibre Reinforced Composite Reflectors for Concentrated Solar Power Plants	1129462	FP7-SME	SME-2011-1
COMTES	103641	Combined development of compact thermal energy storage technologies	4844227	FP7-ENERGY	ENERGY.2011.4.1-4

Acronym	Rcn	Project title	EC funding (2016 EUR)	Programme	Topic
COOLSUN	101033	Development of a tri-generation solar heating and COOLing System including the Use of the heat extracted from the adsorptioN chiller re-cooling circuit	1185304	FP7-SME	SME-2011-1
CSP2	100979	Concentrated Solar Power in Particles	2376507	FP7-ENERGY	ENERGY.2011.2.5-2
CySTEM	197312	Cyprus Solar Thermal Energy Chair for the Eastern Mediterranean	2506250	H2020-EU.4.c.	WIDESPREAD-2-2014
DEARSUN	93078	DEvelopment of a direct solAR heating System capable of covering a full-year thermal load UsiNg high temperature thermal storage	1186469	FP7-SME	SME-1
DESICCANT COOLING	73573	Dehumidification and cooling driven by solar/waste heat using liquid desiccants	262281	FP6-MOBILITY	MOBILITY-2.2
DESOL	75030	Low cost low energy technology to desalinate water into potable water	638472	FP6-SME	SME-1
DESSHC	57484	Demonstrating the Efficiency of Solar Space Heating and Cooling	1609795	FP5-EESD	1.1.4.-6.1.3
DIGESPO	93421	Distributed CHP generation from Small Size Concentrated Solar Power	3548995	FP7-ENERGY	ENERGY.2009.2.5.1
DIMONTEMP	200028	Distributed Monitoring of HTF Temperature at Solar Thermal Power Plants	50000	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
DISTOR	73986	Energy Storage for Direct Steam Solar Power Plants (DISTOR)	2755567	FP6-SUSTDEV	SUSTDEV-1.2.6
DNICAST	109593	Direct Normal Irradiance Nowcasting methods for optimized operation of concentrating solar technologies	3018242	FP7-ENERGY	ENERGY.2013.2.9.2
E2PHEST2US	93225	Enhanced Energy Production of Heat and Electricity by a combined Solar Thermionic-Thermoelectric Unit System	2141110	FP7-ENERGY	ENERGY.2009.2.5.1
ECOSTAR	73988	European Concentrated Solar Thermal Road-Mapping (ECOSTAR)	281402	FP6-SUSTDEV	SUSTDEV-1.2.6
EFISOL	93398	Solar Thermal Cogeneration Plant based on Organic Rankin Cycle	1254173	FP7-SME	SME-1
EINSTEIN	102067	EFFECTIVE INTEGRATION OF SEASONAL THERMAL ENERGY STORAGE SYSTEMS IN EXISTING BUILDINGS	6302072	FP7-NMP	EeB.NMP.2011-2
EUPRES	86842	A cross-European city partnership with large-scale realisation of innovative renewable energy schemes in the tertiary, industrial, public and private sectors	3150452	FP5-EESD	
EUROTROUGH II	54438	Euro trough ii - extension, test and qualification of a full scale loop of eurothrough collectors with direct steam generation	1337272	FP5-EESD	1.1.4.-6.
EU-SOLARIS	106231	THE EUROPEAN SOLAR RESEARCH INFRASTRUCTURE FOR CONCENTRATED SOLAR POWER	4550505	FP7-INFRASTRUCTURES	INFRA-2012-2.2.1.
EXPERT SYSTEM LSSH	54402	Development of an expert system to analyse/optimise the technical/economic feasibility or performance of hybrid large-scale solar heating (lssh) systems (expert system lssh)	546346	FP5-EESD	1.1.4.-5.
FLUIDGLASS	110009	FLUIDGLASS - SOLAR THERMAL FAÇADES	3896366	FP7-ENERGY	ENERGY.2013.4.1.1
FOCALSTREAM	204183	Breakthrough high performance cost competitive solar concentration system for combined heat and power generation	1018752	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015
freescoo	205111	Low temperature heat/solar driven air conditioning system for heating, cooling, dehumidification and ventilation of buildings	50000	H2020-EU.2.3.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
FRESH NRG	107423	FREsnel for Solar Heat with New Receiver and Geometry	2519045	FP7-ENERGY	ENERGY.2012.4.1.1
FRIENDS2	194373	Framework of Innovation for Engineering of New Durable Solar Surfaces	347366	H2020-EU.1.3.3.	MSCA-RISE-2014

Acronym	Rcn	Project title	EC funding (2016 EUR)	Programme	Topic
GLASUNTES	196681	Innovative high temperature thermal energy storage concept for CSP plants exceeding 50 % efficiency	259558	H2020-EU.1.3.2.	MSCA-IF-2014-GF
GREEN SOLAR REGIONS	57556	Optimised Solar Assisted Heating and Ventilation Design in Copenhagen, Piemonte and Poland as Part of European Green Sol	670748	FP5-EESD	1.1.4.-6.1.3
helioSTEAM	197461	A novel concentrated solar steam system for industrial applications with a high degree of pre-manufacturing at extremely low prices.	50125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
HELIOtube	199275	Inflatable solar collectors for a low cost CSP Plant with irreducibly small carbon footprint	1847660	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015
HELITE	200412	High precision and performance heliostat for variable geometry fields of Thermosolar Plants	50000	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
HIGH-COMBI	85696	High solar fraction heating and cooling systems with combination of innovative components and methods	1324178	FP6-SUSTDEV	SUSTDEV-1.1.1
HITECO	95892	New solar collector concept for high temperature operation in CSP applications	3570784	FP7-ENERGY	ENERGY.2010.2.5-2
HP-LP-SOLAR-FACADE	99062	A Novel Heat Pump Assisted Solar Façade Loop Heat Pipe Water Heating System	214938	FP7-PEOPLE	FP7-PEOPLE-2010-IIF
HYBRID-CHP	52904	Hybrid solar collector/CHP system (HYBRID-CHP)	677241	FP5-EESD	1.1.4.-5.
HYDRA	70393	Hybrid latent/sensible compact storage Devised for combined thermal solar energy applications: Refrigeration, heating and Air-conditioning	450740	FP5-EESD	1.1.4.-5.3.2
HYSOL	108326	INNOVATIVE CONFIGURATION FOR A FULLY RENEWABLE HYBRID CSP PLANT	6213605	FP7-ENERGY	ENERGY.2012.2.5.2
INDITEP	70234	Integration of dsg technology for electricity production - (INDITEP)	3470409	FP5-EESD	1.1.4.-5.
Innova MicroSolar	205663	Innovative Micro Solar Heat and Power System for Domestic and Small Business Residential Buildings	3999384	H2020-EU.3.3.1.	EE-04-2016-2017
IN-POWER	207407	Advanced Materials technologies to QUADRUPLE the Concentrated Solar Thermal current POWER GENERATION	4914608	H2020-EU.2.1.3.;H2020-EU.2.1.2.	NMBP-17-2016
INSHIP	207022	Integrating National Research Agendas on Solar Heat for Industrial Processes	2456515	H2020-EU.3.3.5.;H2020-EU.3.3.3.;H2020-EU.3.3.2.;H2020-EU.3.3.4.	LCE-33-2016
INSUN	103644	Industrial Process Heat by Solar Collectors	4230542	FP7-ENERGY	ENERGY.2011.4.1-2
INTERSOLAR	110019	Development and demonstration of intelligent non-contact inspection technology for concentrated solar power plants	1071336	FP7-SME	SME-2013-1
ISSA	81749	Construction and field test activities of an innovative single-room solar driven air-conditioning system	48401	FP6-MOBILITY	MOBILITY-4.1
JORDAN , ULRIKE	71086	Experimental and Computational Analysis of Flow Patterns at Inlet Devices of Solar Water Stores	185174	FP5-EESD	1.1.4.-6.
LARGE SCALE SOLAR CO	54165	Air conditioning based on thermal solar energy- development of a low temperature absorption chiller for larger scale solar cooling in the building sector (large-scale solar cooling)	524414	FP5-EESD	1.1.4.-6.
LCSAC	198914	Low cost solar absorption cooling	50125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
LIGHTHOUSE	205077	LIGHTHOUSE: concentrated thermal solar power directly connected to the heating and cooling systems of buildings at the local level.	50000	H2020-EU.2.3.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
MACCSOL	95857	The development and verification of a novel modular air cooled condenser for enhanced concentrated solar power generation	4426315	FP7-ENERGY	ENERGY.2010.2.5-1

Acronym	Rcn	Project title	EC funding (2016 EUR)	Programme	Topic
MACSHEEP	101598	New Materials and Control for a next generation of compact combined Solar and heat pump systems with boosted energetic and exergetic performance	2311115	FP7-ENERGY	ENERGY.2011.4.1-1
MARIO MOTTA	65205	Thermodynamic design and optimisation of advanced solar assisted desiccant cycles for mediterranean climates	189544	FP5-EESD	1.1.4.-6.
MATS	100479	Multipurpose Applications by Thermodynamic Solar	13142182	FP7-ENERGY	ENERGY.2010.2.9-1
MED-CSD	87801	Combined solar power and desalination plants: technico-economic potential in Mediterranean Partner countries	1116076	FP7-ENERGY	ENERGY-2007-2.5-02
MEDISCO	80017	MEDIterranean food and agro industry applications of Solar COoling technologies	1657612	FP6-INCO	INCO-2004-B1.5;INCO-2002-B1.5
MEDITERRANEAN-AIRCON	81326	An advanced solar-driven air conditioning system for Mediterranean climate	1328159	FP6-INCO	INCO-2004-B.3
MEEFS RETROFITTING	102074	Multifunctional Energy Efficient Façade System for Building Retrofitting	7492975	FP7-NMP	EeB.NMP.2011-3
MEMDIS	86935	Development of stand-alone, solar thermally driven and Pv-supplied desalination system based on innovative membrane distillation	1239043	FP5-EESD	
MERITS	107963	More Effective use of Renewables Including compact seasonal Thermal energy Storage	4669705	FP7-ENERGY	ENERGY.2011.4.1-4
MinWaterCSP	200380	MinWaterCSP - Minimized water consumption in CSP plants	5861372	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-02-2015
MOSAIC	205864	MOdular high concentration SolAr Configuration	5077734	H2020-EU.3.3.2.	LCE-07-2016-2017
MSLOOP 2.0	206074	Molten Salt Loop 2.0: key element for the new solar thermal energy plants.	2243085	H2020-EU.3.;H2020-EU.2.	FTIPilot-01-2016
MUSTEC	211264	Market uptake of Solar Thermal Electricity through Cooperation	2356102	H2020-EU.3.3.7.;H2020-EU.3.3.3.;H2020-EU.3.3.2.	LCE-21-2017
NANODAOHP	186337	Nanoparticle based direct absorption oscillating heat pipes for solar thermal systems	222138	FP7-PEOPLE	FP7-PEOPLE-2013-IIF
NanoDAOHP	190981	Nanoparticle based direct absorption oscillating heat pipes for solar thermal systems	15000	FP7-PEOPLE	FP7-PEOPLE-2013-IIF
NECSO	106941	Nanoscale Enhanced Characterisation of SOlar selective coatings	1869617	FP7-NMP	NMP.2012.1.4-3
NEGST	87883	New generation of solar thermal systems	1093079	FP6-SUSTDEV	SUSTDEV-1.1.1
NESTER	199326	Networking for Excellence in Solar Thermal Energy Research	1060798	H2020-EU.4.b.	H2020-TWINN-2015
NEXT-CSP	205807	High Temperature concentrated solar thermal power plan with particle receiver and direct thermal storage	4947420	H2020-EU.3.3.2.	LCE-07-2016-2017
NEXTOWER	207409	Advanced materials solutions for next generation high efficiency concentrated solar power (CSP) tower systems	4915443	H2020-EU.2.1.3.;H2020-EU.2.1.2.	NMBP-17-2016
OMSOP	106967	Optimised Microturbine Solar Power system	4457501	FP7-ENERGY	ENERGY.2012.2.5.1
OPICS	70374	Optimised Integrated Collector Storage: low-cost solar thermal systems for houses and offices	463573	FP5-EESD	1.1.4.-5.2.4
OPICS	86883	Optimized integrated collector storage: low-cost solar thermal systems for houses and offices	463573	FP5-EESD	

Acronym	Rcn	Project title	EC funding (2016 EUR)	Programme	Topic
ORC-PLUS	195491	Organic Rankine Cycle - Prototype Link to Unit Storage	6264940	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-03-2014
PEGASUS	205804	Renewable Power Generation by Solar Particle Receiver Driven Sulphur Storage Cycle	4695365	H2020-EU.3.3.2.	LCE-07-2016-2017
PIME'S	94484	CONCERTO communities towards optimal thermal and electrical efficiency of buildings and districts, based on MICROGRIDS	11963822	FP7-ENERGY	ENERGY.2008.8.4.1
PITAGORAS	186981	Sustainable urban Planning with Innovative and low energy Thermal And power Generation from Residual And renewable Sources	8430379	FP7-ENERGY	ENERGY.2012.8.8.2
Polarsol Phase One	197421	Disrupting the energy market with the innovation in solar heating	50125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
Polarsol Phase Two	204995	Polarsol - a disruptive hybrid heat management solution for global markets	2059050	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
POLYSOL	98108	Development of a modular, all-POLYmer SOLar thermal collector for domestic hot water preparation and space heating	1171358	FP7-SME	SME-1
POSHIP	87135	The potential of solar heat in industrial processes	471178	FP5-EESD	
POWERSOL	81331	Mechanical power generation based on solar Thermodynamic Engines	1214801	FP6-INCO	INCO-2004-B1.5
PreFlexMS	195027	Predictable Flexible Molten Salts Solar Power Plant	14398100	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-03-2014
Prisma	211295	Innovative and highly-efficient solar thermal collector for Building façades	49157	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
PROTEAS PS SYSTEM	67935	Triple hybride concentrating pv system for the co-generation of electricity, heat and cooling power	1003875	FP5-EESD	1.1.4.-6.
PS10	57595	10 Mw Solar Thermal Power Plant in Southern Spain		FP5-EESD	1.1.4.-6.5.2
PV-TE-MCHP	209530	A Novel Hybrid Photovoltaic–Thermoelectric Power Generation System Employing the Flat-plate Micro-channel Heat Pipe	192158	H2020-EU.1.3.2.	MSCA-IF-2016
RAISELIFE	200815	Raising the Lifetime of Functional Materials for Concentrated Solar Power Technology	9291723	H2020-EU.2.1.3.	NMP-16-2015
Re-Deploy	199520	Re-deployable solar boilers based on concentrating solar collectors for ESCO type sale of thermal energy to industrial processes.	2025207	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015
RESTRUCTURE	100980	Redox Materials-based Structured Reactors/Heat Exchangers for Thermo-Chemical Heat Storage Systems in Concentrated Solar Power Plants	2220366	FP7-ENERGY	ENERGY.2011.2.5-1
ROCOCO	85644	ROCOCO - Reduction of costs of solar cooling systems	585466	FP6-SUSTDEV	SUSTDEV-1.1.1
RO-SOLAR-RANKINE	107610	Development of an Autonomous Low-Temperature Solar Rankine Cycle System for Reverse Osmosis Desalination (RO-SOLAR-RANKINE)	1406646	FP6-SME	SME-1
SACE	61352	Solar Air Conditioning in Europe	417987	FP5-EESD	1.1.4.-6.1.1
SACPEH	86884	Solar air conditioning system using very low cost variable plastic ejector, with hybrid potential for different markets	826527	FP5-EESD	
SARTEA	196113	SOLAR ADSORPTION REFRIGERATOR WITH THIN-LAYER/ENHAMCED ADSORBENT	195455	H2020-EU.1.3.2.	MSCA-IF-2014-EF
SCOOP	101374	Solar Collectors made of Polymers	3268726	FP7-ENERGY	ENERGY.2011.4.1-1

Acronym	Rcn	Project title	EC funding (2016 EUR)	Programme	Topic
SDHp2m	199617	Advanced policies and market support measures for mobilizing solar district heating investments in European target regions and countries	1919298	H2020-EU.3.3.7.;H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-04-2015
SECESTTP	85691	Supporting the development of a European solar thermal technology roadmap	374812	FP6-SUSTDEV	SUSTDEV-1.1.1
SEFI	197585	Solar Energy for Food Industry	50125	H2020-EU.2.3.1.;H2020-EU.3.2.	SFS-08-2015-1
SESPer	211753	Solar Energy Storage PERovskites	235157	H2020-EU.1.3.2.	MSCA-IF-2016
SFERA	91047	Solar Facilities for the European Research Area	8174729	FP7-INFRASTRUCTURES	INFRA-2008-1.1.2
SFERA-II	110563	Solar Facilities for the European Research Area-Second Phase	7015861	FP7-INFRASTRUCTURES	INFRA-2012-1.1.17.
SHINE	109061	Solar Heat Integration Network	3488705	FP7-PEOPLE	FP7-PEOPLE-2012-ITN
SmartHeat	205134	SmartHeat - An eco-innovative solution towards zero-carbon household heating	50000	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
SOCOLD	72253	Development and implementation of a cost effective adsorption refrigeration system utilising high temperature (120 °C) solar Compound Parabolic Collectors (CPC) (SOCOLD)	1252983	FP6-SME	SME-1
SOcool	205130	SunOyster cooling	50000	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
SOcool	211760	SunOyster cooling (SOcool)	1374888	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
SOLABS	67210	Development of unglazed solar absorbers (resorting to coloured selective coatings on steel material) for building facades, and integration into heating systems (solabs)	1366856	FP5-EESD	1.1.4.-6.
SOLAC	80860	Investigations of the absorber component of a solar desiccant air conditioning system	48401	FP6-MOBILITY	MOBILITY-4.1
SOLAIR	69263	Advanced solar volumetric air receiver for commercial solar tower power plants ('SOLAIR')	2008343	FP5-EESD	1.1.4.-6.
SOLAR LOUVRE	54164	Solar louvre building integrated collector (SOLAR LOUVRE)	400613	FP5-EESD	1.1.4.-6.
SOLAR TRES	86841	Molten salt solar thermal power 15MWe demonstration plant (target action 'C')	5784766	FP5-EESD	
SOLARBREW	103642	Solar Brewing the Future	2689196	FP7-ENERGY	ENERGY.2011.4.1-2
SOLARCLIM	57667	Solar Air-Conditioning for Buildings, Demonstration, Analysis and Assessment	939047	FP5-EESD	1.1.4.-6.1.3
SOLARIS	91806	A novel modular solar air source heat pump system	1179532	FP7-SME	SME-1
SOLARPEMFC	83087	Power generation from solar energy based on PEM fuel cell	265321	FP6-MOBILITY	MOBILITY-2.3
SOLARSTORE	89222	Improvement of the efficiency of a solar thermal system by integration of a thermochemical storage process	1103753	FP5-EESD	
Solar-Store	208562	Solar Powered Thermochemical Heat Storage System	192158	H2020-EU.1.3.2.	MSCA-IF-2016
SOLATERM	90568	Promotion of a new generation of solar thermal systems in the MPC	947207	FP6-SUSTDEV	SUSTDEV-2005-1.1.1-2

Acronym	Rcn	Project title	EC funding (2016 EUR)	Programme	Topic
SOLEGLASS	100221	All Glass Mid Temperature Direct Flow Thermal Solar Vacuum Tube	2237089	FP7-SME	SME-2011-2
SOLERA	85693	Integrated small-scale solar heating and cooling systems for a sustainable air-conditioning of buildings	925563	FP6-SUSTDEV	SUSTDEV-1.1.1
SOLFACE	73803	High flux solar facilities for Europe		FP6-INFRASTRUCTURES	INFRASTR-1
SOLGATE	54153	Solar hybrid gas turbine electric power system (SOLGATE)	1967420	FP5-EESD	1.1.4.-5.
SOLHYCARB	78505	Hydrogen from Solar Thermal Energy: High Temperature Solar Chemical Reactor for Co-production of hydrogen and carbon black from natural gas cracking	2364820	FP6-SUSTDEV	SUSTDEV-1.2.6
SOL-MBDI	87167	Widening the use of European solar thermal technologies in Mediterranean countries following the successful model of Greece and Cyprus. Part A: Spain, Portugal	226101	FP5-EESD	
SOL-MED II	70471	Widening The Use Of European Solar Thermal Technol In Mediterranean Countries Following The Successful Model Of Greece. Part B: I, F, Ro, Bg, Tr	592748	FP5-EESD	1.1.4.-5.3.3
SOL-MED II	86979	Widening the use of European solar thermal technol in Mediterranean countries following the successful model of Greece.part B: I, F, Ro, Bg, Tr	592748	FP5-EESD	
SOLNET	87530	Advanced solar heating and cooling for buildings	2110488	FP6-MOBILITY	MOBILITY-1.2
SOLPART	199440	High Temperature Solar-Heated Reactors for Industrial Production of Reactive Particulates	4366563	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-02-2015
SOLPCM	185764	Solar Collector and PCM Thermal Façade for Low Carbon Buildings	309977	FP7-PEOPLE	FP7-PEOPLE-2013-IIF
SOLUGAS	90333	Solar Up-scale Gas Turbine System	6694218	FP7-ENERGY	ENERGY-2007-2.5-04
SOLZINC	59848	Solar carbothermic production of Zn from ZnO (SOLZINC)	1685862	FP5-EESD	1.1.4.-6.
STAGE-STE	111484	Scientific and Technological Alliance for Guaranteeing the European Excellence in Concentrating Solar Thermal Energy	10021198	FP7-ENERGY	ENERGY.2013.10.1.10
STATIC-2	60073	Stagnation proof transparently insulated flat plate solar collector (STATIC-2)	636302	FP5-EESD	1.1.4.-6.
STOLARFOAM	103583	Thermochemical Storage of Solar Heat via Advanced Reactors/Heat exchangers based on Ceramic Foams	229639	FP7-PEOPLE	FP7-PEOPLE-2011-IEF
STORRE	103961	High temperature thermal energy Storage by Reversible thermochemical Reaction	2255345	FP7-ENERGY	ENERGY.2011.2.5-1
SUNSTORE2	89232	Solar thermal and long term heat storage for district heating systems	1063277	FP5-EESD	
SWITCH	57574	Switch Solar Water Integrated Thermal Cooling and Heating Systems	214639	FP5-EESD	1.1.4.-6.1.3
TCSPower	100642	Thermochemical Energy Storage for Concentrated Solar Power Plants	2991896	FP7-ENERGY	ENERGY.2011.2.5-1
TENCENT	198896	The next generation of Hybrid Concentrating Solar Power Plants	50125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
TERMISOL	80004	New Low-Emissivity the Long Lasting Paints for Cost-Effective Solar Collectors	1036007	FP6-INCO	INCO-2004-B1.5;INCO
THERMALCOND	96989	Polymeric composite materials with enhanced thermal conductivity properties for heat exchangers applications	1143413	FP7-SME	SME-1
THERMOTEX	96632	The development of a new more efficient and easy to install high strength solar collector withstanding high temperature (120°)and operating pressures form circulating water and externals	907343	FP7-SME	SME-1

Acronym	Rcn	Project title	EC funding (2016 EUR)	Programme	Topic
THESEUS	57691	Theseus-50 MWe Thermal Solar European Station of Frangokostello Crete - Implementation Phase	632682	FP5-EESD	1.1.4.-5.2.4
TRANSREGEN	196298	Portable thermal fluid regeneration system for Solar Thermal Plants	50125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
TRANSSOL	57008	Transnational access to the 'plataforma solar de almería' : the european solar thermal test centre (1° phase)	2132979	FP5-HUMAN POTENTIAL	1.4.1.-2.
TRANSSOL-II	58557	Transnational access to the 'plataforma solar de almería' : the european solar thermal test centre (2° phase)	665461	FP5-HUMAN POTENTIAL	1.4.1.-2.
WASCOP	199297	Water Saving for Solar Concentrated Power	5941608	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-02-2015
No acronym	61561	Thermal conditioning of buildings by solar roof, and radiant floor, including displacement ventilation and natural skyligh	29299	FP5-EESD	1.1.4.-5.
No acronym	56930	Air-cooled, solar (gas) -driven nh3-h2o absorption system for air conditioning and other cooling applications using a compound parabolic collector	30184	FP5-EESD	1.1.4.-5.
No acronym	61364	Solar space conditioning with a chemical heat pump	30184	FP5-EESD	1.1.4.-5.

Table 0-2 EU funded projects of multiple RES technologies, where solar thermal is one of the funded technologies

Acronym	Rcn	Project title	EC funding (2016 EUR)	Framework Programme	Topic	RE technologies
BIOSOD	86964	Development of an autonomous biomass-solar thermally driven distillation system	1097073	FP5-EESD		Solar Thermal, Bioenergy
BIODISH	51191	Development of a ceramic hybrid receiver for biogas fired dish-stirling-systems for electric power supply ('BIODISH')	587161	FP5-EESD	1.1.4.-5.	Solar Thermal, Bioenergy
REMAP	84048	Action plan for high-priority renewable energy initiatives in Southern and Eastern Mediterranean area	451194	FP6-POLICIES	POLICIES-3.2	Wind, Solar Thermal
EUROCARE	52230	Infrastructure co-operation network in area of combustion and solar energy	201224	FP5-HUMAN POTENTIAL	1.4.1.-2.	Solar PV, Solar Thermal
EUROSUNMED	109592	EURO-MEDITERRANEAN COOPERATION ON RESEARCH & TRAINING IN SUN BASED RENEWABLE ENERGIES	5302986	FP7-ENERGY	ENERGY.2013.2.9.1	Solar PV, Solar Thermal
GREEN SOLAR CITIES	85686	Global renewable energy and environmental neighbourhoods as solar cities	7294590	FP6-SUSTDEV	SUSTDEV-1	Solar Thermal, Bioenergy
INTENSOL	97198	Transparent Fresnel Based Concentrated Photovoltaic Thermal System	1019607	FP7-SME	SME-1	Solar PV, Solar Thermal
PV/HP GENERATION	92655	A Micro-generation System Using PV/heat-pipe Roof Modules	200424	FP7-PEOPLE	FP7-PEOPLE-IIF-2008	Solar PV, Solar Thermal
REELCOOP	109511	Research Cooperation in Renewable Energy Technologies for Electricity Generation	5211510	FP7-ENERGY	ENERGY.2013.2.9.1	Solar PV, Solar Thermal, Bioenergy
RESSOL-MEDBUILD	93381	RESearch Elevation on Integration of SOLar Technologies into MEDiterranean BUILDings	1082554	FP7-REGPOT	REGPOT-2009-2	Solar PV, Solar Thermal
SECRHC-PLATFORM	100483	Support to the activities of the European Technology Platform on Renewable Heating and Cooling	1049463	FP7-ENERGY	ENERGY.2010.4.5-1	Geothermal, solar thermal, bioenergy
SOLAR-ERA.NET	105893	ERA-NET on Solar Electricity for the Implementation of the Solar Europe Industry Initiative	2046115	FP7-ENERGY	ENERGY.2012.10.1.2	Solar PV, Solar Thermal
SOLAR-ERA.NET Cofund	200090	SOLAR-ERA.NET Cofund	5930150	H2020-EU.3.3.3.;H2020-EU.3.3.2.;H2020-EU.3.3.4.	LCE-18-2015	Solar PV, Solar Thermal
SOLEURAS	67851	European-central asian solar energy conference tashkent may 2003	25218	FP5-INCO 2		Solar PV, solar thermal, wind
SOLFORRENEW	99608	A comprehensive framework for high-resolution assessment and short-term forecasting of the solar resource for renewable energy applications	223528	FP7-PEOPLE	FP7-PEOPLE-2010-IOF	Solar PV, Solar Thermal
SUNSTORE 4	94908	Innovative,multi-applicable-cost efficient hybrid solar (55%)and biomass energy(45%) large scale (district) heating system with long term heat storage and organic Rankine cycle electricity production	6633766	FP7-ENERGY	ENERGY.2009.4.5.1	solar thermal, bioenergy

Annex 3

Technology Sector Report
Wind energy

(Deliverable D2.3)

Authors:
Onne Hoogland (Trinomics)
Elske Veenstra (Trinomics)
Perla C. Torres Vega (Trinomics)
Liliana Guevara Opinska (Trinomics)
Guillaume Dekelver (Tractebel)
Romain Gellee (Tractebel)
Tine Boon (Tractebel)

Trinomics

1 Introduction

This report is one in a series of eight technology reports for the study *Impacts of EU actions supporting the development of renewable energy (RE) technologies*, prepared for the European Commission. The report has two objectives: describing how EU research and development (R&D) funding related to wind energy technologies has impacted the wind energy sector in the EU and describing more broadly the development of the wind energy sector to which the EU R&D funding has contributed. It is based on a compilation of data from several databases, a questionnaire among coordinators of EU-funded R&D projects, case studies, interviews and literature research. The methodology applied for this study is documented in a separate deliverable.[1] Where relevant, limitations and assumptions are mentioned throughout this report.

The abundance of wind resources throughout Europe combined with the increasing need for renewable sources of energy have boosted the development of the wind energy market over the last 20 years. Traditionally, wind farms were constructed onshore but due to increased public resistance to wind farms and restrictions on the available land offshore wind farms were conceived as an option for further growth of the wind energy sector. The first offshore wind park was developed in 1991 in Vindeby, Denmark and the first large-scale offshore park was developed in 2000, also in Denmark in Middelgrunden. Offshore wind farms are typically located in seas and oceans on the continental shelf but can also be installed in lakes, fjords and shelter coastal areas. Offshore wind speeds are typically much higher and more constant than onshore wind speeds. In shallow waters (up to ~ 50 m), traditional fixed-bottom wind turbine technologies are preferred. For deeper-waters (over 40m) floating turbine technologies are being developed. As the name implies fixed-bottom offshore technologies refer to structures where the foundation of the turbine is fixed to the sea floor. A number of solutions are presently available, including: steel jacket structures, monopiles, gravity base structures, tripod piled and tripod suction bucket structures. Floating wind turbines are mounted on floating structures usually anchored to the ground via either tension-leg or catenary loose mooring systems. Currently the only floating wind farm at commercial scale in operation is located in Hywind, Scotland. It was developed by the Norwegian energy company Equinor (formerly Statoil).

A more recent area of interest in the wind energy sector is airborne wind energy. Airborne wind energy is a wind energy technology that is based on autonomous aerial vehicles linked to the ground by a tether. In theory such systems will benefit from the higher velocity of wind at elevated altitudes while also avoiding the costs of constructing high-altitude towers. An additional foreseeable benefit of airborne wind will be its replicability as the designs will require less customization associated for example to the foundation. In addition, small wind turbines (1 kW to 300 kW) for domestic and small-scale commercial use have recently also gained interest.

In addition to the development of the above mentioned technologies, research in the wind sector has increasingly focused on aspects related to Operations and Maintenance (O&M) of wind farms and to the integration of electricity produced from wind energy into the grid.

[1] Trinomics (2018) - Study on impacts of EU actions supporting the development of renewable energy technologies – Literature review and methodology (Deliverables D1.1 and D1.2)

In addition to funding R&D through the H2020 programme in the areas above (and others) in line with the EU's Strategic Energy Technology Plan (SET-Plan), the European Commission also supports stakeholder platforms to enhance cooperation and provide the Commission with advice on R&D priorities. The European Technology and Innovation Platform on Wind (ETIPWind) is a good example of this. ETIPWind provides a platform through which the European wind energy community can communicate, coordinate and collaborate with regards to priorities in research, innovation and technology. The European Energy Research Alliance (EERA)[2] Joint Programme for Wind Energy is another important initiative that strengthens European wind energy research. Various of the FP7 and H2020 projects presented throughout this report, such as INNWIND.EU and EERA DTOC, consist of consortia which were built through the EERA JP Wind vehicle.

[2] EERA is a public research pillar of the EU's SET-Plan.

2 Historical R&D funding

2.1 EU R&D funding

2.1.1 Evolution over time

The EU has funded wind energy technologies through the Framework Programmes (FPs) for R&D. Since FP5, wind energy technologies have received a total of EUR 565 million for 225 research projects and another EUR 95 million for 30 projects in combination with other technologies (see Table 2.1). Projects in combinations with other RE technologies include for instance projects regarding ocean and wind energy development at the same location.

Table 2.1 EU funding per Framework Programme (1998 to mid-March 2018, in 2016 million euros[3])

	Wind energy		Wind energy and other RE technologies	
Framework programme	**EU funding**	**No. projects**	**EU funding**	**No. projects**
FP5	75.35	57	7.59	7
FP6	55.25	20	14.24	2
FP7	293.87	74	44.41	12
H2020	140.96	74	28.38	9
Total EU funding	**565.43**	**225**	**94.61**	**30**

Source: CORDIS (2018)
Note: Funding includes all funds made available through the R&D framework programmes. It is not limited to the energy challenge but also includes funding through other programmes/instruments such as the SME instrument. H2020 includes all projects awarded and registered in CORDIS up to mid-March 2018. As H2020 runs from 2014 to 2020, not all funding had been awarded at this point.

EU R&D funding for wind energy has undergone a step change from FP6 to FP7 with a six-fold increase in the amount allocated. For H2020 the total funding is not yet known as the programme has not finished, but the funding that has been allocated so far is already at a higher level than the funding of FP5 and FP6.

2.1.2 Evolution of research topics

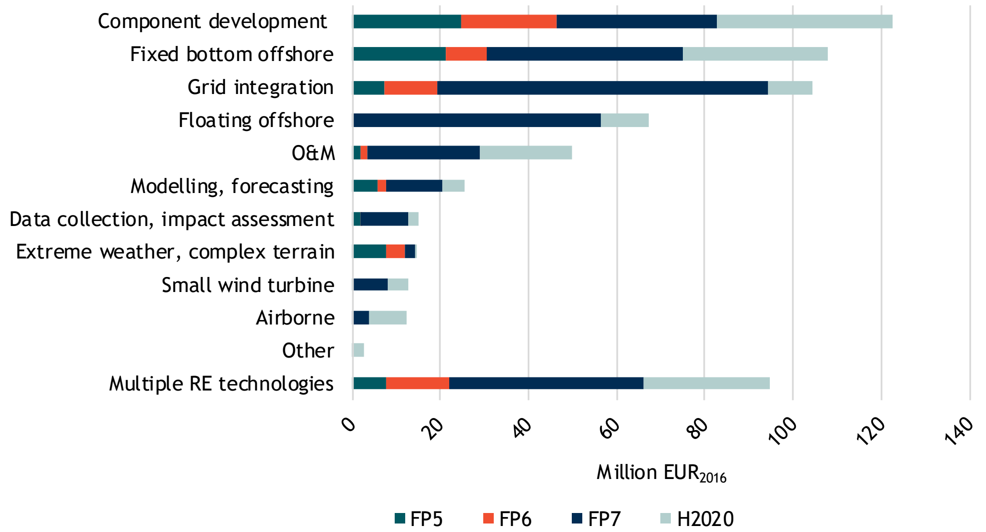
Figure 2.1 provides a good basis for understanding the changes in research priorities and the development of the wind energy sector as it matured over the last 20 years. Both figures show that EU funding has been spread across several thematic areas and sub-technologies.

Component development has been the largest area of funding in terms of budget and number of projects. This category encompasses component design, standardization, manufacturing and demonstration. Projects classified under component development refer to those component improvements that are of relevance for the on and offshore wind sectors (e.g. blades). Component improvements regarding different offshore support structures have been classified as floating or fixed-bottom offshore. In contrast to other thematic areas that were supported much more during the later framework programmes, the support for component development has been relatively constant from FP5 onwards. During FP5 and FP6 research focused primarily on component development, fixed-bottom

[3] Historical values have been inflation adjusted to arrive at 2016 constant values. This has been done to show the values of budgets, prices and other monetary indicators without the impact of varying price levels over the years so that they can be compared more accurately over time.

offshore and extreme weather, complex terrain projects. In addition, research on large wind turbines started gaining momentum.

Figure 2.1 EU funding per sub-technology/area (2016 Million Euro)



Source: CORDIS (2018)
The area 'multiple RES technologies' includes projects in which wind is one of multiple RE technologies.

A good example of a project on large wind turbines is the FP6 project UpWind, which is highlighted in the project spotlight box below. The project helped to develop large wind turbines of up to 10 MW for on- and offshore locations. At the time the conclusions from the research project were that the development of large wind turbines is feasible but not yet economically viable. FP7 projects provided continuity in terms of support for technologies and research areas already developed under FP5 and FP6. The FP7 INNWIND.EU (see project spotlight box in Section 3.2.3) project is the continuation of the research undertaken during UpWind.

Project spotlight: UpWind (Integrated Wind Turbine Design)

UpWind (FP6) ran from March 2006 to February 2011 and was Europe's largest European R&D wind energy project. UpWind brought together experiences from 40 different leading industrial and research institutions. The project focused on making the already available technology more cost effective. In particular, it explored how to improve design methods, wind turbine components and materials to allow upscaling to 8-10 MW wind turbines standing in huge on- and offshore wind farms. There was a strong focus on the development and the demonstration of lightweight and innovative components, such as large 100 meter blades, supra-conducting generators and new fixed and semi-floating offshore substructures. This increase in unit capacity proved to be the key driver in reducing the LCOE. In doing so, UpWind helped European wind energy companies in maintaining their favourable position in the global market.

Source: http://www.ewea.org

As component development matured - especially pertaining to large wind turbines - projects focused on addressing the logistics of deployment, installation and operation of large-scale wind turbines in the range of 5 MW to 10 MW. A good example is the FP7 project LEANWIND. As seen from Figure 2.1, O&M received increased support during FP7 and H2020 compared to the earlier FPs.

As costs for traditional fixed-bottom offshore foundations proved prohibitive in waters deeper than 50 m, floating offshore technologies started to gain more interest. From FP7 onwards floating offshore wind technology started to be funded, showing that the EU recognised the large energy generation potential available in deeper waters and the improved technological and financial viability of the technology thanks to the advances for wind energy technology. Moreover, the ability to harvest offshore wind energy in deeper waters will translate into an increased accessibility to utilise the potential of offshore wind energy for those countries that have coastline along the Atlantic or Mediterranean, both of which are much deeper than the North or Baltic seas. Examples of EU-funded projects on floating offshore technologies include ICFLOAT, DEMOWFLOAT and FLOATGEN (see project spotlight box below).

During FP7, projects such as TWENTIES and BEST PATHS made substantial contributions towards supporting further wind energy integration into the grid. The TWENTIES project involved six demonstration projects in several EU countries to remove barriers that prevent the electric system from accepting more wind energy into the system. BEST PATHS also supported demonstration projects to prove the benefits of novel technologies combined with innovative system integration approaches (see also project spotlight boxes below).

Moreover, as traditional onshore wind technology matured, funding of new technologies such as small wind turbines and airborne wind energy became more prevalent. These sub-technologies received funding only during FP7 and H2020. Substantial progress has been made in these areas despite them remaining niche technologies at the moment. Examples include AWESCO and REACH, which have resulted in new developments in airborne wind technologies.

Project spotlight: BEST PATHS (Beyond State-of-the-Art Technologies for Power AC Corridors and Multi-terminal HVDC Systems)

Best PATHS (FP7-ENERGY) brought together a group of eight Transmission System Operators (TSOs) together with a generation company and manufacturing and research organisations to propose five demonstration projects focused on addressing several barriers preventing renewable electricity from penetrating the European transmission network on a larger scale. The focus of the demonstrations was on finding solutions to allow for transition from High Voltage Direct Current (HVDC) lines into HVDC grids. It also focused on upgrading and repowering existing alternating current network parts and on the integration of superconducting high power DC links within AC meshed networks.

Source: European Commission, 2018, Community Research and Development Information Service; and project website (http://www.bestpaths-project.eu/)

Project spotlight: TWENTIES (Transmission system operation with large penetration of Wind and Other renewable Electricity sources in Networks by means of innovative Tools and Integrated Energy Solutions)

TWENTIES (FP7-ENERGY) was a project that brought together an international consortium of six Transmission System Operators (TSOs), two generator companies and five manufacturers and research organisations to develop six demonstration projects. The demonstration projects aimed at removing barriers that prevented the electric system from welcoming more onshore and offshore wind electricity by showing the benefits of novel technologies coupled with innovative system management approaches. The project was divided into three major task forces. Task force 1 focus on the contribution of variable generation and flexible load to system services. Task force 2 dealt with the reliable offshore network

and wind development whereas task force 3 looked at the flexibility of the transmission grid. The project showed that wind farms can provide a wide area voltage control and secondary frequency control services to the system. It also found that virtual power plants can enable the reliable delivery of ancillary services such as voltage control and reserves. One of the TWENTIES' demonstration projects, DC GRID, focused on the challenges related to the integration of offshore intermittent power into AC onshore grids over long distances. This was addressed by using DC Grids based on Voltage Source Converters. The DC GRID demo project resulted in a DC Grid mock-up and a DC Circuit Breaker prototype.
Source: European Commission, 2018, Community Research and Development Information Service; and https://windeurope.org/fileadmin/files/library/publications/reports/Twenties.pdf

2.1.3 Top recipients

The top 10 recipients of EU funding for wind energy technologies includes five research institutes/universities as well as four private companies and one energy agency. These organisations have received 26 % of the EU funding during the time period from 2008 to early 2018, showing that wind energy is a field of research that is not concentrated in the hands of a few organisations but has many participating organisations instead.[4]

The top recipient of EU funding in the time period specified was Danmarks Tekniske Universitet (Technical University of Denmark). The University was involved in coordinating five projects on wind energy during FP7. Out of these project three of them focused on offshore wind energy (DEEPWIND, INNWIND.EU and EERA-DTOC; see project spotlight boxes in Section 3.2.3 and Section 5.4 for more information on the last two projects). The University was also active during FP6, coordinating four different projects on wind energy. The German research institute Fraunhofer Gesellschaft Zur Foerderung Der Angewandten Forschung coordinated two FP7 research projects focused on component design (WAlID and HIPRWIND). The Institute is also coordinating an ongoing H2020 project focused on increasing energy efficiency in the wind energy industry by applying concepts from the aeronautic sector.

Compared to other RE technologies, the number of private companies in the top 10 is high, which can be explained by the maturity of the wind energy sector and the presence of several major EU-based companies. Currently, the German/Spanish turbine manufacturer Siemens Gamesa is one of the leading companies manufacturing wind turbines. Before announcing their merger in 2016, Siemens (Siemens Aktiengesellschaft and Siemens Industry Software NV) was involved in coordinating one FP7 and another H2020 wind project. Gamesa Innovation and Technology S.L. coordinated three FP7 projects including FLOATGEN, which is described in detail in a project spotlight text box and as a case study (Annex A). The Portuguese project developer EDP Renováveis is a major player in the global wind energy sector. Currently the company is coordinating the project DEMOGRAVI3 focused on substructures and offshore logistics.

[4] In RE sectors such as ocean (44 %), geothermal (53 %) and hydro (71 %), the top 10 organisations attract a relatively large share of the total funding. For bioenergy (14 %), solar PV (25 %), wind (26 %), biofuels (31 %) and solar thermal (32 %), the top 10 organisations attract much lower shares of the total funding available.

Table 2.2 Top 10 recipients of EU funding by organisation (2008 - mid March 2018, in 2016 euros)

Rank	Organisation	Type of organisation	Funding
1	Danmarks Tekniske Universitet	Research institute/University	16 629 946
2	Siemens Gamesa	Turbine manufacturer	10 752 936
3	EDP Renováveis	Project developer	9 975 746
4	Fraunhofer Gesellschaft Zur Foerderung Der Angewandten Forschung E.V.	Research institute	9 589 599
5	Esteyco S.A.	Engineering company	9 404 055
6	Sintef	Research institute	8 031 237
7	Toshiba Transmission & Distribution Europe Spa	Manufacturer/EPC company (transmission and distribution systems)	6 737 229
8	Stichting Energieonderzoek Centrum Nederland	Research institute	6 347 409
9	Katholieke Universiteit Leuven	University	5 710 089
10	Energistyrelsen	Energy agency	4 946 787

Source: CORDIS (2018)
The source data covered H2020 funding and FP7 funding from 2008, which includes 60 % of total funding for wind energy identified in section 2.1. No data was available for recipients of FP5, FP6 and part of the FP7 funding. Projects under 'wind energy and other RE technologies', as mentioned in the introduction of section 2.1, are not included in this analysis because the funding for these projects could not be split reliably over the different technologies covered.

The top 3 recipient countries of EU R&D funding on wind energy are Spain, Germany and the United Kingdom (see Table 2.3). These three countries received 49 % of the total EU funding available for wind energy. Just after are Denmark and the Netherlands, two smaller Member States that have been very active in the wind energy sector (Denmark is considered one of the leading countries in the global market). It is interesting to note that the five top Member State recipients of EU funding are also the countries, although not in the same order, with highest national funding allocated to the wind sector in the period 1996-2015 (see section 2.2.2).

Table 2.3 Top 10 recipients of EU funding by country (2008- mid March 2018, in 2016 euros)

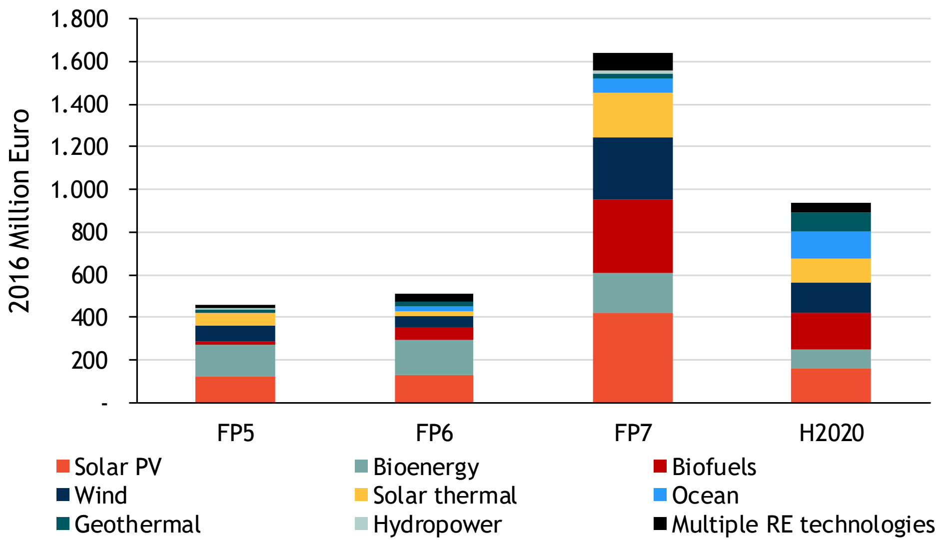
Rank	Country	Funding
1	Spain	77 769 333
2	Germany	48 410 584
3	United Kingdom	42 051 836
4	Denmark	37 340 540
5	Netherlands	25 842 037
6	Italy	19 176 997
7	Norway	17 769 687
8	Belgium	15 346 633
9	France	11 621 514
10	Portugal	9 079 937

Source: CORDIS (2018)
The source data covered H2020 funding and FP7 funding from 2008, which includes 60 % of total funding for wind energy identified in section 2.1. No data was available for recipients of FP5, FP6 and part of the FP7 funding. Projects under 'multiple RES technologies', as mentioned in the introduction of section 2.1, are not included in this Table.

2.1.4 Share of funding for each sector in proportion to the overall funding of all renewable energy technologies

Overall, wind energy projects received 15.9 % of the EUR 3 603 million awarded to RE technologies through the FP5, FP6, FP7 and H2020 programmes. In FP5 they received 16.4 % of total funding available, but in FP6 their share reduced to 10.7 %. The highest share achieved was for FP7 projects, when wind energy projects accounted for 17.9 % of the available funding, while for H2020, this decreased to 15 % so far. Taking all these funding programmes into account, wind energy (15.9 %) was the fourth largest recipient after solar PV (23.2 %), bioenergy (16.8 %) and biofuels (16.6 %).

Figure 2.2 Share of funding for each technology sector in proportion to overall funding (H2020 only up to mid-March 2018, in 2016 euros)



Source: CORDIS (2018)
The area 'multiple RES' includes projects of multiple RE technologies.

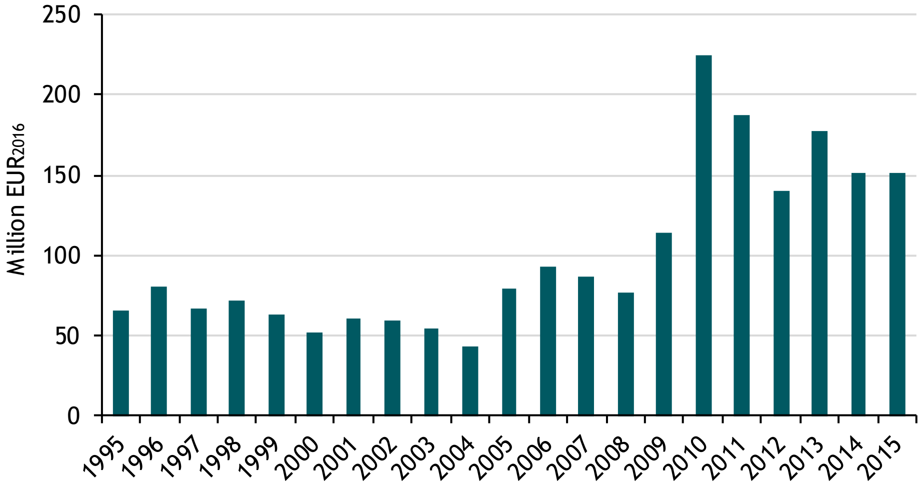
2.2 Member State R&D funding

2.2.1 Evolution over time

Annual R&D funding by Member States increased after 2008, from EUR 68 million on average between 1995-2008 to EUR 164 million on average between 2009-2015 (see Figure 2.3). This is 3.5 times as high as the average annual EU funding between 2009-2015 (EUR 47 million). Member State R&D funding for wind energy peaked in 2010, after which it declined to a relatively stable level from 2012 onwards. Wind energy is the third largest recipient of Member State R&D funding (after biofuels and solar PV).[5]

[5] Own elaboration based on data from OECD iLibrary.

Figure 2.3 Annual Member State R&D funding in the EU for wind energy (1995 to 2015, in 2016 euros)

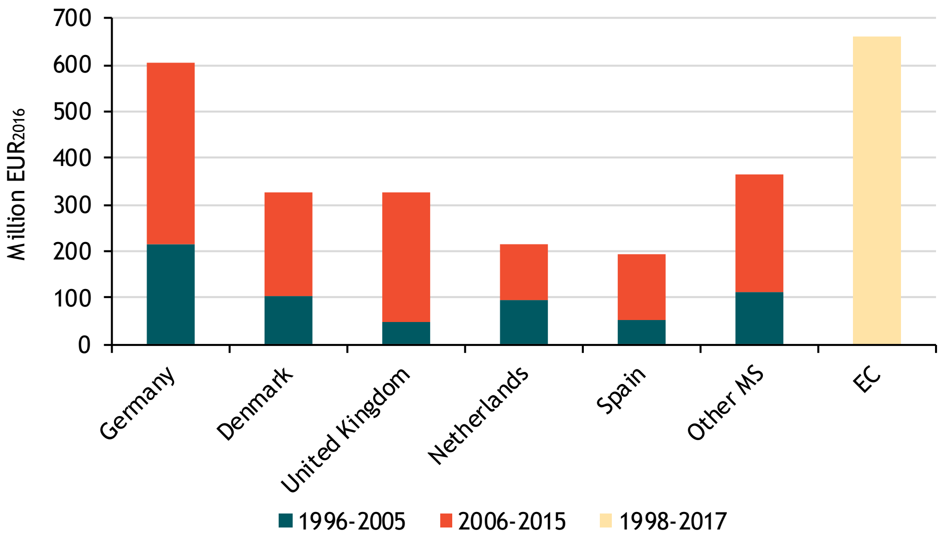


Source: Based on data from OECD/IEA (2018).
Note: Data for 20 EU countries was available in this source: the EU15 plus Czech Republic, Estonia, Hungary, Poland, and Slovakia. Data for Italy was not available for 2010 and 2015, data for the UK was not available for 2008, and data for the Netherlands was not available for 2004.

2.2.2 Largest Member State funders

Figure 2.4 shows the EU funding compared to the largest five Member State funders: Germany, Denmark, the United Kingdom, the Netherlands and Spain. Together they provided 82 % of total Member State funding; they were also the top five recipients of EU funding in the period from 2008 to mid-March 2018. These countries have a relatively large potential for wind energy compared to other RE technologies (particularly Denmark, United Kingdom and Netherlands) and/or have a strong wind energy industry (particularly Germany, Denmark and Spain).

Figure 2.4 Wind energy R&D budgets of the top 5 funder Member States (1996-2015) and the European Commission (1998-2017)



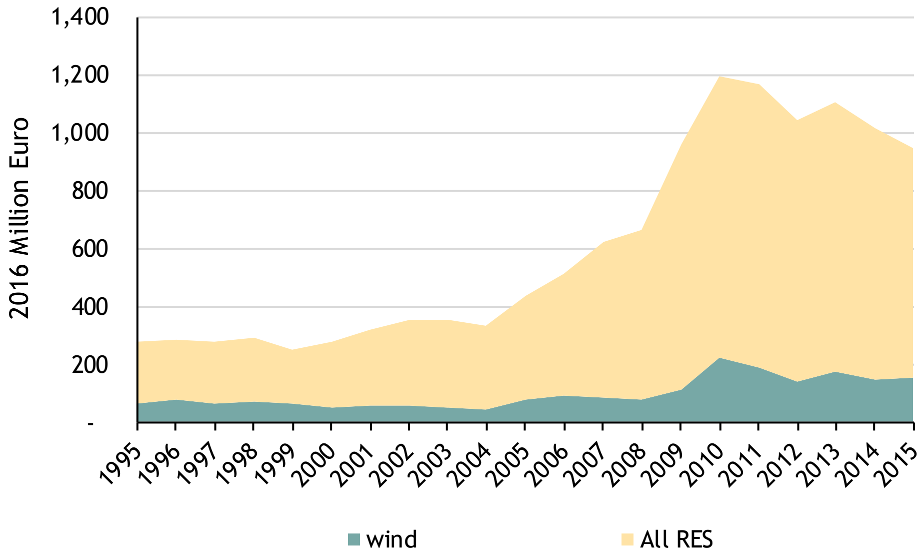
Source: Own elaboration based on data from OECD iLibrary (2018), Eurostat (2018) and CORDIS (2018). Data for Italy was not available for 2010 and 2015, and data for the UK was not available for 2008.
Note: Time window of comparison between Member State and European Commission funding is shifted 2 years due to data availability of Member State budgets for the scope of analysis (FP5-H2020). Projects under 'wind energy and other RE technologies', as mentioned in the introduction of section 2.1, are not included in this analysis.

2.2.3 Share of total renewable energy technology funding

In the period of 1995 to 2015 Member States allocated 20 % of their RE National RD&D funding to wind energy. From 1995 to 2000 the share of funding for wind energy was particularly high, with shares between 30 % and 40 %. From 2000 onwards the share of wind energy oscillated around 20 % with shares between 17 % and 19 % in the most recent years.

In absolute numbers, Member State R&D budgets for wind energy have increased considerably, growing from EUR 60 million in the earlier years to more than EUR 150 million in recent years. Overall, wind energy has been one of the key RE technologies supported by Member States, ranking third behind solar PV and bioenergy.

Figure 2.5 Share of national R&D funding for wind energy in proportion to the overall funding for all RE technologies



Source: Based on data from OECD/IEA (2018).
Note: Data for 20 EU countries was available in this source: the EU15 plus Czech Republic, Estonia, Hungary, Poland and Slovakia. Data for Italy was not available for 2010 and 2015, data for the UK was not available for 2008, and data for the Netherlands was not available for 2004.

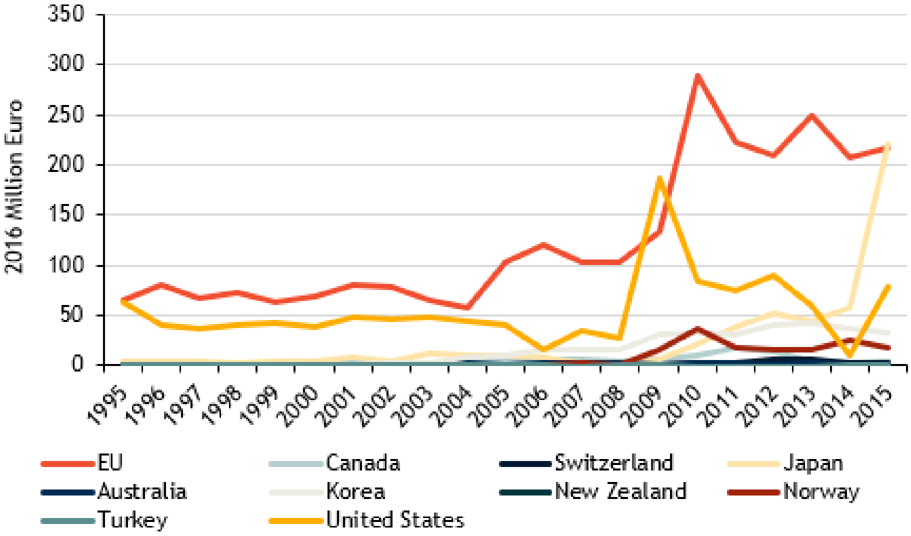
2.3 Private and international R&D funding

2.3.1 International public R&D funding

The combined funding for wind energy from the EU and Member States in the period between 1995 and 2015 was on average EUR 126 million per year. The United States of America (USA) provided EUR 55 million per year on average, whilst Japan provided EUR 25 million/year. Japan also had an exceptionally high R&D budget for wind energy in 2015 of EUR 220 million. US funding for wind energy peaked in 2009 due to the American Recovery and Reinvestment Act, which supported many clean energy technologies as a stimulus to the US economy. Consistent time series on Chinese funding are not available. Nonetheless recent documents estimate that in 2016 the Chinese public expenditure for R&D in the wind sector was EUR 238 million, which is the same order of magnitude as EU and Member State funding combined.[6] Other countries with significant R&D budgets for wind energy are South Korea, Norway and Canada.

[6] World Bank Group (2017) - Accelerating Innovation in China's Solar, Wind and Energy Storage Sector.

Figure 2.6 Comparison of international R&D funding for wind energy



Source: OECD/IEA (2018).
Note: EU covers EU and MS funding. National budgets for 2016 were excluded from the analysis because they are early estimates and lack reliability/coverage. Data covers 20 EU countries: the EU15 and Czech Republic, Estonia, Hungary, Poland, Slovakia and the European funding programmes FP5, FP6, FP7 and H2020. For countries outside the EU, national budgets were available for Australia, Canada, Japan, Korea, New Zealand, Norway, Switzerland, Turkey and the USA. Data for Italy was not available for 2010 and 2015, and data for the UK was not available for 2008. China was excluded from the analysis as reliable data for the time period of interest was not available. Projects under 'wind energy and other RE technologies', as mentioned in the introduction of section 2.1, are not included in this analysis.

2.3.2 *Private R&D funding*

There is limited data available on private R&D funding for RE technologies and the sources of the data that is available are generally not fully traceable. Nevertheless, there are some estimates that can be used to get an idea of the order of magnitude of private R&D funding in the main regions across the world. Table 2.4 provides the estimates by Frankfurt School-UNEP Centre/BNEF for Europe and the USA. These figures indicate that 2017 private R&D budgets in Europe (EUR 400 million) are significantly higher than in the USA (EUR 200 million). Furthermore, the estimates indicate that private R&D funding is higher than public R&D funding (+/- EUR 220 million - see previous section). Bottom-up estimates of the R&D budgets of major EU-based wind turbine manufacturers, point to higher budgets with estimates for Vestas (> EUR 200M) and Siemens Gamesa (close to EUR 200M) combined already equating to EUR 400 million.[7] Other sources estimate even higher private R&D spending in the EU, with values over EUR 1 000 million.[8] Overall, these figures underline the importance of the EU wind energy sector in the global market.

Table 2.4 Corporate R&D budgets for wind energy in Europe and the USA

Region	Corporate R&D budgets (billions of euros)		
	2015	2016	2017
Europe	0.5	0.2	0.4
USA	0.1	0.0	0.2

Source: Frankfurt School-UNEP Centre/BNEF – Global Trends in Renewable Energy Investment. 2016-2018 editions.

[7] Data presented by the JRC at the wind energy conference organised on 7 November 2018 as part of this study. Data based on OEM annual reports and investor presentations.
[8] Deloitte and Wind Europe estimate that the EU industry spends 5 % of its GDP on R&D and that its GDP is around EUR 22 million in 2016. 5 % * 22 M = EUR 1 100 Million of private R&D spending. Source: Deloitte and Wind Europe (2017) Local impact, global leadership: The impact of wind energy on jobs and the EU economy. Available at https://windeurope.org/wp-content/uploads/files/about-wind/reports/WindEurope-Local-impact-global-leadership.pdf

2.4 Conclusions

Wind energy has been one of the main recipients of EU R&D funding for RE technologies with a 16 % share. EU R&D funding for wind energy increased sharply from EUR 55 million in FP6 to EUR 294 million in FP7 and has remained at a high level under Horizon 2020 thus far (EUR 141 million by mid-March 2018).

The evolution of EU-funded research topics suggests a clear vision behind the changing priorities in wind energy research during the last 20 years. Supported projects addressed topics with general relevance for the wind energy sector, such as component design, grid integration and O&M, as well as topics related to specific sub-technologies. As onshore technologies matured, funding shifted towards fixed-bottom offshore and larger turbines. Topics with specific relevance for fixed-bottom offshore wind energy have been supported as early as FP5, whereas floating offshore, small wind turbines and airborne wind energy started to receive funding under FP7.

The top recipients of EU R&D funding include four private companies and the main research institutes for wind energy. The number of private sector companies among the top recipients is higher than for most other RE sectors because of the maturity of the wind energy sector and the presence of several large global market players in the EU.

Member State R&D funding (average of EUR 164 million/year between 2009 and 2015) for wind energy is 3 to 4 times the size of EU R&D funding (average of EUR 47 million/year from 2009 to 2015). The countries with the largest national budgets are Germany, Denmark, United Kingdom, Netherlands and Spain. Member States spent about 20 % of their overall R&D expenditure for RE technologies on wind energy.

The combined EU and Member State public R&D budgets for wind energy are relatively high when compared to other regions or countries. In absolute terms, only China invested more money on wind R&D than the EU and its Member States in 2016. USA and Japan have budgets less than half the EU/Member States budgets combined in most of the years. Also the EU private sector has leading R&D budgets internationally, adding to the strong position of the EU wind energy sector.

3 Research effectiveness

R&D projects can lead to patents, publications, spin-offs and several other, less concrete but potentially important direct outputs such as standardisation and knowledge exchange. Such impacts are the most direct outputs of R&D funding and therefore provide the most objective view on the effectiveness of research budgets spent. In this section we discuss those indicators and their relation to R&D funding for the wind energy sector.

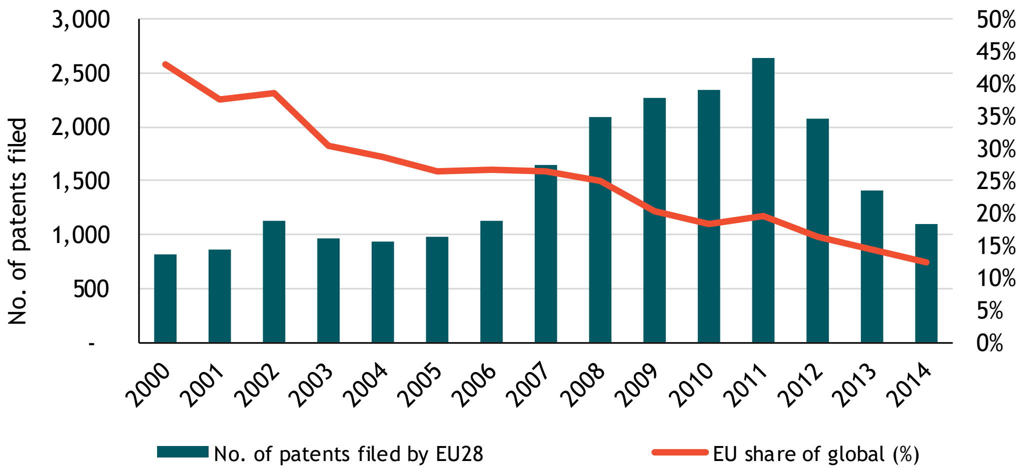
3.1 Patents

Patents are a commonly used indicator to measure the output of R&D funding as they provide a direct measurement of the impact in terms of novel knowledge generated. Furthermore, patent data are readily available, in a standardised form. However, some limitations have to be taken into account, such as the fact that filing a patent is not an objective of all research projects and that the economic value of patents varies significantly.

3.1.1 Evolution over time

Figure 3.1 shows the evolution of patents filed for wind energy technologies in the EU. The number of EU patents increased until 2011, after which it returned to pre-2007 levels.

Figure 3.1 Evolution of wind energy patents filed by EU countries



Source: IRENA INSPIRE (2017)
Notes: IRENA INSPIRE draws upon the EPO PATSTAT database. The scope is based on patents filed worldwide and not only in the European Patent Office.

There is a downward trend in EU's share of global patents, from 43 % in 2000 to 12 % in 2014. This is partly due to increased patenting activity in other countries/regions and partly due to decreasing patenting activity within the EU, especially since 2011. The European onshore wind energy market reached a certain level of maturity in terms of technology evolution and optimisation, supply chain and O&M during the 2006-2012 period, having as a result a reduced focus on patenting. In contrast, the Asian industry was still emerging and new turbine manufacturers such as Goldwind and Mitsubishi emerged and evolved, bringing out more patents. The strongest growth has occurred in China, where the number of patents filed grew from about a 100 per year in the early 2000s to more than 4 000 per year in 2011. But also South Korea, Japan and the USA have grown their patenting activity to levels comparable or higher than the EU.

The global cumulative number of patents related to wind during the time period was 104 920 of which the EU as a whole filed 22 399 (21 %).[9] More than 7 000 patents were filed in Germany, number one in the EU with 32 % of the total, followed by Denmark (17 %), Spain (15 %), the United Kingdom (8 %) and Austria (5 %). This is consistent with the list of largest R&D funding Member States. The Netherlands is the exception, ranking as the 4th largest funder but only 10th in terms of patents filed (2 % of the total number). In comparison, during the same time period China filed 26 588 patents, the USA filed 17 313, the Republic of Korea filed 10 380, Japan filed 9 705 and Canada filed 4 050.

Although as a proportion of the total patents filed globally, EU's position has diminished, in absolute terms EU organisations continue to file over 1,000 patent applications per year. Based on responses to the questionnaire (see section 3.4) a number of respondents reported patents as an outcome of the EU funded research projects. Many of the H2020 projects continue to focus on technology improvement of offshore wind turbines. For example, the project TELWIND reported a patent application. This project focuses on the development of a ground-breaking buoyant platform for offshore wind which allows to make a qualitative leap in the lowering of the construction and installation costs. ROMEO is another H2020 project which has already resulted in patent applications and which focused on reducing O&M costs of offshore wind farms.

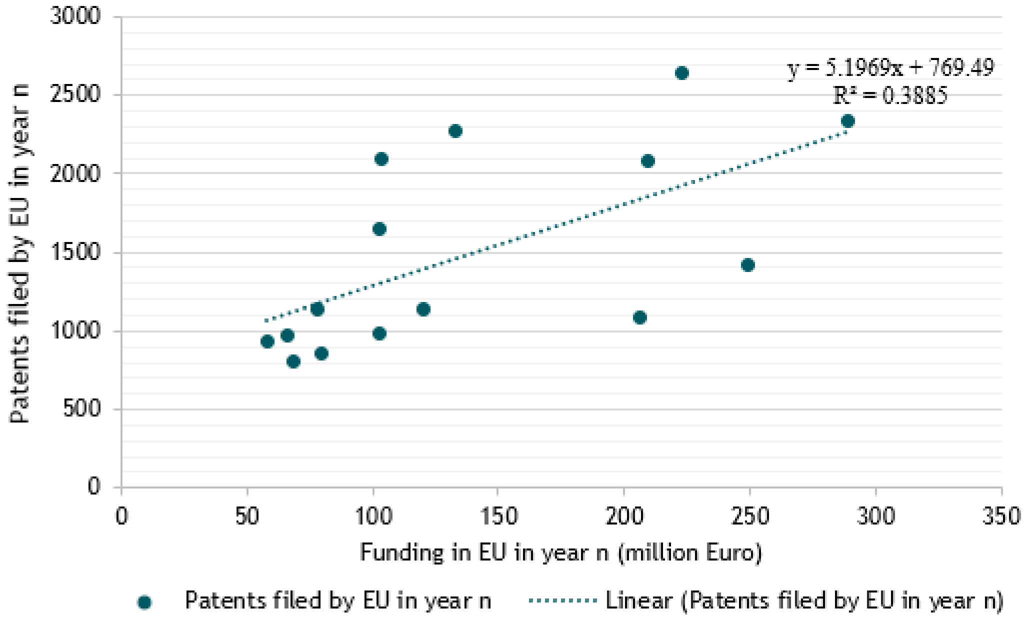
3.1.2 Effectiveness of R&D funding in producing new patents

In theory, higher R&D budgets in a region are expected to lead to an increase in the number of patents filed from that region. The extent to which this relation exists in the sector provides insights into the research objectives and the effectiveness of the research.

Figure 3.2 compares the total amount of patents filed to the amount of EU R&D funding (Member States + EU combined), accounting for a time lag between the moment of funding and the patent application. The highest correlation is however visible if no time lag is taken into account. Even then, there is no strong correlation between the number of patents and the amount of EU funding. This is in line with the findings for other RE sectors.

[9] IRENA INSPIRE (2018) Patent Evolution of Renewable Energy Technologies

Figure 3.2 Patent effectiveness



Notes: We tested a delay of 0, 1, 2, 3, 4 and 5 years for the patents filed from year 2000-2014. 2015 data of patents was excluded because the source (IRENA) mentioned it is common to have delays of 3 years from a patent application and the year is reflected in the database. The correlation went up when 2015 data was excluded. A delay of 0 years between funding year and patents filed showed the highest correlation (R^2 = 0.3885). We use the IRENA INSPIRE as a database. This sources draws upon the EPO PATSTAT database. The scope is based on patents filed worldwide and not only in the European Patent Office.

3.2 Publications

Research papers are a useful indicator to measure the output of R&D funding. Publications have a close relation with public R&D funding, allowing us to differentiate the effect of public R&D funding from private R&D funding. Furthermore, there is enough data available to make a comparison between the EU's performance and the rest of the world. Publications are categorised by country on the basis of the address of the author. If it has authors from different regions, the publication is counted for both regions.

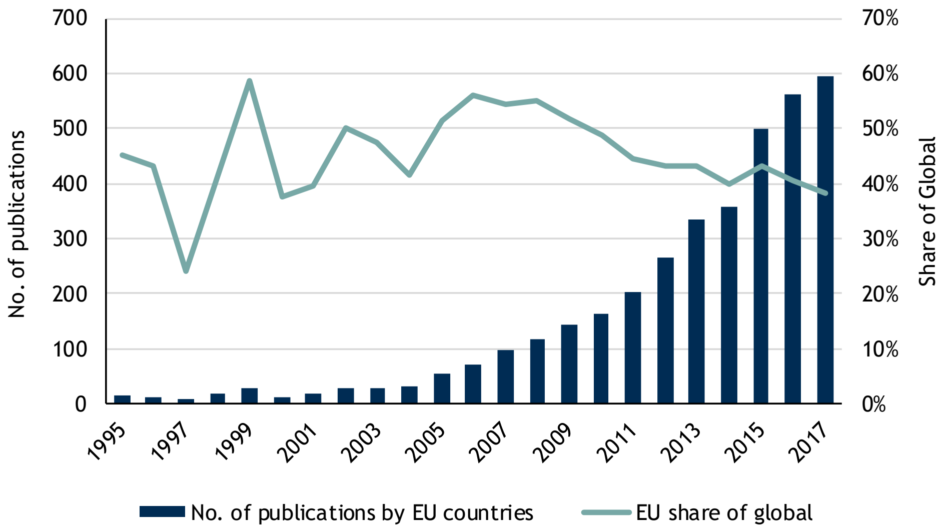
3.2.1 Evolution over time

Figure 3.3 shows the evolution of wind energy publications by EU-based authors over the years. The number of publications on wind energy had an upward trend over the years, similar to that of EU R&D funding for wind energy.

EU-based authors were involved in 43 % of the global publications between 1995-2017, making it the global leader. Outside of the EU, the largest number of publications came from the USA (22 %), China (16 %), and Canada (5 %). In recent years, researchers from China and the USA have increased their numbers of publications significantly, reaching around 220 publications per year, while still remaining at a distance from the EU (almost 600 publications in 2017).

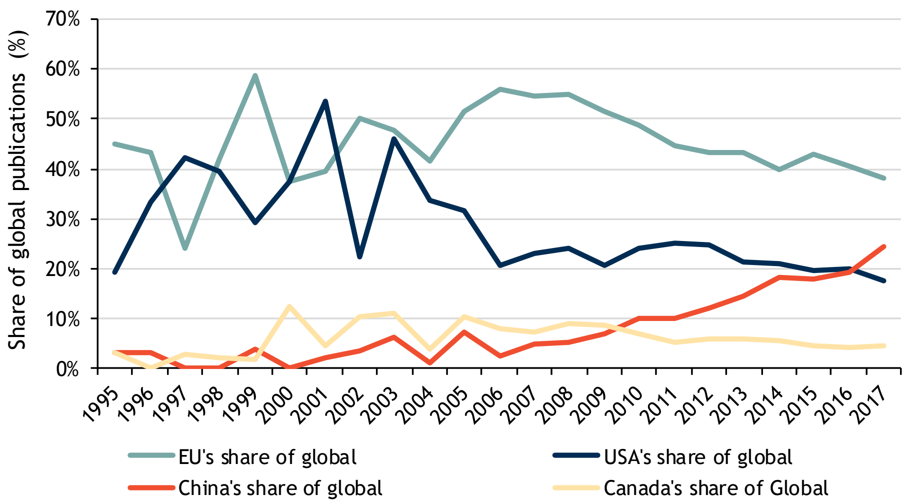
In the EU, the UK is leading with 1 038 publications between 1995 and 2017, followed by Spain (546), Denmark (530), Germany (476), and Italy (271). The top five Member States include four of the largest funders of R&D and recipients of EU funding, which suggest a relationship between public R&D funding and the number of publications.

Figure 3.3 Evolution of wind energy publications by EU countries (1995-2017)



Source: Web of Science (2018), using keywords: ('wind energy' or 'wind power') and ('onshore' or 'offshore' or 'blades' or 'farm') in the title, topics and abstract of articles between 1995-2017. The share of global refers only to those publications with an address listed. 1 % of the global publications had no address listed in that period of time.
Notes: One article can have multiple authors (therefore, also multiple countries). The count is the number of articles in which at least one author listed an EU Member State as their address.

Figure 3.4 Comparison of the share of wind global publications between key countries



Source: Web of Science (2018)
Notes: The shares of the different countries/regions are not cumulative since one article can have multiple authors/countries.

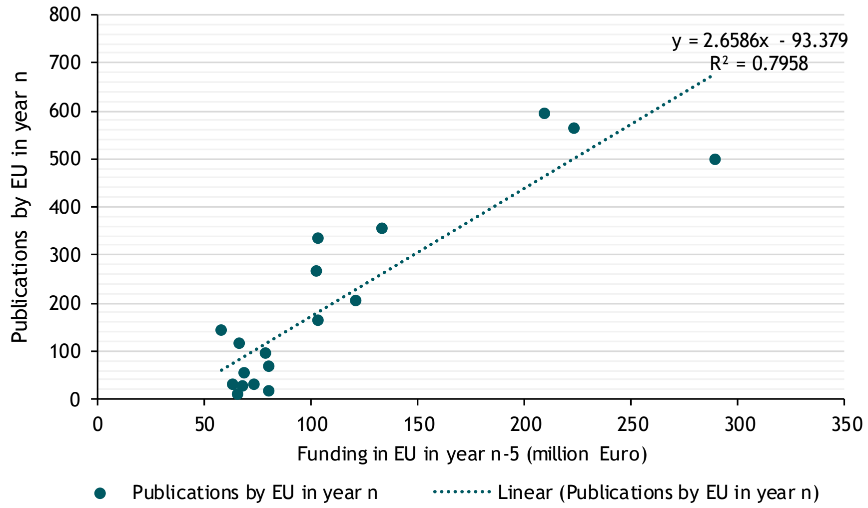
3.2.2 Effectiveness of R&D funding in producing publications

In theory, higher R&D budgets in a region are expected to lead to a higher number of publications from that region. The extent to which this relation exists in the sector provides insights into the objectives of the research and the effectiveness of the research.

Figure 3.5 compares the total amount of EU publications to the amount of EU R&D funding (Member State + EU combined), accounting for a time lag between the moment of funding and the publication. The number of publications correlates more closely to R&D funding than the number of patents does.

This is in line with the findings for other RE sectors and underlines that publishing is often one of the primary outputs of research projects.

Figure 3.5 Publication effectiveness



Notes: We tested the publication effectiveness of R&D funding for the period 1995-2015. Funding in EU includes EU funding and Member State funding. We tested different delays (0,1,2,3,4 and 5 years) to evaluate which one had the highest correlation. The highest R^2 was found using 5 years of delay (0.7958), while the lowest was obtained with no delay (0.6724).

3.2.3 Contribution of EU funding

Between 2008-2017[10] (FP5, FP6, FP7 and H2020), 268 publications explicitly reported benefitting from EU funding. This represents 8 % of the total number of EU publications in those years. Not all publications report their sources of funding, therefore it is likely that the actual figure is higher. Projects such as INNWIND.EU have made invaluable contributions to the sector, including through the publication of hundreds of academic publications since 2013. In addition to supporting academic excellence, INNWIND.EU project results have largely contributed to the development, performance and cost competitiveness of the offshore wind technology (see project spotlight box below).The importance of publications as a research output is confirmed by the responses to the questionnaire (see section 3.4), where publications were reported as the third most common output of EU-funding. For example, AVATAR is a FP7-ENERGY project that reported publications as one of the outcomes of its EU-funded research. The project focused on validating design methods for large wind turbines (10-20 MW). The project brought together a consortium consisting of world class experts from the European Energy Research Alliance (EERA) Joint Program Wind working in the aerodynamics subprogram.

[10] Before 2008 no information was collected on the funding sources relevant to the publication. From 2008 onwards, the number of publications that provided this information increased, but especially in the early years (2008-2010) few publications reported this information.

Project spotlight: INNWIND.EU (Innovative Wind Conversion Systems (10-20 MW) for Offshore Applications

INNWIND.EU is a FP7 project and successor of the UpWind project (FP6). The project brought together participants from 28 leading industrial and research institutions from EU member states and the US and focused on one of the main challenges of the offshore wind industry: the economy of scale of the wind turbine generator. It concluded that it is more cost-efficient to install offshore turbines with a high rated capacity of 10 MW or more in deep waters and further from shore. INNWIND.EU research focused on innovations on, and demonstration of, key components of the 20 MW wind turbine. Innovations related to the rotor aerodynamics, the design of 100m blades, direct drive and supraconducting generators and new fixed and semi-floating offshore substructures. INNWIND.EU largely contributed to the development, performance and cost competitiveness of the offshore wind technology.

Source: http://www.innwind.eu *and interview with Peter Hjuler Jensen, Deputy Head of DTU Wind Energy*

The top EU organisations in terms of publications are listed in Table 3.1, together with their rank in terms of funding received through the EU Framework Programmes. It shows that three out of the top 5 publishing organisations also rank among the top recipients of EU funding, which does show that EU funding supports academic leadership.

Table 3.1 Top organisations in the EU contributing to wind energy publications (1995-2017)

Rank	Organisation	Country	No. Publications	EU funding rank
1	Technical University of Denmark	Denmark	304	1
2	Aalborg University	Denmark	142	21
3	University of Strathclyde	UK	111	30+
4	Delft University of Technology	Netherlands	91	17
5	Centre National de la Recherche Scientifique (CNRS)	France	80	30+
6	Polytechnic University of Catalonia	Spain	78	30+
7	Helmholtz Association	Germany	70	30+
8	University Of Manchester	UK	60	30+
9	National Technical University of Athens	Greece	58	30+
10	Universidade de Lisboa	Portugal	55	30+

Source: Web of Science (2018)

3.3 Start-ups and spin-offs

The creation of start-ups and spin-offs is another potential impact of research projects, which can function as an important link between research and industrial development. However, as start-ups and spin-offs are not reported consistently, questionnaire results are used to provide insight into these impacts.

Five out of the 35 projects that responded to the questionnaire reported the creation of a start-up or spin-off as a result of participating in an EU-funded project. Two of these projects (REACH AND WTSS) are highlighted in the 'project spotlight' boxes throughout this report. The other three projects are listed below and were funded under instruments that are meant to support existing start-ups.

- ABLE: developed a patented technological solution to extend the lifespan of wind turbine blades. The project received H2020 support in developing a company strategy, business model and intellectual property protection strategy. In addition, the project received help in the industrial scaling of its product, operations, sales and international growth of the company (for more information visit: http://www.regenblade.com/).
- AIRCRANE: the objective of the project is the demonstration of the feasibility (technological and economic) of a self-climbing telescopic crane for the construction of wind turbines. H2020 funding focused on developing appropriate tools to introduce the technology to the market and contributed to the development of a start-up and two patent applications.
- WELL: focuses on developing a business model for a patented system (in Europe and the USA) that permits the replacement of wind turbine blades without the need for large tonnage cranes. The system is based on a ‘telescopic lift’ principle and should have an impact on reducing the O&M expenses of wind farms. The project has focused on the scalability and commercial expansion strategy (in Europe and globally) of the company (for more information visit: http://koalalifter.com/).

Overall, the EU has funded 46 SMEs in the wind energy sector through the SME instrument (part of H2020) which aims to support innovative ideas developed by small and medium-sized companies, the development of their technologies, as well as the expansion and internationalisation of the companies.

Projects in the spotlight: REACH, AMPYXAP3, EK200-AWESOME, and NextWind

Resource Efficient Automatic Conversion of High-Altitude Wind (REACH) is a H2020 project funded under the H2020 pillars “Industrial leadership” and “Societal Challenges”. REACH is a result of the Airborne Wind Energy System Modelling, Control and Optimisation (AWESCO) research project that led to the development of a pilot project on airborne wind technology. It developed the airborne kite from technology readiness level (TRL) 1 up to 5. The project is now aiming at TRL7, with a prototype that will be installed for long-term operational demonstration. REACH is an example of a successful EU funded project that started with research and evolved to technological validation in real environmental conditions.

Similar projects funded by the SME Instrument include AMPYXAP3, EK200-AWESOME and NextWind, led by two SMEs (Ampyx Power and Enerkite). These are also consortium partners in the AWESCO research network. This setup shows that EU financing instruments support both technological development and commercialisation.

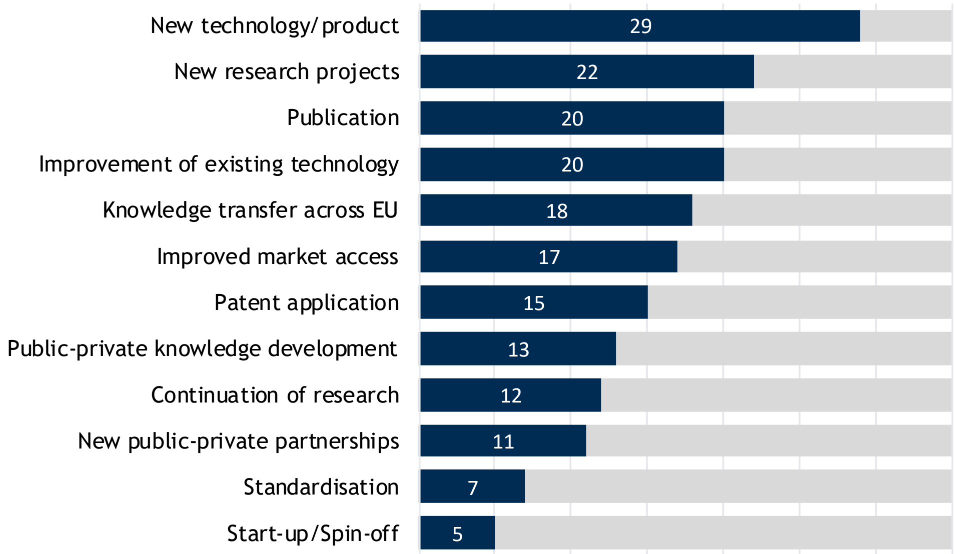
Source: https://cordis.europa.eu/project/rcn/199241_en.html and interview with Roland Schmehl, Associate Professor, Delft University, Kite Power Research Group

3.4 Other research outputs

While patents, publications and start-ups/spin-offs are often the most tangible and easily quantifiable outputs of EU-funded research of RE technologies, there are many other outputs that contribute to the development of a sector. In order to get a better understanding of these other impacts, a questionnaire was sent out to project coordinators of EU-funded R&D projects. 163 project coordinators were contacted out of which 35 replied.[11] The results of the questionnaire are presented in Figure 3.6 below.

[11] In terms of budget, the projects that responded to the questionnaire represent 18,8 % of the total EU funding budget for wind energy (excluding funding for projects under ‘multiple RE’). The projects that responded to the questionnaire represent the following topics within the FPs: FP7 ENERGY (2), FP7 PEOPLE (2), H2020 ERC-StG (1), H2020 FTIPilot (3), H2020 ICT (1), H2002 LCE (4), H2020 MSCA-IF (2), H2020 MSCA-ITN (4), H2020 NMBP (1),H2020 SIE (9) and H2020 SMEInst (6)

Figure 3.6 Impacts of EU funding based on questionnaire results (out of 35 responses in total)



Source: Own elaboration based on questionnaire conducted as part of this study.

Based on the results of the questionnaire, a common output of EU-funded projects is the development of new technologies or products (29 out of 35 responses) and the improvement of existing technologies or products (20 out of 35). These findings are consistent with the analysis in Section 2.1.2 on the evolution of research topics where component (product) development has been made a priority from FP5 onwards. Examples of technology advances realised by EU-funded projects include the development of larger turbines (e.g. UpWind), more lightweight and reliable generators (SUPRAPOWER) and new fixed and semi-floating offshore substructures (e.g. INNWIND.EU). Furthermore, new software to support the mapping of wind resources in the Baltic, Irish and North Sea areas was developed by NORSEWIND whereas EERA-DTOC created a software tool to help in minimizing costs of planning, developing and operating offshore wind farms.

Project spotlight: NORSEWIND

NORSEWInD is an EU 50 % funded project of 7.6 million to provide a reliable offshore wind atlas of the North, Irish and Baltic Seas. The project was funded under the FP7-ENERGY programme. The project developed a suite of techniques to integrate physical wind measurement data from a network of LIDAR (Light Detection and Ranging) on offshore installations and to upload these data to satellite. Northern seas wind index database project helped increasing the accuracy of data for the wind power forecasting system. The increased accuracy of the meteorological parameters has a direct impact on the precision of the wind resource and the short-term wind power prediction for a better power forecast of offshore wind farms.

See annex A for a detailed case study on the NORSEWIND project.

Other commonly reported outputs include the creation of new research projects (22 out of 35) and the continuation of research that may otherwise be discontinued (12 out of 35). Throughout this report a couple of examples of projects that build on results of other projects are highlighted (see AWESCO and REACH; UpWind and INNWIND.EU). In addition, several examples are provided to show the development of technologies from the experimental stages to maturity such as in the case of fixed-bottom offshore. Moreover, some of the EU-funded projects allowed for continuity and further improvements to already well developed projects funded by means other than the EU FPs. For example, DEMOWFLOAT builds on the work of WindFloat Phase 2, a joint venture which was also supported by the Portuguese funding program for innovation. Conversely, the results of INNWIND. EU are being used by several H2020 projects such as ReaLCOE, Life50+ and EcoSwing and by national and private projects like the Danish projects JacketForce and EUDP InduFlap 2, the U.K. project DemoWind CHEG or the Vestas commercial project on a 4-rotor single turbine.[12]

EU-funded projects also contributed to the creation and strengthening of public-private partnerships, which is important for assuring that the research is relevant for the market and contributes to strengthening the EU industry. Eleven out of 35 projects reported the establishment of a new public-private partnership as a result of the project. As discussed previously, the wind industry has been very interested and active on wind energy research since FP5 (the top recipients of EU funding include four private companies). In addition, the design of the R&D Framework Programme is akin to creating consortia that often include public institutions and private companies. Based on this, thirteen out of 35 projects also reported joint knowledge development with the private sector as an output. These public-private collaborations can for instance be achieved through joint training of researchers undertaken by academia and industry, as in the case of the H2020 project SPARCARB. Joint initiatives not only result in a collaboration between private and public enterprises but also support academic excellence.

Seventeen out of 35 respondents reported that their EU-funded project has benefited from improved market access for participants. This is an important outcome, as market barriers must be eradicated in order to commercialise the developed technologies successfully and strengthen the European wind industry. More than half (18/35) of the respondents also reported that the project had a positive impact on knowledge dissemination across Europe, which should be expected from projects that include consortiums made up of partners from different countries where international cooperation is required. This is an important outcome of the R&D Framework Programmes as wind energy knowledge and technology are highly concentrated in a small number of EU countries.

3.5 Conclusions

The significant Member State and EU budgets for wind energy have been effective in establishing and maintaining a global leading academic position. The EU is number one in terms of publications and has been able to preserve this leading position in spite of the strong growth in publications from China and the USA.

R&D budgets show a modest correlation with the patenting activity. The EU's share of global patents has been declining consistently. In recent years a decline in the absolute number of EU patents has also been observed. This could be partly attributed to the maturity of EU companies which may require less innovations for the continuation of their business. Nevertheless, the downward trend is worrying and may be an indication of diminishing technology leadership of the EU wind energy sector.

EU-funded research projects have also enabled the creation of start-ups and spin-offs. Additionally, more than 40 SMEs have been supported in their development from a start-up to market entry and further growth.

[12] INNWIND.EU presentation imparted by Anand Natarajan, Brussels 2018

Notable research outputs of EU funding in the wind sector include new technology/product developments and improvements of existing technologies. In addition, as discussed under section 2.1.2 and exemplified by a number of projects highlighted in this chapter, EU-funded R&D projects made significant contributions to the development of increasingly large wind turbines (AVATAR, INNWIND.EU, UpWind) and the development of technology for the fixed bottom and floating offshore markets (TELWIND, INNWIND.EU). In addition, funding has facilitated cooperation and knowledge sharing between academia and industry and resulted in new public-private initiatives.

4 Technology development

One of the core objectives of R&D funding on RE technologies is to contribute to the development of the technology to make it cost competitive and allow for its increased uptake. The impacts on technology development can be assessed technologically, or from an economic point of view, looking at the costs, performance and competitiveness of the technology. This section focuses on key indicators to assess these aspects.

4.1 Capex

Capex (capital expenditure) refers to the initial investment costs of wind energy assets. Cost-reducing innovations can contribute to a downward trend in capex, which in turn can make the sector more cost competitive and allow for increased uptake of the technology. One of the main limitations of this indicator is that capex is highly location- and technology-specific, and will therefore vary between projects. To be able to provide an overview of the evolution of the capex over time, we consider global historic estimations of capex, including the estimations for regions outside the EU.

Capex of wind energy technologies can be split into the costs of the wind turbines, the balance of plant, and financial costs. It varies from EUR 905/kW to EUR 5 205/kW (see Figure 4.1).[13] The most recent time series from IRENA shows a clear downward trend for onshore wind from EUR 1 665/kW in 2010 to EUR 1 334/kW in 2017. As mentioned in Section 2.1.2, extensive research on component development since FP5 has contributed to improvements in the design, manufacturing and efficiency of wind turbines and other components. Since FP5, projects such as LOWCOST2BLADE2MW focused on decreasing the costs of wind turbines. During FP6 NEWGEN3MW focused on developing a 3 MW direct drive generator. Such component improvements are currently contributing to lower equipment costs and thus lower capex. Increasing wind turbine size has been one of the main drivers of cost reductions. The general trend is to upgrade designs from turbines of less than 1 MW to 2.5-3.5 MW turbines.[14]

The trend in the capex for offshore wind energy is less clear. Capex for offshore wind is about twice as large as for onshore wind. In the early days of offshore wind, the easiest locations (i.e. close to the coast and in shallow waters) were developed, and the technology was more or less a copy of onshore wind technologies (e.g. CLOWEBS-2000, OPTI PILE, 5MW-OFFSHORE-WEC). This kept capex relatively low. However, these first offshore projects suffered very high and unexpected operational expenditures (see section 4.2).

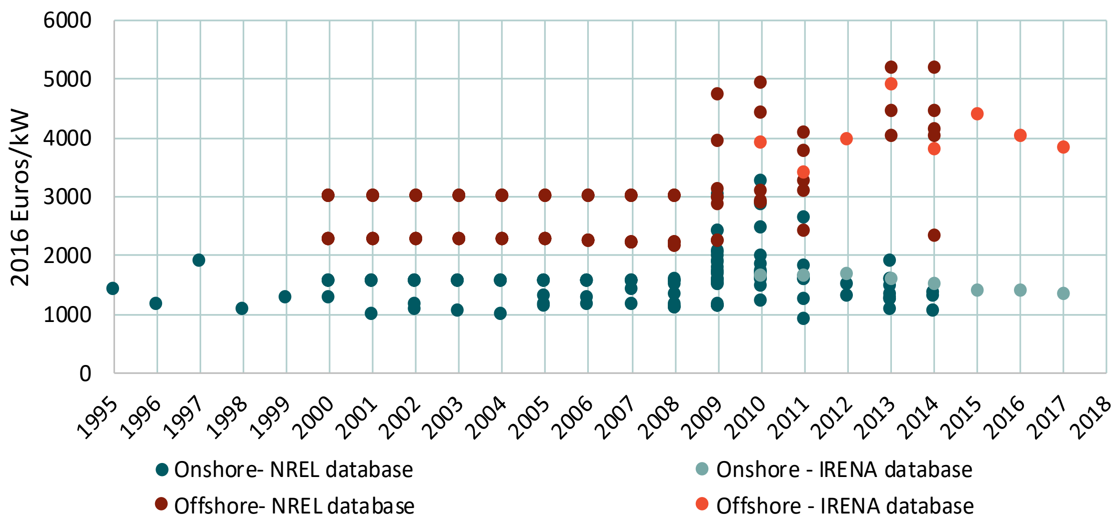
The subsequent phase of market expansion saw an increase in capex, as more challenging zones were developed and technological issues from the early projects required substantial technological evolutions (e.g. offshore purpose-made equipment). Turbines became larger and more efficient. However, the supply chain that served offshore wind farms was immature and operated on a project basis. As such, the larger wind turbines that flooded the market drove up the installation costs. The

[13] Wind energy capex is very location dependent due to differences e.g. between onshore and offshore, type of land/soil and infrastructure available, and specifically for offshore how far from the shore and water depth. The capex will also strongly depend on the technology of choice e.g. direct drive vs. gearbox.
[14] EC (JRC), Wind Energy Status Report- 2016 Edition

industry developed rapidly after 2010 with products and services specifically designed for offshore wind, while improvements in the supply chain provided a large number of opportunities to reduce capital and operating costs and increase power generation (e.g. DEEPWIND, INNWIND.EU, LEANWIND). For example, the WTSS project contributed to lower capex (and opex) by developing a new offshore floating wind turbine support structure that can optimise installation, commissioning, O&M and decommissioning of wind farms. The development of a new superconductor-based generator during the project SUPRAPOWER can lower the overall turbine head mass and results in lower size and costs of offshore wind turbines.

The capex for offshore wind began to decrease rapidly after 2015 mainly due to increased unit capacity. In this way, balance of plant and installation costs per kW were also drastically reduced, leading to LCOE reductions in the order of 30 % to 50 % compared to 3 years ago (see section 4.3). As the offshore wind industry gains experience, the main risks such as turbine availability, installation costs and timing, and O&M will be better managed, thus resulting in an overall lower risk profile and lower capital costs.

Figure 4.1 Evolution of wind energy capex for electricity generation (1990-2017)



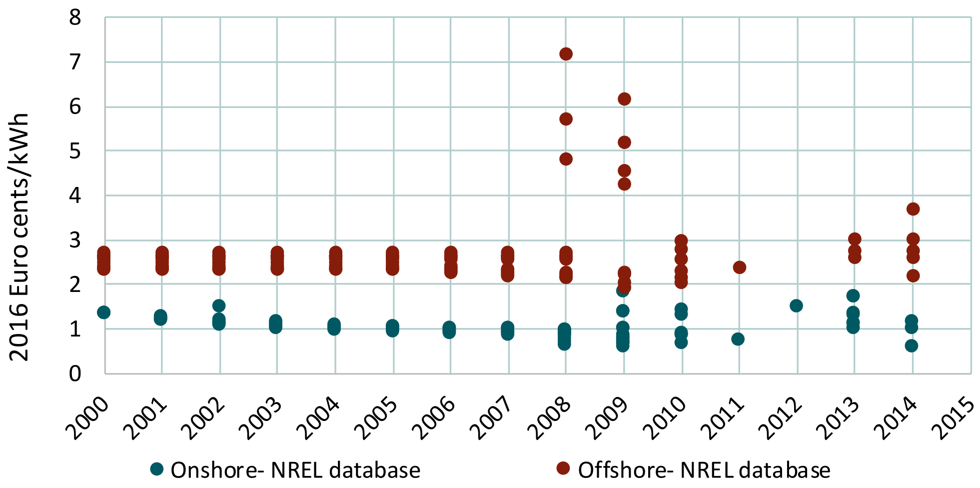
Notes: All figures are global, unless specified otherwise.
Data was obtained from the NREL and IRENA databases. IRENA's data is the "Global weighted average" based on their database with ~15,000 projects. The NREL data is based on collection of historic estimations from publications and information collected from energy projects. For sources with more than one estimation (for example a range of minimum and maximum), each estimation is considered as a data point.

4.2 Opex

Opex (operational expenditure) includes fixed and variable costs for operation and maintenance (O&M) of the plants. Similar to capex, cost-reducing innovations can contribute to a downward trend in opex, which in turn can make the sector more cost competitive. Opex is less location-specific than capex, but can show large variations between sub-technologies due to other reasons.

Consistent information on O&M is difficult to obtain as cost data (management costs, land lease, etc.) are not systematically collected or reported.[15] Figure 4.2 shows the evolution of global opex estimates for wind energy. These range from 0.6 to 1.8 EURct/kWh for onshore wind energy. Opex are substantially higher for offshore wind turbines, ranging from 2 to 4 €ct/kWh.

Figure 4.2 Evolution of wind energy opex for electricity generation (global figures, 2000-2015)



The technology improvements and installation experience contributing to lower capex for offshore wind also resulted in a reduction of the opex, as suppliers responded to growing demand for larger, more efficient projects, and the technology became better suited for offshore conditions. EU-funded projects related to O&M have been funded much more prominently from FP7 onwards. Initial wind energy research was focused on technological improvement based on wind turbine and balance of plant design; as operational capacity increased, more emphasis was needed on O&M aspects.

In this sense, FP7 projects such as SUPRAPOWER and LEANWIND started to address the challenges associated with O&M cost reductions. The development of a new, lightweight and robust wind turbine generator by SUPRAPOWER is expected to reduce O&M and transportations costs and increase the lifecycle of the offshore wind farms. LEANWIND's objectives also included cost reductions across the offshore wind lifecycle and supply chain through the application of 'lean' principles to the sub-structure and vessel design, wind farm logistics and O&M (see project spotlight box below).

[15] IRENA (2018) Renewable Power Generation Costs in 2017

Project spotlight: LEANWIND (Logistic Efficiencies And Naval architecture for Wind Installations With Novel Developments

LEANWIND was a 4-year project that started in December 2013. It was led by a 31-partner consortium and has been awarded EUR 10 million by the European Commission against a total cost of EUR 15 million. The primary objective was to spur cost reductions across the offshore wind farm lifecycle and supply chain through the application of lean principles and the development of state of the art technologies and tools. 'Lean' principles were originally developed by Toyota to optimise processes in manufacturing industries; these principles of optimisation and efficiency have subsequently been adopted by many other industries to remove wasteful stages and streamline processes. This new 'lean' paradigm has been applied to each of the critical project stages: logistical processes, shore-based transport links, port and staging facilities, vessels, lifting equipment, safety and O&M. The project has resulted in the development of new and improved concept designs for installation vessels to cater for turbines of up to 10 MW. The project reported possible reductions in the total farm lifetime cost of far offshore sites (60 m water depth) by 18% with the use of the LEANWIND semi-submersible platform. The logistics and financial models developed during the project are already being used by EirWind, an industry led research project focused on advancing the offshore wind industry in Ireland.

Source: www.leanwind.eu and presentation by Ms. Rachel Chester at the "Wind energy conference: the impact of EU R&D funding" Brussels, November 2018

4.3 LCOE

The Levelised Cost of Energy (LCOE) is an indicator that can compare project costs of different energy generation technologies.[16] Similar to capex and opex, cost-reducing innovations can contribute to a downward trend in LCOE, which in turn can make the technology more cost competitive. While LCOE is a relatively comprehensive measure of the technology's costs, it does not include all the costs for delivering energy, such as ancillary services and transmission and distribution costs.

Figure 4.3 and Figure 4.4 show the evolution of wind energy LCOE. NREL estimates for onshore wind energy show a rapid decline from 2000 to 2008, a fluctuating pattern up to 2013, and further cost decreases from 2013 to 2014 with the lowest estimates below 3 EURct/kWh. The average of the estimates provided by NREL indicate a cost reduction of approximately 60 % between 2000 and 2014. The more recent global estimates provided by IRENA show some fluctuations through the years but an overall cost decrease of 20 % between 2010 and 2017, illustrating the effect of the continued efforts to reduce costs and improve the performance of wind energy technology.

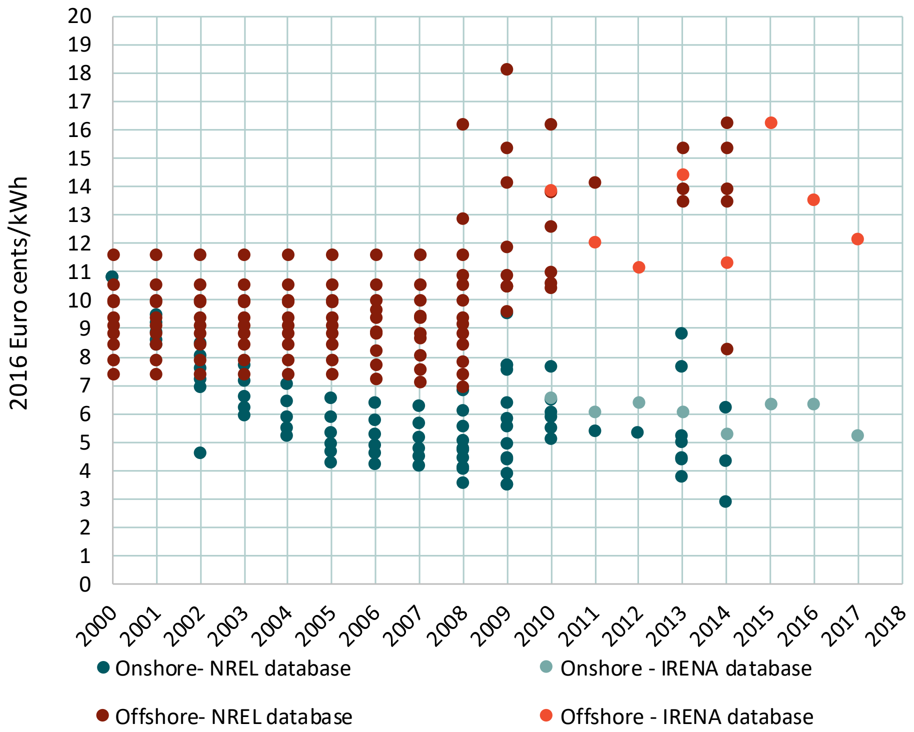
NREL estimates for offshore wind energy LCOE show an upward trend from 2007 to 2011. As mentioned in section 4.1, the first offshore wind energy projects were placed at the easiest locations and used onshore technologies which kept capex down but resulted in unexpected operational expenditures later on. Hence, the older cost estimates are probably not fully reliable nor representative of the costs for offshore wind energy at that time. Furthermore, installed capacities for offshore wind energy were very limited up to 2011. Relatively recent IRENA estimates show a fluctuating pattern with estimates ranging

[16] The levelized cost of energy (LCOE) is an indicator of the price of electricity required for a project where the revenues would equal costs, including making a return on the capital invested equal to the discount rate. The main factors affecting this indicator are capital costs, fixed and variable O&M costs, the capacity factor, the discount rate and the lifetime of the investment. The IRENA Cost Database calculation uses a simple discounted cash flow method (DCF) to take into account the value of money for the capital expenditure. Taxes, subsidies or other incentives are not included. The NREL data uses the Capital Recovery Factor (CRF) method, to annualise the Capital Costs.

from 12 to 16 EURct/kWh. These estimates are still slightly higher than the agreed strategic LCOE targets (at final established in the SET-Plan for fixed offshore wind of less than 10 EURct/kWh by 2020 and less than EURct/kWh by 2030.[17] Nonetheless an encouraging and noticeable LCOE decrease (-25%) can be discerned for the three most recent years. Costs are coming down largely due to economies of scale. This trend is expected to continue, to the point where developers are expected to increasingly be able to operate without subsidies, such as demonstrated by recent contracts signed in the Netherlands and Germany for subsidy-free offshore wind, to be operational by 2022 and 2024 respectively.

In comparison, LCOE for solar PV was 10 EURct/kWh in 2017. The LCOE for conventional hydro is estimated between 0.9 and 17.2 EURct/kWh and that of small hydro (less than 15 MW) between 1.5 to 19.5 EURct/kWh. In 2017 electricity from bioenergy was in the range 4.5 EURct/kWh and 15 EURct/kWh). In terms of fossil fuel based electricity generation the LCOE of brown coal lies between 4.6 and 8.0 EURct/kWh, of hard coal 6.3 to 9.9 EURct/kWh and of combined cycle power plants 7.8 to 10 EURct/kWh.[18] From this numbers it is clear that onshore wind is a competitive source of electricity and even offshore projects are starting to achieve LCOE values that can compete with other sources of electricity.

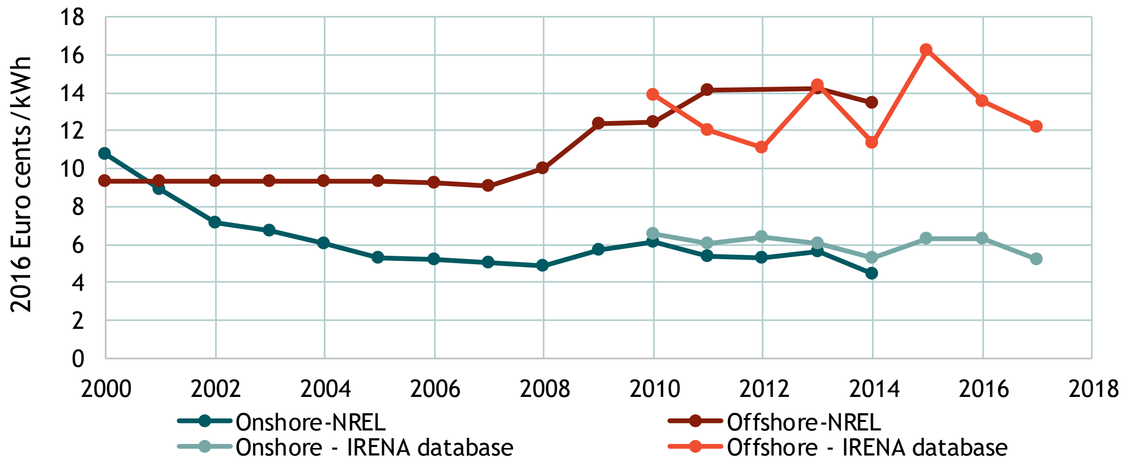
Figure 4.3 Evolution of wind energy LCOE for electricity generation (all data points, 2000-2017)



Notes: LCOE was calculated for the NREL database values using the market values of NREL (19-54% capacity factor and 20 years of plant lifetime). A discount rate of 7.5% was used as per IRENA's methodology, and the capex was annualized using the Capital Recovery Factor Method. LCOE from IRENA was obtained directly from the database and converted to EUR_{2016}.

[17] SET-plan Steering Committee (2018) Offshore Wind Implementation Plan
[18] Fraunhofer Institute for Solar Energy Systems (2018) "LCOE Renewable Energy Technologies"

Figure 4.4 Evolution of wind energy LCOE for electricity generation (yearly averages, 2000-2017)



Given the capital intensity of offshore wind farms, the cost of capital is a key driver of the LCOE, which can explain the trend in offshore wind LCOE to a large extent (see Section 4.1).

During FP7, several EU-funded projects supported component improvements of large wind turbine generators. Examples include INNWIND.EU and SUPRAPOWER (see projects spotlight box below). The development of lightweight and more resistant components resulted in more reliable wind farm generators which in turned helped to lower capital and operational costs. In addition to component improvement, research during FP7 also focused on providing cost reductions across the offshore wind farm lifecycle and supply chain. The LEANWIND project is an example of this.

Project spotlight: SUPRAPOWER

SUPRAPOWER was an EU FP7-ENERGY funded research project that developed a new compact 10 MW superconductor-based generator as a major innovation in offshore wind turbine technology. This generator has been patented in Europe (Spain, Germany, UK and France) and the USA. This has resulted in 30 % weight reduction of the generator resulting in easier installation processes, the elimination of the gearbox and hence a more reliable and efficient drivetrain, the reduction of maintenance requirements and the increase of efficiency, leading to a reduction of the overall LCOE. The project has experimentally validated the superconducting generator concept on a small-scale machine designed and built for this purpose.

See annex A for a detailed case study on the SUPRAPOWER project. Source: http://suprapower-fp7.eu

4.4 Conclusions

The costs of wind energy have decreased significantly over the past 20 years, leading to a situation in which onshore wind energy is competitive with other electricity sources. Thanks to performance improvements and capex reductions, the LCOE for onshore wind energy decreased by more than 50 % between 2000 and 2017 (from above 10 EURct/kWh to 5 EURct/kWh).

For offshore wind, the costs increased in the early years of deployment (2007 to 2015) due to a range of factors including the move towards deeper waters and the need to adapt onshore wind energy technology to offshore conditions. From 2015 to 2017 a clear downward trend in the LCOE of offshore wind energy is visible, to be attributed largely to economies of scale. A trend that is expected to continue.

EU-funded R&D contributed to the cost reductions in the wind energy sector in several ways. It supported the development of offshore wind energy technology in general and the development of lightweight materials and larger wind turbines specifically. Furthermore, EU-funded projects contributed to cutting logistical costs for deployment and improved the reliability of wind turbines, thereby reducing operational costs.

5 Social, economic and environmental impacts

Public R&D funding for RE technologies can lead to several social, economic and environmental impacts. In this section we evaluate a range of indicators that provide insight into these impacts: installed capacity, annual generation, industry turnover, imports/exports, jobs and share of energy consumption. A direct link between these indicators and R&D funding is however hard to establish, as the impact of R&D funding is confluent with numerous other factors that drive or prevent deployment. Thus, the indicators presented in this chapter cannot be directly attributed to R&D funding, rather they provide a useful indication of the developments in the European wind energy sector.

5.1 Installed capacity

Installed capacities of wind energy provide (near) carbon free energy that prevents, to a large extent, the need for fossil fuel-based energy. As such, it could be used to assess environmental impacts. Installed capacity refers to the maximum installed generation capacity and is expressed in MW for electricity production.

5.1.1 Current installed capacity

Wind energy has become the largest renewable electricity source in the EU in terms of installed capacity with 168 600 MW in 2017. One third (31 %) of global installed wind capacity is in Europe.[19] In the EU, wind power is only absent in Malta. Germany has the most capacity, at 49 600 MW (32 % of the EU total), followed by Spain (15%), the United Kingdom (11 %) and France (7 %). Together, they account for 65 % of the EU total.

The majority of the installed capacity consists of onshore wind (92 %) (see Figure 5.2). Offshore wind capacity is however growing and has increased from only 67 MW in 2000 to over 12 000 MW in 2016.[20] Europe is the global leader in offshore wind and accounts for 86% of global installed capacity (UK alone is responsible for 36 % of the global installed capacity).[21] As said, the United Kingdom is the leading Member State (42 % of EU's installed capacity), followed by Germany (33 %), Denmark (10 %), the Netherlands (8 %) and Belgium (6 %). Most of the offshore wind farms are built in the North Sea, with significant deployment in the Irish Sea and Baltic Sea as well. These offshore locations are rather shallow and traditional offshore foundations can be easily installed (see project spotlight box on NORSEWIND in section 3.4). For fixed-bottom foundations, monopiles are expected to continue being the most common choice.[22]

As installed capacity grows so does the need to explore more challenging, deep-water locations. For such cases floating offshore technologies are usually best suited as they can reach potentially very deep waters where bottom mounted foundations are not feasible; in deep waters where fixed offshore is possible, floating offshore will likely be financially advantageous.

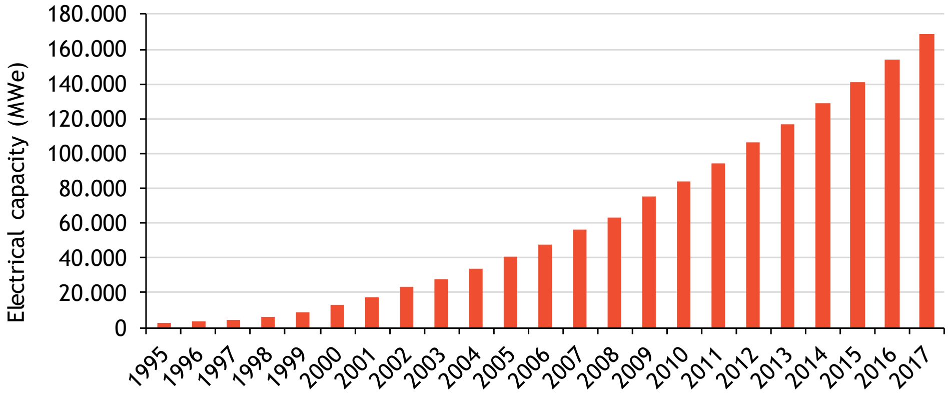
[19] Deloitte and Wind Europe (2017) Local impact, global leadership: The impact of wind energy on jobs and the EU economy. Available at https://windeurope.org/wp-content/uploads/files/about-wind/reports/WindEurope-Local-impact-global-leadership.pdf
[20] Figures based on IRENA database.
[21] Deloitte and Wind Europe (2017) Local impact, global leadership: The impact of wind energy on jobs and the EU economy. Available at https://windeurope.org/wp-content/uploads/files/about-wind/reports/WindEurope-Local-impact-global-leadership.pdf
[22] EC (JRC), Wind Energy Status Report- 2016 Edition

5.1.2 Evolution over time

Installed capacity of wind energy in the EU has grown significantly over the past 20 years, from only 2 400 MW in 1995 to 40 000 MW in 2005, reaching 168 6000 MW in 2017 (see Figure 5.1). The number of Member States with wind power installed has also risen from 15 in 1995 to 27 in 2016.

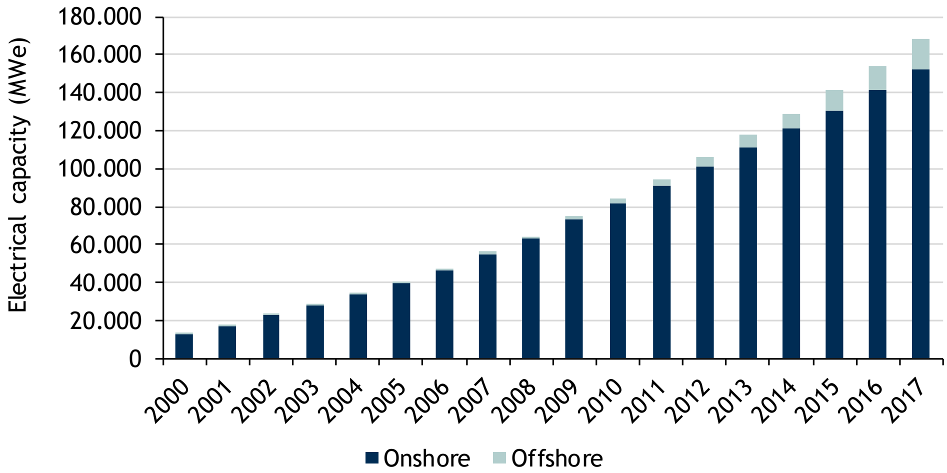
In 1995, Germany, Denmark, the Netherlands, the United Kingdom and Spain had the largest wind power capacity (these countries are also the largest R&D funders). Over the years, deployment in France, Italy, Sweden and Poland picked-up while in Denmark and the Netherlands cooled down. In parallel to the deployment of new wind farms, repowering with more efficient wind farms is gaining traction, especially in countries with high installed capacities and scarcity of suitable deployment areas.

Figure 5.1 Installed capacity of wind energy plants in the EU



Source: Eurostat (2018)

Figure 5.2 Installed capacity of wind energy plants in the EU by sub-technology



Source: IRENA (2017)

As installed capacities increased, newer offshore parks had to be installed farther away from the coast in deeper waters. The costs for traditional foundations, which are fixed to the seabed, become prohibitive in waters deeper than 50 m. Next to the opening up of new shallow zones for offshore development in the North Sea and the Baltic Sea, where traditional foundations can easily be applied, there is other potential in more difficult sites (e.g. Atlantic, Mediterranean, further offshore) that require floating solutions. EU R&D contributed to the development of floating offshore wind technology through various projects, including FLOATGEN, which was designed as a starting point for the development of commercial floating wind farms and demonstrated a multi-megawatt floating wind system in the Mediterranean sea (see project spotlight box below). In a similar way, the DEMOWFLOAT project demonstrated the performance and reliability of a new floating structure called WindFloat through the installation of a pilot 2MW turbine in Portuguese waters. Another example is ICFLOAT which developed models for analysing the stability, efficiency and feasibility of floating wind turbines.

Project spotlight: FLOATGEN

FLOATGEN was an FP7 project that developed and deployed a 2 MW floating turbine foundation in the Atlantic Ocean as a precursor to the installation of commercial offshore wind farms. The project focused on the expansion and the development potential of offshore wind farms into windier and deeper waters that were not commercially viable. The main result relied in the design of a patented floating foundation, allowing for a simplified installation and hence leading to cost reductions. The 2 MW floating offshore wind turbine Floatgen was tugged to its permanent offshore installation site in France on 15 May 2018.

See annex A for a detailed case study on the FLOATGEN project.

Project spotlight: ICFLOAT (Coupled fluid-solid numerical modelling for deep-water and far-offshore Floating wind turbines using an adaptive element method

ICFLOAT developed an open-source code numerical model to analyse the stability, efficiency and feasibility of floating wind turbines, as well as the interactions between fluids and floating solids. Computer models are suitable because they can analyse several different configurations thereby limiting expensive laboratory or onsite testing. In addition to targeting floating wind turbines, the work directly impacts on other types of marine renewable energy devices (e.g. tidal turbines, wave energy converters) and can be applied to a wide range of applications, such as for example, the air flowing around an airplane or the blood circulating in arteries.

Source: https://cordis.europa.eu/result/rcn/143902_en.html

Project spotlight: DEMOWFLOAT/Windfloat Atlantic

DEMOWFLOAT was an FP7 project that demonstrated the performance and reliability of the WindFloat technology with a 2 MW pilot turbine in Portugal. WindFloat uses innovative floating structures that enable the harvesting of abundant wind resources in deep waters where bottom-mounted foundations are not feasible. The EU supports the technology on its path from prototype to full commercialization through the 25 MW WindFloat Atlantic project, which benefits from a EU-backed loans of 60 million euro by InnovFin Energy Demonstration Projects.

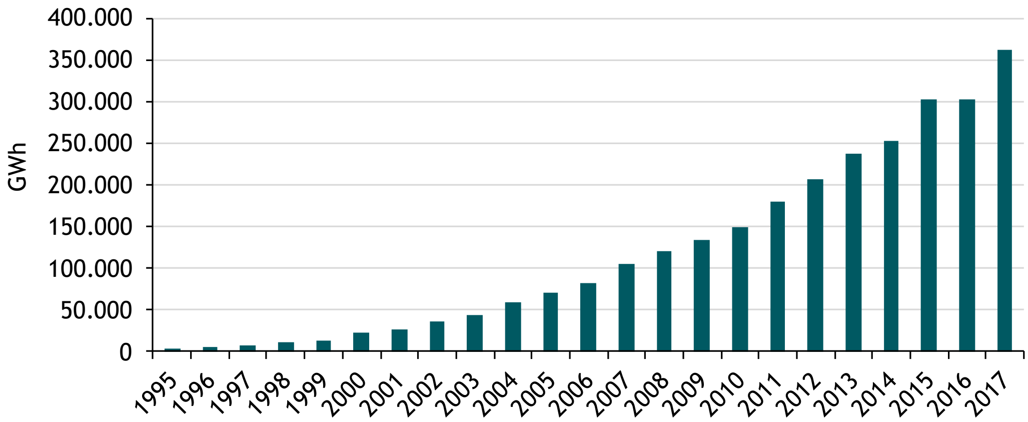
Source: European Commission, 2018, Community Research and Development Information Service

5.2 Annual generation

While installed capacity is a commonly used indicator to measure the progress in deploying RE technologies, it can be somewhat misleading due to differences in capacity factors. Annual generation includes the effects of these differences and is therefore a valuable indicator to complement the statistics on installed capacities.

Annual electricity generation by wind turbines has increased significantly between 1995-2016. Not only did the installed capacity in the EU grow each year, but the turbines have also become more powerful and efficient. In 2015, the wind turbines installed in the European onshore wind market exhibited the highest average rated power compared to other regions in the world.[23] While the attention and efforts were on increasing the rated power of wind turbines (larger and more efficient blades), considerable improvements were also made on their operation and availability (e.g. better performance of the drive train) thus increasing the MWh produced per MW of capacity. Innovations have also focused on the layout of the wind parks to reduce the wake effect (e.g. WAKE, MASOWAKE, EERA-DTOC)[24], resulting in more energy produced per km^2.

Figure 5.3 Annual electricity generation in the EU from wind



Source: Eurostat (2018)

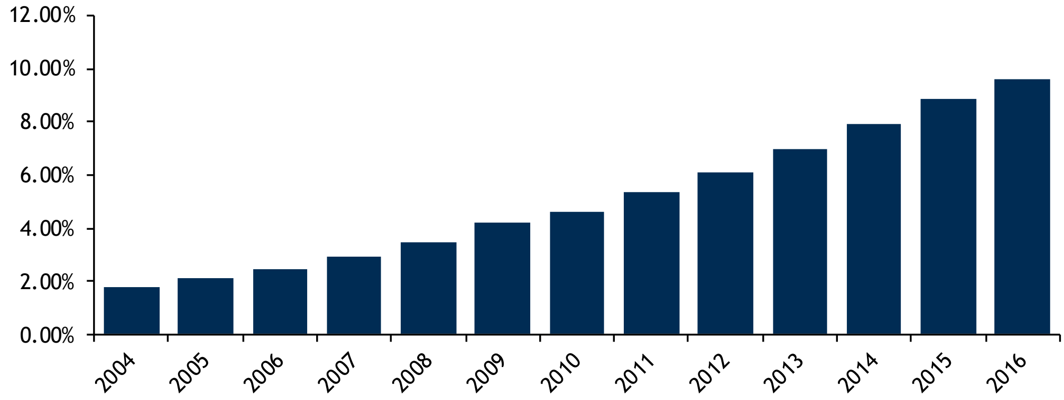
5.3 Share of wind energy in electricity consumption

This indicator is calculated as the proportion of wind energy produced in a certain location relative to the gross final electricity consumption in the same area.

The share of wind energy in gross final electricity consumption in the EU has increased over the years, from 1.8 % to 9.6 %, thanks to a marked increase in deployment (see Figure 5.4). Considering that the overall RE share in the EU electricity consumption was just below 30 % in 2016, the contribution of wind energy to decarbonising the electricity sector has been significant.

[23] EC (JRC), Wind Energy Status Report- 2016 Edition
[24] The wake effect refers to the reduction of wind speed after passing a wind turbine, which can reduce the energy production of a neighbouring turbine.

Figure 5.4 Share of gross final electricity consumption from wind energy in the EU



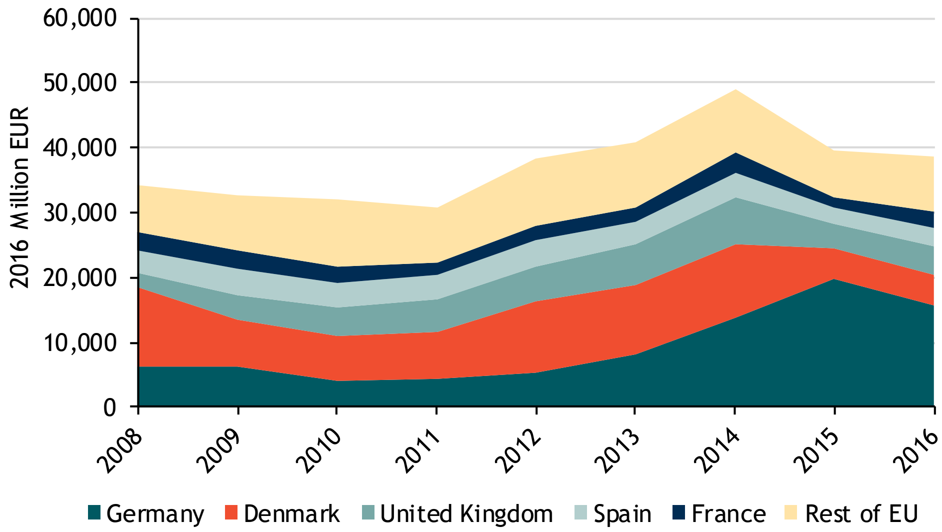
Source: Eurostat (2018)

5.4 Industry turnover

Wind industry turnover is the total amount invoiced from the market sales of goods and/or services supplied to third parties by all sellers. Following the definition of EurObserv'ER, it focuses on the main economic activities of the supply chain including manufacturing, installation of equipment, and operation and maintenance (O&M). A growing turnover indicates a growing market. The sector's turnover is not only driven by new installations in the EU, but also by exports.

Over the period 2008-2016, industry turnover has increased from over EUR 30 billion to nearly EUR 40 billion a year, with a peak in 2014 of EUR 49 billion (see Figure 5.5). Most of it was generated in Germany, Denmark, United Kingdom, Spain and France, which together accounted for 76 % of EU turnover.

Figure 5.5 Wind energy industry turnover in the EU



Source: EurObserv'ER reports 2010-2017.
Notes: Data is missing for Croatia on years 2008-2011.

The decrease in EU wind industry turnover after 2014 is explained in large part by Vestas moving manufacturing capacities outside of the EU, as well as by a slowdown of the offshore sector in Germany and the UK, and increased reliance on outsourcing products. Spain maintained a high industrial turnover despite a slowdown of domestic industry caused by the moratorium on all RE support schemes in 2010-2011, during the economic downturn. This can be mostly attributed to the Spanish company Gamesa, the world's third largest wind turbine exporter. The Netherlands also saw positive figures thanks to a strong export of components. This was further assisted by a growing domestic sector in recent years, with a record year of new installations in 2015 (both onshore and offshore).

Examples of projects potentially with high impact on industry turnover are EERA-DTOC and FLOATGEN. The research in EERA-DTOC project resulted in the creation of software to optimise the design of clusters of wind farms taking into account the wake effect. The software is now commercially available.

Project spotlight: EERA-DTOC (EERA Design Tools for Offshore Wind Farm Cluster)
The project was funded by FP7, ran from January 2012 to June 2015 and was coordinated by the Technical University of Denmark - DTU Wind Energy. The EERA-DTOC project combined expertise to develop a multidisciplinary integrated software tool for an optimised design of offshore wind farms and clusters of wind farms. A commercial software implementation is now available as a spin-off. To minimise the cost of planning, developing and operating offshore windfarms the tool takes into account: the wind climate in wind farm clusters; large wind farm wake effects; economic benchmarking and uncertainty modelling; geo information system integration; and optimised work flow and multi-user approach.
Source: http://www.eera-dtoc.eu/

5.5 Jobs

Employment is an important indicator to understand the socio-economic impact of RE technology deployment. While linking jobs to R&D funding is difficult due to the number of confounding factors, it is easier to relate RE deployment and jobs. Different methods exist to estimate employment figures. A consistent time-series was only available for 2008-2016.

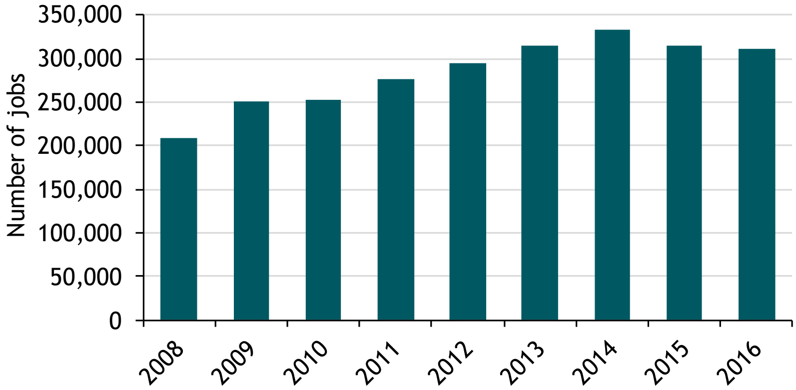
The development of the EU wind energy sector has created a relatively high number of jobs compared to the other RE sectors, ranking only behind bioenergy. Between 2008 and 2016, the number of direct and indirect jobs grew from 200 000 to over 300 000 (see Figure 5.6). The slight decrease in 2015-2016 can be attributed to Germany and the United Kingdom, which experienced a slow-down of the offshore sector (see also section 5.4).

Currently, the EU wind energy jobs are mostly in turbine manufacturing, installation and electricity production, and indirectly in many other industries and economic sectors. The O&M sector is expected to become the greatest source of new wind energy jobs by 2030.[25] In order to meet the growing demand for jobs in the sector there is a need to provide adequate training and skill-development opportunities. A number of R&D projects have focused on providing the necessary training and on closing the gap between academic research and the skills needed to work in the wind industry. The FP7 SYSWIND project focused on training of mechanical, civil and electronic engineers as well as of computer scientists in system identification for conditioning and health monitoring of wind turbines

[25] ETIP Wind (2016) Strategic research and innovation agenda 2016

(i.e. O&M sector). AEOLUS4FUTURE and SPARCARB are examples of projects in a similar domain financed by H2020.

Figure 5.6 Evolution of EU jobs in wind energy



Source: EurObserv'ER reports 2010-2017.

With global jobs in wind energy estimated to be just over a million, the EU share is close to 30 %, which underlines the important position of the EU industry in the global wind energy sector.[26] The EU, through its R&D Framework Programmes, has supported the research of many of the companies which are currently important market players in Europe and globally and which employ a large number of people. For example, the German company ENERCON has participated in several EU-funded projects (5MW-OFFSHORE-WEC, WINDGRID, 7MW-WEC-BY-11) since FP5. It's manufacturing cluster in Viana do Castelo and Lanheses in Portugal opened in 2006 and employs around 1 500 people directly. It is also estimated that it contributes indirectly to another 1 000 jobs.[27]

5.6 Imports/exports

International trade can provide a measure of the market uptake of wind energy technologies, either internally or externally (leading to increased growth of the domestic sector). Similarly, increased activity in the sector will lead to an higher demand for intermediate goods used in the manufacturing process, of which a part is usually imported. Increasing imports of these intermediate goods also provide an indication of sector growth.

EU R&D Framework Programmes have supported the wind manufacturing industry since the early stages. A good example is the FP5 project 5 MW WIND TURBINE, coordinated by Vestas. At the time, the project focused on R&D of a 5 MW wind turbine. Today Vestas is one of the leading manufacturers of 2 and 4 MW turbines. Vestas' blade factory in Daimiel, Ciudad Real, Spain became operational in 2008. By 2008 the factory was employing 500 people and created about 1 000 indirect jobs.[28] Nordex was also supported in early technology development stages. During FP5 the company coordinated the project ESTONIA 20 MW WIND, which focused on the R&D of a new tower/erection concept for a 2.5 MW wind turbine. It also aimed at demonstrating the viability of this concept in a 20 MW wind farm in Paldiski, Estonia. The French large turbine manufacturing company, Vergnet, was also supported during FP5. The company coordinated the WINDPLUS project which focused on grid integration aspects.

[26] IRENA (2017) – Renewable Energy and Jobs, Annual Review 2017
[27] Deloitte and Wind Europe (2017) Local impact, global leadership: The impact of wind energy on jobs and the EU economy. Available at https://windeurope.org/wp-content/uploads/files/about-wind/reports/WindEurope-Local-impact-global-leadership.pdf
[28] Deloitte and Wind Europe (2017) Local impact, global leadership: The impact of wind energy on jobs and the EU economy. Available at https://windeurope.org/wp-content/uploads/files/about-wind/reports/WindEurope-Local-impact-global-leadership.pdf

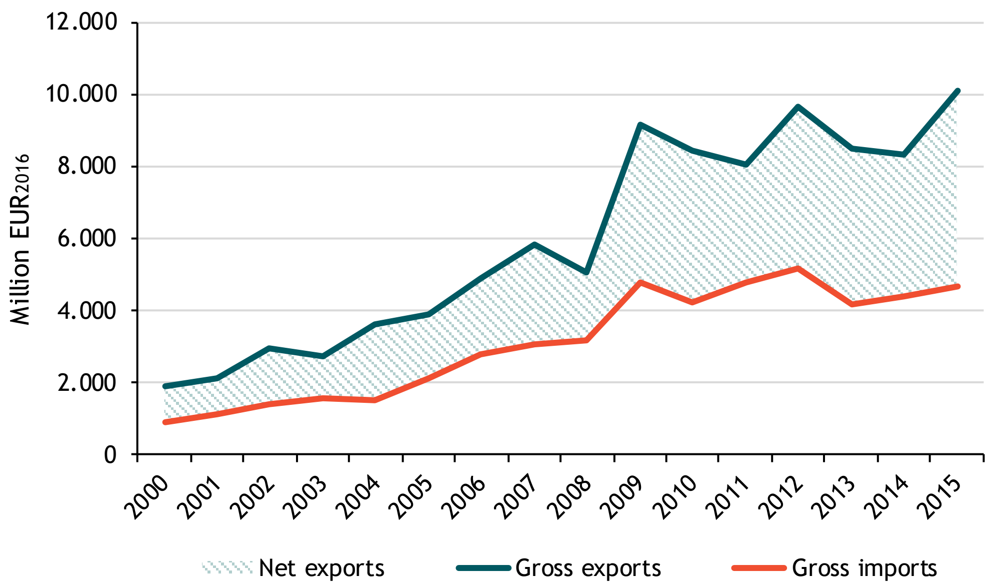
The EU wind energy industry is a net exporter with a positive trade balance of EUR 6 billion in 2015. Recently, however, competition has been increasing, with China becoming a major new player particularly for the Asian market.

Currently, over 80 % of European wind energy companies have a commercial presence and manufacturing sites in more than 80 countries outside of Europe.[29] For example, since 2014 the ENERCON manufacturing site in Viana de Castelo, Portugal (see Section 5.5), exports a large portion of its production to South America and Canada.[30]

Of the 10 biggest wind turbine manufacturers in the world, five are EU-based. As discussed in section 2.1.3 the second highest recipient of EU R&D funding on wind energy between 2008 and mid-March 2018 was Siemens Gamesa. This suggests that research projects are of interest to the industry and that the funding programmes attract and support the development of the European wind industry.

Overall, this indicates that the EU industry can be regarded as a global manufacturing and services hub.

Figure 5.7 Trade balance for wind energy components in the EU

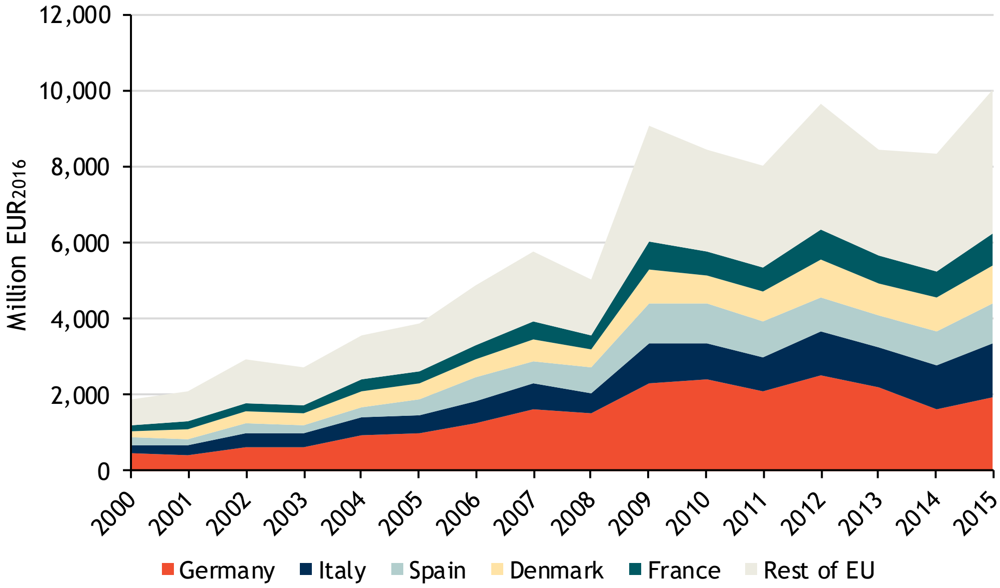


Source: Based on Comext (2018), Lako, P (2008), Eurostat (2018), Wind, I (2009), and Jha, V (2009).
Data for 1999 and 2016 was 0 for all countries so it was excluded.
For an explanation of the methodology used, see Annex C.
Note: export figures include trade in wind energy-specific components (e.g. blades) and general components used not only in wind energy but also in other technologies.

Most EU exports to the rest of the world originate from Germany, Italy, Spain, Denmark and France (see Figure 5.8), largely consistent with the countries with the highest industry turnover and largest R&D budgets. Other top 10 exporters include the United Kingdom, Finland, the Netherlands, Belgium and Austria.

[29] Ibid.
[30] Ibid.

Figure 5.8 Total value of exports of wind energy components from the EU (extra EU28 trade)



Source: Based on Comext (2018), Lako, P (2008), Eurostat (2018), Wind, I (2009), and Jha, V (2009).
Data for 1999 and 2016 was 0 for all countries so it was excluded.
For an explanation of the methodology used, see Annex C.

5.7 Conclusions

The EU wind energy sector is a prime example of how R&D efforts and steady market development can lead to a strong EU industry. Within the EU, the installed capacity for wind energy has been growing steadily from less than 20 GW in 2000 to more than 168 GW in 2017. Such growth has contributed significantly to the decarbonisation of EU's electricity consumption (of which 10 % originate from wind energy) and have provided a significant sales market for EU-based manufacturers.

The EU industry has attained a global leading position with EUR 20 billion annual turnover and more than 300 000 jobs, accounting for 30 % of all wind energy jobs worldwide. Furthermore, it has a significant trade surplus, with net exports of EUR 6 billion/year.

R&D are prerequisites for technological advancement which in turn can lead to cost reductions, performance improvements, deployment and the development of a local industry. This is exemplified by the participation of the majority of the current European market leaders (Siemens Games, ENERCON, Vestas) in many of the EU-funded projects since FP5.

After 2014, a slight decline in EU's industry turnover and jobs can be observed. Potential reasons include increased competition from foreign companies, outsourcing of manufacturing capacities and a slowdown in capacity additions in some Member States, despite an increase in export volumes.

6 Conclusions

Wind energy has consistently been among the main recipient technologies of EU R&D funding. Among R&D funds dedicated to RE over the past 20 years, it accounts for 16% at EU level and 20% at Member States' level. The combined EU and Member States' R&D budgets are the highest worldwide with funding over EUR 200M/year and led to a strong academic position (e.g. more than 30% of publications worldwide). The EU R&D Framework Programmes were paramount to this and also stimulated collaboration and knowledge sharing across the EU.

EU funded research on wind energy has focused on topics such as component design (23 % of funding), grid integration (20 % of funding) and operations & maintenance (9 % of funding). It has also strategically allocated significant budgets to emerging sectors and specific solutions like fixed bottom offshore wind and large scale turbines, eventually leading to their market uptake. Through FP7 and H2020 the European Commission has also been supporting the development of new, lower TRL technologies such as floating offshore and airborne wind.

Today onshore wind energy is a mature technology. LCOE reductions of more than 50% have been achieved since the early 2000s, reaching a cost level that is competitive with other sources of electricity.

Throughout the report several EU-funded projects were highlighted to illustrate the impact of EU funding on the development of offshore wind technologies. These projects allowed wind turbines to be installed farther offshore, capturing stronger and steadier winds and avoiding the limitations of finding suitable on-land sites – thereby contributing to the commercialisation and further exploitation of wind energy in Europe. The costs of offshore wind energy fluctuated in the early years of deployment but have decreased significantly in recent years (25% between 2015 and 2017).

In terms of deployment, the EU wind energy sector has exhibited steady growth. Onshore installed capacity grew from 2 400 MW in 1995 to 154 000 MW in 2016 and offshore from close to zero in 2000 to 12 000 MW in 2016. Wind energy currently provides 10% of the electricity consumed at the EU and one third of its renewable electricity. EU's industry has reached a leading position globally with 30% of global jobs in the sector and €6 billion/year trade surplus. The EU's leadership is especially prominent in offshore wind with more than 80% of global installed capacity.

Annex 3A - Case studies

Case study: FLOATGEN

Author:	Romain Gellee	**Approver:**	Marie BAYARD-LENOIR
Project title:	Demonstration of Two Floating Wind Turbines Systems for Power Generation in Mediterranean Deep Waters (FLOATGEN)		
Lead partner:	IDEOL Espace Mistral – Bât B 375 avenue du Mistral 13600 La Ciotat (France)		
Project location:	France		
Technology area/s:	Wind energy/Floating offshore		
Start and end date:	January 2013 to October-December 2019		
Project cost:	EUR 36 339 264.69	**European Commission funding:**	EUR 19 568 404.00
Other funding sources:			
Quantifiable outputs and impacts:	The floating foundation, the Damping Pool, developed and patented by Ideol, the lead developer of the project. 2 scientific publications 1 patent		
Further information:	http://floatgen.eu/ Marie Bayard-Lenoir, Paul de la Guérivière, Espace Mistral – Bât B, 375 avenue du Mistral, 13600 La Ciotat, France T +33 (0) 609 778 115E marie.bayard@ideol-offshore.com		

Project description

The project began in 2013 bringing together seven partners each with a specific role to play:

- IDEOL (Coordinator – FR): design and provision of the entire floating system (foundation, mooring system and electricity export cable) as well as the wind turbine, towing and installation of the floating unit;
- Ecole Centrale Nantes (FR): ocean engineering expertise ; supply of the mooring system ; access to and monitoring of its offshore test site for the floating demonstrator;
- Bouygues Travaux Publics (FR): floating foundation construction;
- The University of Stuttgart (DE): participation in the study phase simulations;
- RSK GROUP (UK): environmental impact analysis of the floating system;
- ZABALA (ES): project management;
- FRAUNHOFER-IWES (DE): comparative analysis between the proposed FLOATGEN system and other comparable floating solutions.

The project is supported by the European Union as part of the FP7 programme, by the French Environment and Energy Management Agency as part of the national Investments for the Future Programme and by the Pays de la Loire region. This project is a precursor to the consecutive installation of pilot and commercial offshore wind farms. The FLOATGEN demo project sees the deployment of a 2 MW floating turbine in the Atlantic Ocean, at SEM-REV test site located 12 nautical miles from the city of Le Croisic on the French Atlantic coast.

The FLOATGEN project aims to demonstrate the technical and economic feasibility of floating wind turbines, to expand the development potential of offshore wind farms into more windy and deeper waters that are currently not commercially viable and to demonstrate a potential decrease of costs for electricity generation. FLOATGEN is the first floating wind turbine to be installed off the French coast. Equipped with a floating foundation designed by the French expert IDEOL, and built by Bouygues Travaux Publics in Saint Nazaire Port, it is installed on the Centrale Nantes offshore test site, SEM-REV, off the coast from Le Croisic.

The main outcomes expected form this project are, to:

- define and validate appropriate methods and processes for the construction, installation, operation and access of the floating system;
- assess and validate its environmental impact;
- validate performance and cost of operation and maintenance;
- model a pathway for the reduction of energy cost from floating offshore wind turbine systems until cost values are comparable with fixed offshore wind structures and develop a roadmap;
- ensure replicability in other deep offshore locations and transfer knowledge through benchmarking activities.

FLOATGEN is co-financed by the European Commission under the Seventh Framework Programme and is coordinated since 2015 by IDEOL.

Outputs and impacts

The FLOATGEN project was designed as a starting point for the development of commercial floating wind farms. Its objectives: to confirm the technical feasibility and the economic viability of floating wind turbines and to prove that IDEOL's technological solution is the most competitive on the market. The objective of the FLOATGEN project is to demonstrate the technical and economic feasibility of Floating Offshore Wind Turbines to expand the development potential of offshore wind farms into more windy and deeper waters that are not currently commercially viable and to demonstrate the potential in decrease of costs for electricity generation. The project also assesses the performance of such combination of wind turbine and floating structure technology to get the knowledge to improve the performance of future up-scaling projects of this technology.

As the first demonstration unit for IDEOL’s floating base technology, it has provided, and will continue to provide, the consortium partners with an unparalleled experience, particularly in terms of construction methods, deployment and operation, in addition to its value as a showcase model for future export.

Outlook and commercial application of the outputs

After several months of construction, FLOATGEN has been towed at 20 km off the coast from Le Croisic. The foundation will be tested under real operating conditions for at least 2 years. The foundation is suited for harsh condition with wind speeds up to 150 km/h and waves of 14 m high in winter, it will be able to accommodate several types of wind turbine and placed in different water depths.

Full project participant list

To reach its ambitious objectives, the project brings together a Europe-wide industry-led partnership. FLOATGEN has brought together the biggest names in industry and academics. 7 partners from across Europe have joined forces to provide their respective areas of expertise.

Organisation	Country	Type
IDEOL	France	Private company
ÉCOLE CENTRALE DE NANTES	France	Academic institute
BOUYGUES TRAVAUX PUBLICS	France	Private company
UNIVERSITY OF STUTTGART	Germany	Academic institute
RSK GROUP	United Kingdom	Private company
ZABALA	Spain	Private company
FRAUNHOFER-IWES	Germany	Research institute

Case study: NORSEWIND

Author:	Romain Gellee	**Approver:**	To be confirmed
Project title:	Northern Seas Wind Index Database (NORSEWInD)		
Lead partner:	Oldbaum Services Stirling University/Stirling FK9 4NF, Scotland, UK		
Project location:	North Seas		
Technology area/s:	Wind energy/Data resource management		
Start and end date:	January 2008 - July 2012		
Project cost:	EUR 7 900 000.00	**European Commission funding:**	EUR 3 939 517.00
Other funding sources:			
Quantifiable outputs and impacts:	North Seas Wind Atlas Peer-reviewed publications/conference proceedings		
Further information:	http://www.norsewind.eu/norse/ Managing Director of Oldbaum Services (Coordinator), Project NORSEWInD Coordination Andy Oldroyd, Oldbaum Services Ltd, Unit 13a The Alpha Centre, Stirling University, Innovation Park, Stirling FK9 4NF, Scotland, UK T: +44 (0) 1786 469639 E cbha@dtu.dk		

Project description

The Northern Seas Wind Index Database (NORSEWInD) was a ground-breaking EU project to provide a reliable offshore wind atlas of the North, Irish and Baltic Seas. NORSEWInD is developing real-time, internet-based high-quality hub-height wind atlases for the offshore wind energy industry. The project developed a suite of techniques to integrate 12 years of LiDAR data (Light Detection and Ranging) on offshore installations and this now represents the largest single purpose wind LiDAR dataset in the industry worldwide.

It is the product of four years of work under the coordination of Oldbaum Services and carried out by a consortium of 21 partners throughout Europe. NORSEWInD consortium represents a true cross-industrial approach bringing together academics, developers and consultants to achieve the project goal. The group has worked together to bring a physical data led approach to offshore wind resource mapping. With the help of the EU Seventh Framework Programme, industry partners and the effort of some 70 individuals within the NORSEWInD programme, a unique piece of work with great benefits for the entire players in the wind industry has been created.

Outputs and impacts

NORSEWInD was a programme designed to provide a free wind resource map covering the Baltic, Irish and North Sea areas. The project acquired highly accurate, cost-effective, physical data using a combination of traditional meteorological masts, ground based remote sensing instruments LiDAR (Light Detection and Ranging) and SoDAR (Sonic Detection and Ranging). LiDAR instruments used light to measure the wind characteristics, SoDAR instruments measured the wind conditions by means of sound.

One of the objectives of the NORSEWInD array of wind lidars was to evaluate the ability of numerical models to predict winds at hub height (~100 m), in particular the vertical wind speed profile. Five lidars performed perfectly, two slightly failed the first criterion and one failed both. The lidars were operated offshore for periods ranging from six months to more than two years and observed for 107 months of 10-min mean wind profile observations.

The vertical resolution of the ground-based instruments was used to calibrate the satellite data to provide real world data at hub height. The resulting wind map is the first stop for all potential developers in the regions being examined, and as such represents an important step forward in quantifying the quality of the wind resource available offshore. The techniques employed are fully transferrable, meaning that they can be repeated in any offshore environment. This was showcased during the NORSEWInD validation task. Remote sensing has a hugely important role to play within the wind industry. The NORSEWInD programme demonstrates the reduced cost and increased the accuracy of taking offshore wind measurements using this technology.

A major output from the project was a significant number of peer-reviewed journals, attendance at conference, quotes in book chapters, Phd dissertations and reports. A full list can be found here - http://www.norsewind.eu/norse/index.php/publications.

Outlook and commercial application of the outputs

The long-term performance of wind profiling lidars used for offshore wind energy application has shown to the excellent. The Norsewind project proved that the devices operated perfectly, providing accurate data that could easily be used by project developers.

The project provides many industry firsts, including the creation of one of the world's largest satellite SAR (synthetic-aperture radar) repositories for wind; systematic testing of flow distortion and correction on LiDAR measurements; and the systematic 'lifting' of satellite data from reporting height to hub height.

The role of EU funding

The project had a budget of EUR 7 612 090.20 and was funded under the European Commission Seventh Framework Programme under the call FP7. They received a contribution of EUR 3 939 517 which represents 30 %.
Northern seas wind index database project helped increasing the accuracy of data for the wind power forecasting system. The increased accuracy of the meteorological parameters has a direct impact on the precision of the wind resource and the short-term wind power prediction for a better power forecast of offshore wind farms.

Full project participant list

Organisation	Country	Type
Institut für Solare Energieversorgungstechnik e. V (IWES)	Germany	Research institute
Kjeller Vindteknikk (KVT)	Norway	Private company
Statoil Hydro ASA	Norway	Private company
Institue of Physics Latvia	Latvia	Academic institute
Danish Technical University IMM Denmark	Denmark	Academic institute
Dong Energy	Denmark	Private company
GL Garrad Hassan Germany & UK	Germany UK	Private company

Organisation	Country	Type
Koninklijk Nederlands Meteorologisch Instituut	Nederlands	Academic institute
3E	Belgium	Private company
Nautilus Associates	UK	Private company
SmartWIND	UK	Private company
edp renewables	UK	Private company
SSE	UK	Private company

Case study: SUPRAPOWER

Author:	Romain Gellee	**Approver:**	Iker Marino Bilbao - Project Manager, Tecnalia
Project title:	Superconducting, Reliable, Lightweight, and More Powerful Offshore Wind Turbine (SUPRAPOWER)		
Lead partner:	FUNDACION TECNALIA RESEARCH & INNOVATION Mikeletegi Pasealekua 2. E-20009 Donostia-San Sebastián. Gipuzkoa (Spain)		
Project location:	Bizkaia Spain c/ Geldo, Edificio 700 E-48160 Derio - Bizkaia (Spain)		
Technology area/s:	Wind energy		
Start and end date:	December 2012 to May 2017		
Project cost:	EUR 5 152 058.37	**European Commission funding:**	EUR 3 891 058.46
Other funding sources:	Cash/in-kind contributions from industry		
Quantifiable outputs and impacts:	Experimentally validate the superconducting generator concept and generate 1 patent : EP2521252 B1		
Further information:	http://www.suprapower-fp7.eu/ Iker Marino Bilbao & Susana Apiñániz Parque Tecnológico de Bizkaia c/ Geldo, Edificio 700 E-48160 Derio - Bizkaia (Spain) tel.: 902 760 004 tel.: +34 946 430 069 (International calls) iker.marino@tecnalia.com		

Project description

SUPRAPOWER (SUPerconducting, Reliable, lightweight, And more POWERful offshore wind turbine) was an EU Seventh Framework funded research project focused on a major innovation in offshore wind turbine technology, for the development of a novel 10 MW lightweight and reliable generator based on superconducting materials.

Outputs and impacts

One of the objectives was experimentally validating the superconducting generator concept on a small-scale machine, designed and built for this purpose. To keep the maximum likeness between the model and the full-scale generator, the scaling down was achieved by reducing the number of poles, maintaining the size of the superconducting field coils identical in the full generator and the small-scale machine. Also, the most innovative full-scale generator features (superconducting coils, cooling systems, cryostat and quench detection) are similar. This resulted in a scale machine which fulfils the basic performance parameters of the 10 MW machine, but with a substantial reduction of diameter, weight and power permitting which means it can be tested on a laboratory bench.

The objectives of the SUPRAPOWER project overall objectives were to:

- reduce the head mass, size and cost of offshore wind turbines by means of a compact superconducting generator;
- reduce operating, maintenance and transportation costs and to increase life cycle using an innovative direct-drive system;
- increase the reliability and efficiency of high power wind turbines through a drive-train specific integration in nacelle;
- maximise the power conversion and wind response of the wind turbine by means of dedicated control systems/procedures;
- facilitate the development of the offshore wind potential and support its drastic increase.

And the specific aimed impacts were:

- Reduction of the LCOE of the offshore wind by means of a higher power rate lightweight superconducting generator. This cost reduction could permit to achieve the offshore wind sector market perspectives;
- 30 % weight reduction with respect to a permanent magnet generator. This permits easier installation processes, reduces vessels and crane costs and decreases mechanical requirements for foundations and floating platforms;
- Elimination of the gearbox enabling a more reliable and efficient drivetrain;
- Low maintenance requirements with respect to other superconducting solutions thanks to the use of a cryogenics liquids free cooling system;
- High on-site efficiency (95 %);
- Developing a wind generator independent from the rare earth materials market, which has shown high price volatility.

Outlook and commercial application of the outputs

The main outcome of SUPRAPOWER project is a novel 10 MW superconducting generator. This generator has been patented (EP2521252 B1) in Europe (Spain, Germany, UK and France) and the USA. The patented concept has been developed in detail and validated through a scale machine. Additionally, some more exploitable results have been achieved in the project, mainly related to the development of the components of the generator and the design, installation and operation procedures of large power rating superconducting wind turbines.

The role of EU funding

SUPRAPOWER was an FP7 project and had a budget of EUR 5 398 019.03 with EUR 3 891 058.45 funded by the EU. The project provided an important breakthrough in offshore wind industrial solutions by designing an innovative, lightweight, robust and reliable 10 MW class offshore wind turbine based on a superconducting generator, considering all the essential aspects of electric conversion, integration and use of manufacture. This new generator shows a 26 % weight reduction in comparison to a permanent magnet generator that permits to achieve up to EUR 1 million of cost reduction in a 10 MW wind turbine.

Full project participant list

Organisation	Country	Type
Tecnalia Research & Innovation	Spain	Private company
Columbus Superconductors	Italy	Private company
Institute of Electrical Engineering, Slovak Academic of Sciences	Slovakia	Research institute
University of Southampton	United Kingdom	Academic institute
Karlsruher Institut Technologie	Germany	Research institute
D2M Engineering	France	Private company
Etulos Solute SL	Spain	Private company
Ingeteam Services SA	Spain	Private company
Tecnalia Research & Innovation	Spain	Research institute

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Annex 3C – Methodological note on imports and exports

The value of the following components were assessed for wind:

Table C.1 HS6 product codes relevant to wind energy sector

HS6 code	Brief product description
730820	Towers and lattice masts, of iron or steel
841290	Parts of non-electrical engines and motors, N.E.S
848210	Ball bearings
848220	Tapered roller bearings, incl. cone and tapered roller assemblies
848230	Spherical roller bearings
848240	Needle roller bearings
848250	Cylindrical roller bearings (excl. needle roller bearings)
848280	Roller bearings, incl. combined ball/roller bearings (excl. ball bearings, tapered roller bearings, incl. cone and tapered roller assemblies, spherical roller bearings, needle and cylindrical roller bearings)
848340	Gears and gearing for machinery (excl. toothed wheels, chain sprockets and other transmission elements presented separately); ball or roller screws; gear boxes and other sped changers, incl. torque converters
850161	AC generators 'alternators', of an output less than or equal to 75 kVA
850162	AC generators 'alternators', of an output greater than 75 kVA but less than or equal to 375 kVA
850163	AC generators 'alternators', of an output greater than 375 kVA but less than or equal to 750 kVA
850164	AC generators 'alternators', of an output greater than 750 kVA
850231	Generating sets, wind-powered*
850300	Parts suitable for use solely or principally with electric motors and generators, electric generating sets and rotary converters, N.E.S
850421	Liquid dielectric transformers, having a power handling capacity less than or equal to 650 kVA
850422	Liquid dielectric transformers, having a power handling capacity greater than 650 kVA but less than or equal to 10 000 kVA
850423	Liquid dielectric transformers, having a power handling capacity greater than 10 000 kVA
850431	Transformers having a power handling capacity less than or equal to 1 kVA (excluding liquid dielectric transformers)
850432	Transformers, having a power handling capacity greater than 1 kVA but less than or equal to 16 kVA (excluding liquid dielectric transformers)
850433	Transformers having a power handling capacity greater than 16 kVA but less than or equal to 500 kVA (excluding liquid dielectric transformers)
850434	Transformers having a power handling capacity greater than 500 kVA (excluding liquid dielectric transformers)
854449	Electric conductors, for a voltage less than or equal to 1.000 V, insulated, not fitted with connectors, N.E.S
854460	Electric conductors, for a voltage greater than 1 000 V, insulated, N.E.S
890790	Rafts, tanks, coffer-dams, landing-stages, buoys, beacons and other floating structures (excl. Inflatable rafts, vessels of heading 8901 to 8906 and floating structures for breaking up)

HS6 code	Brief product description
902830	Electricity supply or production meters, incl. calibrating meters therefor
903020	Oscilloscopes and oscillographs
903031	Multimeters for voltage, current, resistance or electrical power (excl. recording device)
903039	Instruments and apparatus for measuring or checking voltage, current, resistance or electrical power (excl. recording device, multimeters, and cathode ray oscilloscopes and oscillographs)

Source: Comext database and Jha (2009)
* Single use technology

Table C.2 NACE2 codes relevant to wind energy sector

NACE2	Definition
24	Basic metals
28	Other machinery and equipment
27	Electrical equipment
30	Manufacture of other transport equipment
26	Computer, optical & electronic

Annex 3D - List of EU-funded projects:

Table D.1 Wind energy EU-funded projects

Acronym	Rcn	Project title	European Commission funding (2016 euros)	Framework Programme	Topic
5 MW WIND TURBINE	54135	Research and development of a 5 mw wind turbine (5 mw wind turbine)	2 311 192	FP5-EESD	1.1.4.-5.
5MW-OFFSHORE-WEC	89227	5MW wind energy converter for off-shore application	3 147 362	FP5-EESD	
7MW-WEC-BY-11	90994	Pilot Demonstration of Eleven 7MW-Class WEC at Estinnes in Belgium	3 650 035	FP7-ENERGY	ENERGY-2007-2.3-04
ABLE	205029	Air Blade Life Extension	50 000	H2020-EU.2.3.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
ACCUWIND	86938	Accurate wind speed measurements in wind energy	529 624	FP5-EESD	
ACTAGREEN	187865	Aeroelasticity Control for Transportation And GREen ENergy	231 838	FP7-PEOPLE	FP7-PEOPLE-2013-IEF
ActiveWindFarms	104435	Active Wind Farms: Optimization and Control of Atmospheric Energy Extraction in Gigawatt Wind Farms	1 533 819	FP7-IDEAS-ERC	ERC-SG-PE8
ACWIND	109034	Advanced Control Approaches for Airborne Wind Energy Technologies	N/A	FP7-PEOPLE	FP7-PEOPLE-2012-IEF
ADCON - DEMOWIND	89220	Demonstration of six advanced control technology 1.3mw scale wind turbines operating at three sites with distinctly different environmental conditions	2 730 471	FP5-EESD	
Aeolus	87315	Distributed Control of Large-Scale Offshore Wind Farms project proposal	2 790 303	FP7-ICT	ICT-2007.3.7
AEOLUS4FUTURE	193997	Efficient harvesting of the wind energy	3 821 334	H2020-EU.1.3.1.	MSCA-ITN-2014-ETN
Aeropaft	194764	Delay of flow separation and stall on Aerofoils using a Passive Flow control Technology which will improve aerodynamic performance and stability of wind turbines increasing their range of operation	50 120	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
AIRCRANE	197158	New building methodology for improved full-concrete wind towers for wind turbines.	50 125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
AMPYXAP3	197306	Commercial introduction of the first Airborne Wind Energy system: Renewable energy at costs below fully depreciated coal fired power plants	2 506 250	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014
ANEMOS	64848	Development of a next generation wind resource forecasting system for the large-scale integration of onshore and offshore wind farms (ANEMOS)	3 214 689	FP5-EESD	1.1.4.-5.
ANEMOS.PLUS	86586	Advanced tools for the management of electricity grids with large-scale wind generation	2 900 013	FP6-SUSTDEV	SUSTDEV-1;SUSTDEV-1.1.7
AutoWinSpec	185465	Automated mechanical property and fatigue life assessment of composite wind turbine blades in less than 4 hours	1 020 443	FP7-SME	SME-2013-1
AVATAR	111290	AdVanced Aerodynamic Tools for lArge Rotors	6 732 874	FP7-ENERGY	ENERGY.2013.2.3.1

Acronym	Rcn	Project title	European Commission funding (2016 euros)	Framework Programme	Topic
AWESCO	193938	Airborne Wind Energy System Modelling, Control and Optimisation	3 006 512	H2020-EU.1.3.1.	MSCA-ITN-2014-ETN
AWESOME	196612	Advanced Wind Energy Systems Operation and Maintenance Expertise	2 869 229	H2020-EU.1.3.1.	MSCA-ITN-2014-ETN
BEST PATHS	197829	BEYOND STATE-OF-THE-ART TECHNOLOGIES FOR POWER AC CORRIDORS AND MULTI-TERMINAL HVDC SYSTEMS	35 585 167	FP7-ENERGY	ENERGY.2013.7.2.3
Briareo	194769	Implementation of a vertical axis micro-wind turbine capable of working at high efficiency even at a low wind speed.	50 120	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
CLEVERFARM	51595	Advanced management and surveillance of wind farms ('CLEVERFARM')	667 828	FP5-EESD	1.1.4.-6.
CLOUD DIAGNOSIS	197169	Providing Predictive Maintenance for Wind Turbines Over Cloud	50 125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
CLOUD DIAGNOSIS	204563	Development of Low Cost Cloud Monitoring for the Diagnosis and Prognostic of the Wind Turbines	878 129	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015
CLOWEBS-2000	57717	Klasorden 42 Mw; A Demonstration Of Cost-Optimised Large Scale, Offshore Wind Energy In The Baltic Area	6 707 266	FP5-EESD	1.1.4.-6.5.1
CLUSTERDESIGN	101379	A Toolbox for Offshore Wind Farm Cluster Design	3 761 994	FP7-ENERGY	ENERGY.2011.2.3-2
CL-Windcon	205917	Closed Loop Wind Farm Control	4 931 423	H2020-EU.3.3.2.	LCE-07-2016-2017
CMDrive	200428	Condition Monitoring of Wind Turbine Drive-Trains via Non-Contact Acoustic Sensors	2 289 733	H2020-EU.3.;H2020-EU.2.	FTIPilot-1-2015
CMSWIND	103871	Advanced condition monitoring system for the assessment of wind turbines rotating parts	1 913 030	FP7-SME	SME-2011-2
COCONET	101654	Towards COast to COast NETworks of marine protected areas (from the shore to the high and deep sea), coupled with sea-based wind energy potential	9 207 572	FP7-KBBE	OCEAN.2011-4
COD	86911	Concerted action for offshore wind-energy deployment	818 231	FP5-EESD	
COMHUB	51206	Innovative composite hub for wind turbines ('COMHUB')	1 053 730	FP5-EESD	1.1.4.-6.
CONCEPT	107595	Development of a Portable High Energy Nanofocus Computed Tomography system for Glass Reinforced Plastic Wind Turbine Blades	1 338 187	FP6-SME	SME-1
CONMOW	69530	Condition monitoring for off-shore wind farms	1 373 201	FP5-EESD	1.1.4.-5.
CORETO	103963	Adapted Composite Repair Tooling for in-situ wind turbine blades structural rehabilitation	938 559	FP7-SME	SME-2011-1
COWEGS	87004	Community wind energy generation scheme	691 881	FP5-EESD	
DAMPBALDE	54161	Wind turbine rotor blades for enhanced aeroelastic stability and fatigue life using passively damped composites (DAMPBALDE)	1 494 643	FP5-EESD	1.1.4.-6.
DashWin	100581	Development of Advanced Shearography System for On-Site Inspection of Wind Turbine Blades	1 139 429	FP7-SME	SME-2011-1
DEEPWIND	96069	Future Deep Sea Wind Turbine Technologies	3 239 653	FP7-ENERGY	ENERGY.2010.10.2-1
DEICE-UT	109574	Wind turbine blade Anti/De-icing, combined Ultrasonic guided wave and vibration system	1 074 359	FP7-SME	SME-2013-1

Acronym	Rcn	Project title	European Commission funding (2016 euros)	Framework Programme	Topic
DEMOGRAVI3	199361	Demonstration of the GRAVI3 technology – innovative gravity foundation for offshore wind	19 037 466	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-03-2015
DEMOWFLOAT	107972	Demonstration of the WindFloat Technology	3 742 307	FP7-ENERGY	ENERGY.2011.2.3-1
DemoWind	194450	DemoWind ERA-NET Cofund action - delivering cost reduction in offshore wind	7 802 618	H2020-EU.3.3.2.	LCE-18-2014
DemoWind 2	199382	DemoWind 2 ERA-NET Cofund action - delivering cost reduction in offshore wind	8 557 865	H2020-EU.3.3.3.;H2020-EU.3.3.2.;H2020-EU.3.3.4.	LCE-18-2015
DOWNVIND	87894	DISTANT OFFSHORE WINDFARMS WITH NO VISUAL IMPACT IN DEEPWATER	7 417 684	FP6-SUSTDEV	SUSTDEV-1.1.1
DRISCS	111047	Dynamic Response and Instability of Seabed-Coastal Structure Systems under Waves	100 784	FP7-PEOPLE	FP7-PEOPLE-2012-CIG
Eciwind	196383	Cost effective wind turbine of 40 kW of rated capacity	1 310 573	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014
EcoBlade	197578	EcoBlade: Eco-efficient decommissioning of wind turbine blades through on-site material shredding and separation	50 125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
EcoSwing	195203	EcoSwing - Energy Cost Optimization using Superconducting Wind Generators - World’s First Demonstration of a 3.6 MW Low-Cost Lightweight DD Superconducting Generator on a Wind Turbine	10 618 213	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-03-2014
ECO-TURBINE	204252	Development of lamella type of wind turbine made of bio composite polymers	50 000	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
ECOWINDS	105677	European Clusters for Offshore Wind Servicing	1 798 252	FP7-REGIONS	REGIONS-2012-2013-1
EDWTGT	105584	Evaluation and Development of Wind Turbine Generator Technologies	401 757	FP7-PEOPLE	FP7-PEOPLE-2012-IRSES
EeC WITUR	196496	Efficient energy cleaning robotic platform for wind turbines (EeC WITUR)	50 125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
EERA-DTOC	101241	EERA Design Tools for Offshore Wind Farm Cluster	2 966 738	FP7-ENERGY	ENERGY.2011.2.3-2
EK200-AWESOME	205145	EK200 - Airborne Wind Energy and Storage system, catering to Off-grid andMobile End-uses (AWESOME)	50 000	H2020-EU.2.3.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
ELICAN	199304	SELF-INSTALLING TELESCOPIC SUBSTRUCTURE FOR LOW-COST CRANELESS INSTALLATION OF COMPLETE OFFSHORE WIND TURBINES. DEEP OFFSHORE 5MW PROTOTYPE	11 181 987	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-03-2015
ELISA	197175	SELF-BOUYANT PRECAST CONCRETE FOUNDATION FOR THE CRANELESS INSTALLATION OF COMPLETE OFFSHORE WIND TURBINES: FULL SCALE OFFSHORE PROTOTYPE	2 504 107	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014
EOW	208334	A micro dual-axis vertical wind turbine providing an alternative low carbon energy solution capable of working at high efficiency in low wind speeds for use in urban environments.	49 157	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
EPE-PEMC 2004	73412	International Power Electronics and Motion Control Conference 2004, Riga, Latvia	74 177	FP6-MOBILITY	MOBILITY-1.4.2
ESTONIA 20 MW WIND	57499	8 X 2.5 Mw Wind Turbines With Crane-free Erection to be Implemented in Estonia	3 040 161	FP5-EESD	1.1.4.-5.2.2

Acronym	Rcn	Project title	European Commission funding (2016 euros)	Framework Programme	Topic
EWIS	85678	European wind integration study	4 672 660	FP6-SUSTDEV	SUSTDEV-1;SUSTDEV-1.1.7
EXPLOREWIND	67566	Exploring nex concepts for small and medium-sized wind mills to improve performance (EXPLOREWIND)	434 534	FP5-EESD	1.1.4.-5.
EXTOOL	58614	Experience curve : a tool for energy policy programmes assessment (EXTOOL)	256 060	FP5-EESD	1.1.4.-8.
EZXS WTB	57756	Wind Turbine (350 Kw) For Sites with Difficult Access	932 352	FP5-EESD	1.1.4.-5.2.2
FFI	194694	Forward Flow Infusion - Low Cost Composite Manufacturing Process for High Volume Production	50 120	H2020-EU.2.3.1.;H2020-EU.2.1.2.	NMP-25-2014-1
Fibersail	210380	Fibersail: Shaping the Structures of Tomorrow	49 157	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
FIRMWIND	51590	Towards high penetration and firm power from wind energy ('FIRMWIND')	621 166	FP5-EESD	1.1.4.-5.
FLOATGEN	107961	DEMONSTRATION OF TWO FLOATING WIND TURBINE SYSTEMS FOR POWER GENERATION IN MEDITERRANEAN DEEP WATERS	19 721 851	FP7-ENERGY	ENERGY.2011.2.3-1
FLOATMAST	197010	An Innovative Wind Resource Assessment Tension Leg Platform for combined Cup Anemometer and Lidar Reliable and Bankable Wind Measurements for Offshore Wind Parks	50 125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
FLOW	201757	New Floating Platform for offshore wind in deep waters.	50 000	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
FLOWSPA	207129	Floating Offshore Wind Support Platform and Assembly Solution	49 157	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
GW-FortyForty	204302	Gaia-Wind's Advanced Small Wind Turbine FortyForty	50 000	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
HAWE	96067	High Altitude Wind Energy	2 079 127	FP7-ENERGY	ENERGY.2010.10.2-1
HEMOW	98451	Health Monitoring of Offshore Wind Farms	253 591	FP7-PEOPLE	FP7-PEOPLE-2010-IRSES
Hi GEN Marine Turbin	207168	Feasibility study into a portable wind turbine for ships which connects to the existing ships crane	49 157	H2020-EU.2.3.1.;H2020-EU.3.2.5.;H2020-EU.3.2.3.	SMEInst-08-2016-2017
HIGHWIND	98087	Simulation, Optimization and Control of High-Altitude Wind Power Generators	1 574 892	FP7-IDEAS-ERC	ERC-SG-PE7
HIPRWIND	96223	High Power, high Reliability offshore wind technology	11 932 155	FP7-ENERGY	ENERGY.2010.2.3-1
HISP	87896	Hogsara island demonstration project	2 097 968	FP6-SUSTDEV	SUSTDEV-1.1.1
HONEYMOON	67930	A high resolution numerical wind energy model for on- and offshore forecasting using ensemble predictions (HONEYMOON)	1 124 568	FP5-EESD	1.1.4.-5.
HYDROBOND	106383	New cost/effective superHYDROphobic coatings with enhanced BOND strengh and wear resistance for application in large wind turbine blades	2 952 448	FP7-NMP	NMP.2012.2.2-4
HYPER TOWER	209572	Design of Hyper Tall Onshore Wind Turbine Towers	180 360	H2020-EU.1.3.2.	MSCA-IF-2016

Acronym	Rcn	Project title	European Commission funding (2016 euros)	Framework Programme	Topic
ICETOOLS	72318	Wind turbines in icing environment: improvement of tools for siting, certification and operation	496 943	FP5-EESD	1.1.4.-5.
ICEWIS	200327	Intelligent and cost-efficient wind turbine power production using optical sensors	50 000	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
ICFLOAT	98882	Coupled fluid-solid numerical modelling for deep-water and far-offshore floating wind turbines using an adaptive finite element method	209 541	FP7-PEOPLE	FP7-PEOPLE-2010-IEF
IMPMWTDES	57489	Inis Mean Wind-Desalination Plant with Load Management	546 680	FP5-EESD	1.1.4.-5.3.
INFLOW	107971	INdustrialization setup of a FLoating Offshore Wind turbine	12 532 513	FP7-ENERGY	ENERGY.2011.2.3-1
InnoDC	211663	Innovative tools for offshore wind and DC grids	3 827 530	H2020-EU.1.3.1.	MSCA-ITN-2017
INNOWT5000	86947	5mw innovative wind turbine suitable for on land and offshore installations	1 921 773	FP5-EESD	
INNWIND.EU	106004	Innovative Wind Conversion Systems (10-20MW) for Offshore Applications	14 118 277	FP7-ENERGY	ENERGY.2012.2.3.1
INTELWIND	101026	Development of an intelligent condition monitoring system for application on critical rotating components of industrial-scale wind turbines	1 142 369	FP7-SME	SME-2011-1
IRPWIND	111468	Integrated Research Programme on Wind Energy	9 845 789	FP7-ENERGY	ENERGY.2013.10.1.6
IRWES	196402	Integrated Roof Wind Energy System	188 682	FP7-PEOPLE	SIE-01-2014
IRWES	196402	Integrated Roof Wind Energy System	1 700 621	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014
KNOW-BLADE	59844	Wind turbine blade aerodynamics and aeroelastics: closing knowledge gaps 'know-blade'	1 312 587	FP5-EESD	1.1.4.-6.
KORIDION	198413	Feasibility Study for a Breakthrough Core System to Enable Fault Tolerant Manufacture of High Performances Composites Wind Blades	50 125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
LEANWIND	111310	Logistic Efficiencies And Naval architecture for Wind Installations with Novel Developments	10 064 539	FP7-TRANSPORT	OCEAN 2013.4
LIBI	204577	Lightning Interception Blade Implant	826 102	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
LIFES 50plus	196802	Qualification of innovative floating substructures for 10MW wind turbines and water depths greater than 50m.	7 293 025	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-02-2014
Liftra Crane	207688	Liftra Self-Hoisting Crane (LSHC) - a disruptive crane solution for cost effective exchange and service of major wind turbine components	1 941 100	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
LiraTower	198943	Novel concept of cost-effective and simplified in-situ concrete tower of 140m for harnessing higher and more consistent wind velocities and enhancing the power output of wind turbines	50 125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
LOWCOST2BLADE2MW	61318	Development of a Low-cost two Mw Two-bladed Wind Turbine	2 625 376	FP5-EESD	1.1.4.-5.2.2
LOWCOST2BLADE2MW	86811	Development of a low-cost 2Mw two-bladed wind turbine	2 571 832	FP5-EESD	
MARE-WINT	104982	new MAterials and REliability in offshore WINd Turbines technology	3 910 920	FP7-PEOPLE	FP7-PEOPLE-2012-ITN

Acronym	Rcn	Project title	European Commission funding (2016 euros)	Framework Programme	Topic
MEDOW	106752	Multi-terminal DC grid for offshore wind	3 956 319	FP7-PEOPLE	FP7-PEOPLE-2012-ITN
MEGAWIND	54150	Development of a mw scale wind turbine for high wind complex terrain sites (MEGAWIND)	2 624 988	FP5-EESD	1.1.4.-5.
MESOWAKE	186070	Unified mesoscale to wind turbine wake downscaling based on an open-source model chain	353 021	FP7-PEOPLE	FP7-PEOPLE-2013-IOF
METEORES SERVICES	93036	Turning Wind Energy Meteorology into System Integration Services for Energy Market Participants	554 642	FP7-PEOPLE	FP7-PEOPLE-IAPP-2008
MEWi-B	197033	More Efficient Wind Blades	50 125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
MODOBS	81870	Atmospheric modelling for wind energy, climate and environment applications: exploring added value from new observation technique	2 518 866	FP6-MOBILITY	MOBILITY-1.1
MONITUR	106809	Reduction in Maintenance Costs of Wind Turbine Renewable Electricity Generation through Online Condition Monitoring	1 070 328	FP7-SME	SME-2012-1
MOWI	56465	Mathematical modelling of wind power plant for operation optimisation in deregulated electric power system (MOWI)	64 387	FP5-HUMAN POTENTIAL	
NANOPERMAG	95222	HIGH PERFORMANCE NANOSTRUCTURE PERMANENT MAGNETS	219 033	FP7-PEOPLE	FP7-PEOPLE-2009-IIF
NEOHIRE	207883	NEOdymium-Iron-Boron base materials, fabrication techniques and recycling solutions to HIghly REduce the consumption of Rare Earths in Permanent Magnets for Wind Energy Application	4 368 931	H2020-EU.2.1.3.	NMBP-03-2016
NEW ICETOOLS	86818	Wind turbine in Icing environment: improvement of tools for siting, certification and operation	624 057	FP5-EESD	
NEW ICETOOLS	61353	Wind Turbine in Icing Environment: Improvement of Tools for Sitting, Certification and Operation	649 112	FP5-EESD	1.1.4.-5.2.2
NEWGEN3MW	85620	Development of a new principle 3 MW direct drive generator and wind turbine	2 368 017	FP6-SUSTDEV	SUSTDEV-1.1.1
NextWind	210686	Harvesting airborne wind energy using rigid kites.	49 157	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
NIGHT WIND	79800	Grid Architecture for Wind Power Production with Energy Storage through load shifting in Refrigerated Warehouses	849 645	FP6-SUSTDEV	SUSTDEV-1.2.3
NIMO	92781	Development and Demonstration of a Novel Integrated Condition Monitoring System for Wind Turbines	3 759 679	FP7-ENERGY	ENERGY-2007-2.3-04
NJORD	206808	Rugged Long-lasting Vertical-Axis Wind Turbine for Extreme Wind Conditions	50 000	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
NORSEWIND	90351	Northern Seas Wind Index Database	4 396 978	FP7-ENERGY	ENERGY-2007-2.3-06
NOVOGRID	89217	Novel optimisation strategy for the power quality of grid connected wind farms	1 637 611	FP5-EESD	
NUMIWING	110013	Numerical modelling of inflatable airborne wind energy systems	100 784	FP7-PEOPLE	FP7-PEOPLE-2013-CIG
OFFSHOREM&R	86924	Advanced maintenance and repair for offshore wind farms using fault prediction and condition monitoring techniques	1 388 760	FP5-EESD	

Acronym	Rcn	Project title	European Commission funding (2016 euros)	Framework Programme	Topic
OHMWIT	186427	Online Health Monitoring of Wind Turbine Generators and Power Converters	273 880	FP7-PEOPLE	FP7-PEOPLE-2013-IOF
OPTI PILE	86813	Optimisation of Monopile foundations for offshore wind turbines in deep water and North Sea conditions	1 562 452	FP5-EESD	
Opti-LPS	197412	Optimal Lightning Protection System	50 125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
OPTIMAT BLADES	60342	Reliable optimal use of materials for wind turbine rotor blades (OPTIMAT BLADES)	3 085 025	FP5-EESD	1.1.4.-6.
OPTIMUS	185359	Demonstration of methods and tools for the optimisation of operational reliability of large-scale industrial wind turbines	3 359 413	FP7-ENERGY	ENERGY.2012.2.3.2
OPTIWIND	86894	Optimised 2 Mw wind turbines in high wind speed area with smooth grid integration	1 619 735	FP5-EESD	
OPTIWIND	105695	Optimum Power Extraction of Wind Energy by Small to Medium Scale Wind Turbines	1 186 626	FP7-SME	SME-2012-1
OS2500	57711	0S2500/78-Demonstration of a large scale, Second Generation, Off Shore Wind Turbine, complying with new grid requirement	2 008 597	FP5-EESD	1.1.4.-5.2.2
OSGRAM	92308	The development of a graduated radar-absorbing multi-layer structure for wind turbine applications to enable their positioning in areas of optimal power generation	1 059 227	FP7-SME	SME-1
OWEE	86999	Concerted action on offshore wind energy in Europe	633 857	FP5-EESD	
POWDERBLADE	205923	Commercialisation of Advanced Composite Material Technology: Carbon-Glass Hybrid in PowderEpoxy for Large (60-100m) Wind Turbine Blades	2 731 700	H2020-EU.3.;H2020-EU.2.	FTIPilot-01-2016
POWWOW	75090	Prediction Of Waves, Wakes and Offshore Wind	1 270 089	FP6-SUSTDEV	SUSTDEV-1.2.6
PREWIND	75248	Development of a Methodology for Preventive Maintenance of Wind turbines trough the use of Thermography (PREWIND)	137 945	FP6-SME	SME-2
PROND	92277	Small Wind Turbine Composite Blade PRoperties ON Demand by Means of Functionally Graded Materials	49 733	FP7-PEOPLE	PEOPLE-2007-2-2.ERG
PROTEST	86247	PROcedures for TESTing and measuring wind energy systems	2 210 053	FP7-ENERGY	ENERGY-2007-2.3-03
REACH	199241	Resource Efficient Automatic Conversion of High-Altitude Wind	2 681 820	H2020-EU.3.;H2020-EU.2.	FTIPilot-1-2015
RECOFF	54147	Recommendations for design of offshore wind turbines (RECOFF)	1 047 818	FP5-EESD	1.1.4.-5.
RELIAWIND	88411	Reliability focused research on optimizing Wind Energy systems design, operation and maintenance: Tools, proof of concepts, guidelines & methodologies for a new generation	5 782 364	FP7-ENERGY	ENERGY-2007-2.3-01
RENEWITT	75632	Development of new and novel automated inspection technology for glass reinforced plastic wind turbine blades (RENEWIT)	0	FP6-SME	SME-1
Riblet4Wind	196901	Riblet-Surfaces for Improvement of Efficiency of Wind Turbines	3 315 440	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-03-2014
RingMan	101298	Offshore Wind Turbine Towers – A Quicker, Cheaper Flange Supply Route	1 189 412	FP7-SME	SME-2011-1

Acronym	Rcn	Project title	European Commission funding (2016 euros)	Framework Programme	Topic
ROMEO	210289	Reliable OM decision tools and strategies for high LCoE reduction on Offshore wind	9 831 139	H2020-EU.3.3.2.	LCE-13-2016
ROOF-CAPTURE	92579	Innovative Design for Wind Energy Capture in Urban Environments	1 160 401	FP7-SME	SME-1
Rotary Wing CLFC	195649	Closed-Loop Flow Control to Enhance Aerodynamic and Aeroacoustic Performance of Wind-Turbine Blades	171 889	H2020-EU.1.3.2.	MSCA-IF-2014-EF
ROWED	89216	Reliability assured low cost offshore wind energy demo project	3 047 376	FP5-EESD	
SAFEMILLS	187694	Increasing safety of offshore wind turbines operation: Study of the violent wave loads	309 977	FP7-PEOPLE	FP7-PEOPLE-2013-IEF
SAFESHIP	86899	Reduction of ship collision risks for offshore wind farms	756 699	FP5-EESD	
SAFEWIND	87776	Multi-scale data assimilation, advanced wind modelling and forecasting with emphasis to extreme weather situations for a secure large-scale wind power integration	4 456 002	FP7-ENERGY	ENERGY-2007-2.3-02
SATH	208143	New twin floating platform for offshore wind turbines	49 157	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
SEESWIND	200413	SEESWIND, Silent, Efficient and Economic Small Wind Energy.	50 000	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
SEEWIND	85676	South-East Europe wind energy exploitation - research and demonstration of wind energy utilisation in complex terrain and under specific local wind systems	4 277 361	FP6-SUSTDEV	SUSTDEV-1.1.1
SE-NBW	198936	Demonstration of a self-erection system for wind turbine towers	50 125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
SENTRY	211147	Distributed Acoustic Sensing for Cable Monitoring and Surveying for Offshore Wind Farms providing movement, depth, surface disruption and free-span readings	1 357 579	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
SENTRY	211147	Distributed Acoustic Sensing for Cable Monitoring and Surveying for Offshore Wind Farms providing movement, depth, surface disruption and free-span readings	50 000	H2020-EU.2.3.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
S-Gearbox	197176	The Development of a »New« Planocentric Gearbox with a Closed Cage and S-gear Tooth Flank	50 125	H2020-EU.2.3.1.;H2020-EU.3.4.	IT-1-2015-1
SIROCCO	67399	Silent rotors by acoustic optimisation (SIROCCO)	2 143 405	FP5-EESD	1.1.4.-5.
SIWT	85641	Self installing wind turbine	1 735 430	FP6-SUSTDEV	SUSTDEV-1.1.1
SOPCAWIND	103708	Software for the Optimal Place CAlculation for WIND-farms	1 994 974	FP7-ICT	ICT-2011.4.1
SPARCARB	193946	Lightning protection of wind turbine blades with carbon fibre composite materials	1 095 884	H2020-EU.1.3.1.	MSCA-ITN-2014-EID
STABCON	64880	Aerolastic stability and control of large winf turbines (STABCON)	2 433 225	FP5-EESD	1.1.4.-5.
SUPRAPOWER	106228	SUPerconducting, Reliable, lightweight, And more POWERful offshore wind turbine	3 980 800	FP7-ENERGY	ENERGY.2012.2.3.1
SUPWIND	85650	Decision support for large scale integration of wind power	1 381 466	FP6-SUSTDEV	SUSTDEV-1;SUSTDEV-1.1.7

Acronym	Rcn	Project title	European Commission funding (2016 euros)	Framework Programme	Topic
SWIIS	86971	Small wind industry implementation strategy	396 403	FP5-EESD	
SWIP	110097	New innovative solutions, components and tools for the integration of wind energy in urban and peri-urban areas	4 944 160	FP7-ENERGY	ENERGY 2013.2.3.2
SWITLER	201729	SWITLER:Small WInd Turbine Lightweight Efficient generator	50 000	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
SYSWIND	93018	Training future mechanical, civil, electronic engineers and computer scientists in SYStem Identification, Condition & Health Monitoring for a New Generation of WIND Turbines	3 344 873	FP7-PEOPLE	FP7-PEOPLE-ITN-2008
TAUERNWINDPARK	57693	Tauernwindpark Oberzeiring - Wind Energy at Alpine Site with Severe Weather Conditions	1 942 449	FP5-EESD	1.1.4.-5.2.2
TELWIND	199267	INTEGRATED TELESCOPIC TOWER AND EVOLVED SPAR FLOATING SUBSTRUCTURE FOR LOW-COST DEEP OFFSHORE WIND AND NEXT GENERATION OF 10MW+ TURBINES	3 507 276	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-02-2015
TOP WIND	100475	Technology platform Operational Programme Wind	941 964	FP7-ENERGY	ENERGY.2010.2.3-2
TOPFARM	86364	Next generation design tool for optimisation of wind farm topology and operation	1 969 523	FP6-SUSTDEV	SUSTDEV-1.1.1
TOWERPOWER	185460	Continuous monitoring of the structural condition of the tower and supporting structure of floating and static offshore wind turbines	1 472 525	FP7-SME	SME-2013-2
Triblade	205132	New Rotor Blade Design for Wind Turbines	50 000	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
TRIWIND	210384	A novel and versatile 3-tower maritime structure for the cost-efficient installation of all-sizes offshore wind turbines.	49 157	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
TROPOS	101556	Modular Multi-use Deep Water Offshore Platform Harnessing and Servicing Mediterranean, Subtropical and Tropical Marine and Maritime Resources	4 990 413	FP7-TRANSPORT	OCEAN.2011-1
TWENTIES	94496	Transmission system operation with large penetration of Wind and other renewable Electricity sources in Networks by means of innovative Tools and Integrated Energy Solutions	34 399 570	FP7-ENERGY	ENERGY.2009.7.1.1
UNAELCO	109741	Unsteady aeroelastic control for multi-MW wind turbine rotors	75 588	FP7-PEOPLE	FP7-PEOPLE-2013-CIG
UPWIND	78583	Integrated Wind Turbine Design	17 247 011	FP6-SUSTDEV	SUSTDEV-1.2.6
URBAVENTO	198845	An innovative, small footprint, vertical axis wind turbine for decentralized energy-production designed for urban areas, which is cheap to maintain and ensures energy production even at low wind speed	50 125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
VirtuWind	197348	Virtual and programmable industrial network prototype deployed in operational Wind park	4 887 087	H2020-EU.2.1.1.3.	ICT-14-2014
VORTEX	204580	NEW CONCEPT OF AFFORDABLE WIND ENERGY GENERATORS WITHOUT BLADES	1 328 688	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
WALID	106915	Wind Blade Using Cost-Effective Advanced Composite Lightweight Design	3 995 887	FP7-NMP	NMP.2012.2.2-4
WAUDIT	93290	Wind Resource Assessment Audit and Standardization	4 402 999	FP7-PEOPLE	FP7-PEOPLE-ITN-2008

Acronym	Rcn	Project title	European Commission funding (2016 euros)	Framework Programme	Topic
WEGOOI	210375	Wind Energy Generator Onshore and Offshore Inspector	760 143	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
WELL	198546	Wind, Efficient, Light, Lifter	50 125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
WEMSAR	51210	Wind energy mapping using synthetic aperture radar ('WEMSAR')	799 695	FP5-EESD	1.1.4.-6.
WHEAT	91421	Wind to heat turbine development	28 796	FP5-EESD	
WIDIEC	86989	Wind driven electricity and cooling generation	510 012	FP5-EESD	
WILMAR	70545	Wind power integration in a liberalised electricity market (WILMAR)	1 799 376	FP5-EESD	1.1.4.-5.
WIND TURBARS	106156	On-line Intelligent Diagnostics and Predictive Maintenance Sensor System Integrated within the Wind Turbine Bus-Bar structure to aid Dynamic Maintenance Scheduling	1 090 586	FP7-SME	SME-2012-1
Wind-Drone	211547	A powerful UAV-based ICT solution allowing safe, reliable and effective inspections of wind turbines	49 157	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
WINDENG	65294	Wind energy assessment and wind engineering	1 507 352	FP5-HUMAN POTENTIAL	1.4.1.-1.1.
WINDFARMPERCEPTIO N	84155	Visual and acoustical impact of wind farms on residents	197 723	FP6-SOCIETY	SOCIETY;SOCIETY-WP-2005-4.3.1.5
WINDFLOWER	90495	Aeroelastic tailoring of a passive wind turbine rotor and validation of design code	514 451	FP7-PEOPLE	FP7-PEOPLE-IAPP-2008
WINDGRID	86435	Wind on the grid: an integrated approach	2 002 392	FP6-SUSTDEV	SUSTDEV-1;SUSTDEV-1.1.7
WINDHEAT	106820	Opening New Markets for SMEs: Intelligent Ice Sensing and De-icing System to Improve Wind Turbine Efficiency in Cold Climates	1 134 828	FP7-SME	SME-2012-1
WINDMIL	200747	Smart Monitoring, Inspection and Life-Cycle Assessment of Wind Turbines	1 486 224	H2020-EU.1.1.	ERC-StG-2015
WINDPLUS	57692	High Wind Energy Penetration in Hybrid Wind-Diesel Systems, and Innovative Approach Using Back-To-Back Power Electronic	939 042	FP5-EESD	1.1.4.-5.3.2
WINDRIVE	105891	Industrialization of a 3 MW Medium-Speed Brushless DFIG Drivetrain for Wind Turbine Applications	1 623 600	FP7-SME	SME-2012-1
WINDSCANNER	104728	WindScanner.eu - The European WindScanner Facility	4 450 327	FP7-INFRASTRUCTURES	INFRA-2012-2.2.2.
WINDSEC	86358	Wind energy technology platform secretariat	794 365	FP6-SUSTDEV	SUSTDEV-1.1.1
Windtree	207161	Nature inspired energy generation system for urban distributed power	50 000	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
WINDTRUST	186991	Demonstration of more reliable innovative designs on a 2MW Wind turbine	6 296 253	FP7-ENERGY	ENERGY.2012.2.3.2
WINDUR	110766	Small Wind Turbine for Urban Environments	1 167 081	FP7-SME	SME-2013-1
WINGY-PRO	92780	Increasing efficiency of wind power plants for the production of energy	2 739 198	FP7-ENERGY	ENERGY-2007-2.3-04

Acronym	Rcn	Project title	European Commission funding (2016 euros)	Framework Programme	Topic
WInspector	200009	Advanced shearography kit and a robotic deployment platform for on-site inspection of wind turbine blades	2 317 940	H2020-EU.3.;H2020-EU.2.	FTIPilot-1-2015
WINTUR	93864	In-situ wireless monitoring of on- and offshore WINd TURbine blades using energy harvesting technology	1 219 334	FP7-SME	SME-1
WINTUR DEMO	104591	In-situ wireless monitoring of on - and offshore WINd TURbine blades using energy harvesting technology - Demonstration	1 068 078	FP7-SME	SME-2012-3
WinWind	211548	Winning social acceptance for wind energy in wind energy scarce regions	2 088 628	H2020-EU.3.3.7.;H2020-EU.3.3.3.;H2020-EU.3.3.2.	LCE-21-2017
WISE	86830	Wind energy sodar evaluation	698 337	FP5-EESD	
WITRO	198559	Wind and Turbulence Radar for Offshore wind energy	50 125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
WTSS	211377	Wind Turbine Support Structure	49 157	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
ZephyCloud	201725	Making Wind Energy More Bankable…Faster!	50 000	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
No acronym	61365	100 kw axial flux permanent magnet generator for direct drive stand alone wind turbines	30 184	FP5-EESD	1.1.4.-5.
No acronym	61369	Lowis-development of a new wind turbine with vertical uplift hood for areas with low wind speed	30 184	FP5-EESD	1.1.4.-6.
No acronym	52560	Wind generator system with significant technical advantages over existing technology and particularly suited for integration into the built environment .	30 184	FP5-EESD	1.1.4.-5.
No acronym	59876	Wind energy thematic network	525 075	FP5-EESD	1.1.4.-6.
No acronym	54929	Design of new control and monitoring systems for wind turbines	30 184	FP5-EESD	1.1.4.-6.
No acronym	60027	Networking studies on ice and compliant structures	262 538	FP5-INCO 2	

Table D.2 EU-funded projects of multiple RES technologies, where wind energy is one of the funded technologies

Acronym	Rcn	Project title	EC funding (2016 euros)	Framework Programme	Topic	RE technologies
100 %RES-EL HIERRO	70479	Implementation Of 100 % Res Project For El Hierro Island Canary Island- (main Action: Wind-hydro Power Station). First Phase	2 522 330	FP5-EESD	1.1.4.-5.3.1	Wind, hydro
ACORN	111007	Advanced Coatings for Offshore Renewable ENergy	1 044 124	FP7-SME	SME-2013-1	Wind, ocean
ECO-CITY	85713	Joint ECO-City developments in Scandinavia and Spain	13 784 223	FP6-SUSTDEV	SUSTDEV-1;SUSTDEV-2003-CONCERTO	Wind, bioenergy
EURECONF	57676	European Re Conferences 2001/2002: Integrated Initiative for Pv, Wind & Biomass Technologies for European Competitiveness on the World Re Markets	630 072	FP5-EESD	1.1.4.-5.2.1	Wind, solar PV, bioenergy

Acronym	Rcn	Project title	EC funding (2016 euros)	Framework Programme	Topic	RE technologies
EURECONF	86850	European re- conferences 2001/2002: integrated initiative for Pv, wind & biomass technologies for European competitiveness on the world re- markets	630 072	FP5-EESD		Wind, solar PV, bioenergy
H2OCEAN	102016	Development of a wind-wave power open-sea platform equipped for hydrogen generation with support for multiple users of energy	4 630 318	FP7-TRANSPORT	OCEAN.2011-1	Wind, ocean
HEXATERRA	109873	The development of a modular 'stepping locomotion' system for installation on subsea trenching machines used for subsea energy cable burial	1 208 400	FP7-SME	SME-2013-1	Wind, ocean
HPC4E	199142	HPC for Energy	2 003 172	H2020-EU.2.1.1.	EUB-2-2015	Wind, biofuels
HYBRILA	89225	Hybrid renewable energy project supplying electricity to an Irish local authority	2 585 766	FP5-EESD		Wind, hydro
ICONN	198515	European Industrial DoCtorate on Offshore WiNd and Wave ENergy	847 953	H2020-EU.1.3.1.	MSCA-ITN-2015-EID	Wind, ocean
MARINA PLATFORM	93425	Marine Renewable Integrated Application Platform	9 428 112	FP7-ENERGY	ENERGY.2009.2.9.1	Wind, ocean
MARINCOMP	110244	Novel Composite Materials and Processes for Offshore Renewable Energy	2 381 759	FP7-PEOPLE	FP7-PEOPLE-2013-IAPP	Wind, ocean
MARINERGI	207639	Marine Renewable Energy Research Infrastructure	1 966 067	H2020-EU.1.4.1.1.	INFRADEV-02-2016	Wind, ocean
MARINET	98372	Marine Renewables Infrastructure Network for Emerging Energy Technologies	9 450 610	FP7-INFRASTRUCTURES	INFRA-2010-1.1.23	Wind, ocean
MED2010	54142	Large scale integration of PV and wind power in Mediterranean countries (MED2010)	743 476	FP5-EESD	1.1.4.-5.	Wind, solar PV
MERIKA	111362	Marine Energy Research Innovation and Knowledge Accelerator	3 959 479	FP7-REGPOT	REGPOT-2012-2013-1	Wind, ocean
MERMAID	101743	'Innovative Multi-purpose off-shore platforms: planning, Design and operation'	5 609 878	FP7-TRANSPORT	OCEAN.2011-1	Wind, ocean
OceaNET	109180	OceaNET	3 446 918	FP7-PEOPLE	FP7-PEOPLE-2013-ITN	Wind, ocean
Omniflow	196470	Next-generation hybrid wind and solar power technology	50 125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1	Wind, solar PV
ORECCA	94058	Off-shore Renewable Energy Conversion platforms - Coordination Action	1 731 134	FP7-ENERGY	ENERGY.2009.2.9.2	Wind, ocean
PLENOSE	109725	LARGE MULTIPURPOSE PLATFORMS FOR EXPLOITING RENEWABLE ENERGY IN OPEN SEAS	282 075	FP7-PEOPLE	FP7-PEOPLE-2013-IRSES	Wind, ocean
POSEIDON	197564	Market maturation of Floating Power Plant's Floating Wind- Wave-Energy Device	1 147 010	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014	Wind, ocean
REMAP	84048	Action plan for high-priority renewable energy initiatives in Southern and Eastern Mediterranean area	451 194	FP6-POLICIES	POLICIES-3.2	Wind, solar thermal
RiCORE	194433	Risk Based Consenting of Offshore Renewable Energy Projects	1 397 016	H2020-EU.3.3.7.;H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-04-2014	Wind, ocean

Acronym	Rcn	Project title	EC funding (2016 euros)	Framework Programme	Topic	RE technologies
RO-SWEET	69513	Solar and wind technology excellence, knowledge exchange and twinning actions Romanian centre (RO-SWEET)	450 071	FP5-EESD	1.1.4.-5.	Wind, solar PV
SAFS	209673	Development of scew anchors for floating Marine Renewable Energy system arrays incorporating anchor sharing	192 158	H2020-EU.1.3.2.	MSCA-IF-2016	Wind, ocean
SEAMETEC	194749	Smart Efficient Affordable Marine Energy Technology Exploitation using Composites	50 120	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1	Wind, ocean
SOLEURAS	67851	European-central Asian solar energy conference Tashkent may 2003	25 218	FP5-INCO 2		Wind, solar PV,solar thermal
UPWAVE	200258	Demonstration of a 1-MW wave energy converter integrated in an offshore wind turbine farm	20 722 490	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.;H2020-EU.3.3.;H2020-EU.3.3.2.1.;H2020-EU.3.3.2.	LCE-03-2015	Wind, ocean
WETMATE	106010	WETMATE – a 33kV Subsea Wet-Mateable Connector for Offshore Renewable Energy	1 235 224	FP7-SME	SME-2012-1	Wind, ocean

Annex 4

Technology Sector Report Solar PV

(Deliverable D2.4)

Authors:
Onne Hoogland (Trinomics)
Elske Veenstra (Trinomics)
Perla C. Torres Vega (Trinomics)
Eduardo Roman Medina (Tecnalia)
Hanna Kuittinen (Tecnalia)

1 Introduction

This report is one in a series of eight technology reports for the study *Impacts of EU actions supporting the development of renewable energy (RE) technologies*, prepared for the European Commission. The report has two objectives: 1) describing how EU research and development (R&D) funding for the solar photovoltaic (PV) technologies has impacted the solar PV sector in the EU, and 2) describing more broadly the development of the solar PV sector to which the EU R&D funding has contributed. It is based on a compilation of data from several databases, a questionnaire among coordinators of EU-funded R&D projects, case studies, interviews and literature research. The methodology applied for this study is documented in a separate deliverable[1]. Where relevant, limitations and assumptions are mentioned throughout this report.

Solar PV refers to any technology that converts light into electrical energy using semiconductor materials that exhibit the photovoltaic (PV) effect (creation of electrical voltage and electric current upon exposure to light). The individual solid state devices converting light to electricity are called solar (or photovoltaic) cells, and an array of many solar cells form the initial structure of a solar PV module. A solar PV system includes one or more solar modules, and other elements such as supporting structure, cables and inverters, and is designed to produce specific power and voltage output. This study also covers concentrated PV cells (CPV), which is a type of solar PV system that uses optical elements to focus sunlight onto small, highly-efficient solar cells.

Although solar PV cells were first produced in the late 1950s, they were initially only used in satellites. As improvements in manufacturing, performance and quality of PV modules reduced their cost during the 1970s, they began to be used in remote terrestrial applications, such as signalling devices, telecommunications equipment and other critical, low-power needs. In the 1980s, solar PV cells became a popular power source for consumer electronic devices, including calculators, watches, radios, lanterns and other small battery-charging applications. Significant efforts also began to develop PV power systems for residential and commercial uses for stand-alone, remote power (rural electrification) and utility-connected applications.

The PV market has experienced very fast growth showing a close to 40% Compound Annual Growth Rate (CAGR) of global installed capacity between 2000-2017, making it one of the fastest growing industries in the world. Cell and module efficiencies have also increased dramatically across all PV technologies, and over the last ten years the efficiency of average commercial wafer-based silicon modules has increased from about 12 % to 17 %[2]. In terms of costs, progress has been even more spectacular, with cost reductions of more than 90 % since the 2000s. These improvements in terms of costs, efficiency, lifetime, degradation ratios, etc. would not have been possible without huge R&D efforts carried out in Europe, but also in the US, Japan and China.

Although solar PV is now a highly competitive technology, there is still room to improve cell technologies and to increase efficiency through new cell architectures and materials, and module

[1] Trinomics (2018) - Study on impacts of EU actions supporting the development of renewable energy technologies – Literature review and methodology (Deliverables D1.1 and D1.2)
[2] Fraunhofer ISE (2018) Photovoltaics Report 2017. Available: https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf

designs and concepts. For example, the rear-side passivation technologies (e.g. PERC, PERT and PERL) have been widely introduced to production lines over the last years to achieve higher cell and module efficiencies. Currently, the record cell efficiency for commercial level PERC is close to 24 % for monocrystalline silicon solar cells, and over the next years 25-26 % cell efficiency levels can be reached for commercial cells[3]. In laboratory-scale, much higher efficiencies have already been achieved, with module efficiencies approaching 40 % efficiency, utilising technologies further away from commercial application including multi-junction cells and concentrated photovoltaics. For silicon based PV, the research record cell efficiency is 26.7 % and have been achieved for monocrystalline silicon heterojunction (SHJ) solar cells with rear interdigitated back contacts (IBC)[4]. SHJ combines the advantages of crystalline silicon solar cells with thin film, allowing higher levels of efficiency at low material and production cost. Other technologies such as passivating contacts and back junction back contact with passivating contacts (BJBC) are foreseen to bring further efficiency improvements in near future. Similarly, silicon based tandem and multi-junction technologies are expected to lead to even higher average cell conversion efficiencies in upcoming years through the use multiple junctions made of different semiconductor materials. Over the past few years, perovskite technology has emerged a promising candidate to achieve the efficiency levels of silicon based PV devices but at a lower cost, and so far, the technology has shown very fast evolution of record efficiencies. These technologies are expected to make a significant contribution to sustainable PV deployment (in terms of material inputs, land use and energy return on energy investment – EROI).

[3] Sinke, W. (2018) Si PV technology development in new perspective. Presentation at Advancing PV: from passivation to contacts – A passivating contact workshop. Eindhoven, January 2018.
[4] Green MA, Hishikawa Y, Dunlop ED, Levi DH, Hohl-Ebinger J, Ho-Baillie AWY. Solar cell efficiency tables (version 52). Prog Photovolt Res Appl. 2018;26:427–436. https://doi.org/10.1002/pip.3040

2 Historical R&D funding

2.1 EU R&D funding

The EU has funded solar PV technologies through its research and development programmes. Since FP5, over EUR 800 million has been invested in 462 research projects on solar PV technology, and another EUR 24 million for 16 projects has been invested in combinations of solar PV and other technologies (see Table 2.1).

Table 2.1 EU funding per framework programme (1998 to mid-March 2018, 2016 million euros[5])

	Solar PV		Solar PV and other RES	
Framework programme	EU funding	No. projects	EU funding	No. projects
FP5	119.85	101	2.68	6
FP6	127.26	47	-	0
FP7	418.03	198	15.09	7
H2020	161.19	116	6.03	3
Total EU funding	**826.33**	**462**	**23.80**	**16**

Source: CORDIS (2018)
Note: Funding includes all funds made available through the Framework Programmes. It is not limited to the energy challenges but also includes funding through other programmes/instruments such as the SME instrument.
H2020 includes all projects awarded and registered in CORDIS up to mid-March 2018. As H2020 runs from 2014 to 2020, not all funding had been awarded at this point.
The column 'Solar PV and other RES' includes projects in which solar PV is one of multiple RE technologies.

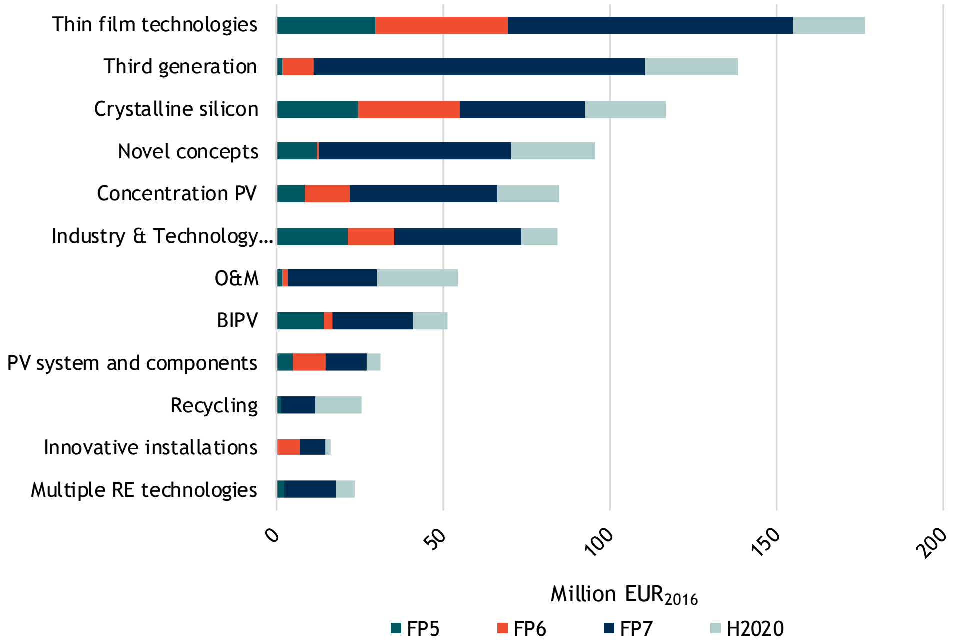
EU R&D funding for solar PV experienced a step change from FP6 to FP7, increasing almost four-fold. For H2020, the total funding is not yet known as the programme has not finished, but the funding that has been allocated so far is already at a higher level than the funding for FP5 and FP6.

2.1.1 *Evolution of research topics*

Research and development is crucial for the advancement of solar PV. Performing joint research addressing well-chosen issues can play an important role in achieving the critical mass and effectiveness required to meet the sector's ambitions for technology implementation and industry competitiveness. The industry has undertaken R&D on many solar PV sub-technologies, of which most received EU funding (see Figure 2.1). Most funding has been allocated to R&D on thin film technologies, especially under FP6 and FP7. Third generation and novel concepts received most funding under later R&D programmes, FP7 and H2020. These sub-technologies also had the largest number of research projects funded in total (see Figure 2.2). Crystalline silicon based technologies have received a significant amount of funding across all four funding programmes.

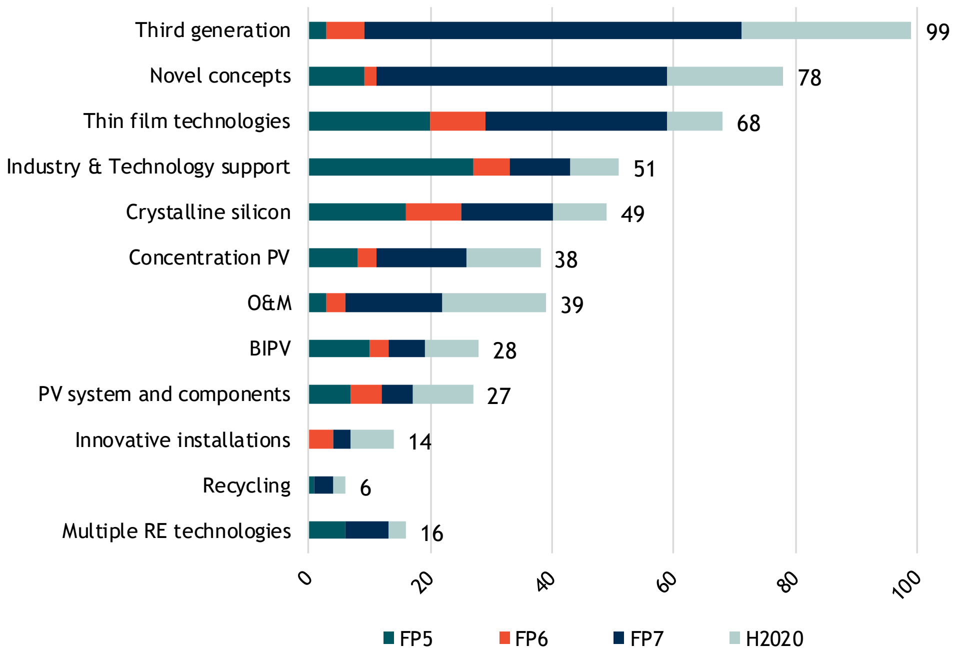
[5] Historical values have been inflation adjusted to arrive at 2016 constant values. This has been done to show the values of budgets, prices and other monetary indicators without the impact of varying price levels over the years so that they can be compared over time more accurately.

Figure 2.1 EU funding per sub-technology/area (2016 million euros)[6]



Source: CORDIS (2018)
The area 'multiple RES technologies' includes projects in which solar PV is one of multiple RES technologies.

Figure 2.2 Number of projects per sub-technology/area



Source: CORDIS (2018)
The area 'multiple RES technologies' includes projects in which solar PV is one of multiple RES technologies.

[6] The classification is partially based on the classification of the EU PV Cluster (see https://www.namec-cluster.org/eupvcluster).
Third generation includes organic PV (OPV), dye-sensitised solar cells (DSSCs), and hybrid organic-inorganic concepts including perovskites.
Novel concepts: PV cells obtained through the application of advanced concepts and materials, such as nanowires, quantum dots, nano-platelets, bio-inspired molecular concepts, or thermophotovoltaics (TPV).
Industry and technology support includes horizontal projects related to research infrastructure, training, market and new business models, standardisation, and legal aspects of PV.
Innovative installations include photovoltaics for distribution systems, PV in transport, infrastructures, low power applications, and demonstrators (exc. BIPV).

Figure 2.1 shows the relevance of different PV technologies in different FP periods. The PV research and technology development activities are characterised by gradual, incremental improvements to achieve higher efficiency, longer lifetime PV devises with lower production and PV system costs. The Framework Programmes from FP5 to H2020 have accordingly supported the European PV sector in achieving these overall goals. The Framework Programmes over the last two decades show however varying strategic importance of the different PV technologies reflecting the general PV sector developments and adapting the research priorities according to the changing context and needs.

At the time when FP5 was launched in 1998, PV was an expensive niche technology, used only in very specific applications. Although considerable part of the FP5 funding was allocated to projects targeting to higher efficiency PV devices based on crystalline silicon and thin-film technologies, it also gave an important impetus to transfer the laboratory level results to industrial-scale, supporting the development of improved production methods and machinery to achieve lower production costs of PV cells and modules. In the early 2000's when the PV market started to take-off in Europe, mainly driven by demand-side policies (such as feed-in-tariffs and tax exemptions), the more advanced production lines and semi-automated manufacturing facilitated the early success of the pioneering PV manufacturing industry in Europe.

The FP6 period (2002-2006) coincided with the emergence of global PV industry and high demand of solar-grade polysilicon, which led to ever rising market prices for polysilicon. The EU PV funding continued to support the efficiency advances and system level cost reductions of the c-Si technology but shifted the focus to include support for development of novel methods to produce polysilicon to secure the EU industry a reliable and affordable access to polysilicon feedstock (see SOLSILC, SPURT, SISI, and SOLSILC DEMO project spotlight boxes). FP6 also supported innovative wafering technologies characterised by less material usage including epitaxial wafer growth technology developed in the FP6 project CRYSTALCLEAR (more details in project spotlight box) or paving the way towards silicon heterojunction technology in the HETSI project, which utilised low temperature growth of ultra-thin layers of silicon onto both sides of a thin crystalline silicon wafer. This line of work was continued in FP7 (2007-2013) in projects such as 20PLμS, R2M-SI, CHEETAH and HERCULES (see project spotlight boxes for more details).

The FP6-7 period also extended the R&I support for lower cost PV technologies such as different thin-film technologies utilising e.g. copper indium selenium (CIS), copper indium gallium selenide (CIGS), and amorphous silicon (a-Si) as semiconductor materials. At that time, the thin-film technologies were considered to provide viable alternatives to c-Si-based technology due to a less costly manufacturing process and reduced use of semiconducting material. For example, the FP6 projects ATHLET and LARGIS explored the large-area thin-film PV technologies to achieve simultaneously lower costs and higher energy yield. FP7 continued to support the wide spectrum of thin-film PV technologies with substantially increased total dedication in projects such as HIPOCIGS and R2R-CIGS (see project spotlight boxes).

Similarly, organic PV (OPV) emerged a R&I funding priority due to the benefits associated to low-cost active layer materials and substrates, low energy input, and easy upscaling. MOLYCELL and X10D are examples of explorative projects, which achieved to take OPV technology closer to market (see more details in project spotlight boxes).

Besides lower cost PV technologies, the FP6-7 period also explored expensive but very high-efficiency PV technologies such as multi-junction PV and concentration photovoltaic systems (CPV) to further expand the EU PV technology portfolio beyond the silicon-based technologies. For example, the FULLSPECTRUM project developed novel materials, concepts and components enhancing light absorption and widening the use of solar spectrum, whereas HICONPV, APOLLON and NACIR projects focused on lowering the costs of high concentration PV systems (see project spotlight boxes for further details).

Towards the end of the FP7 period, the EU manufacturers of c-Si PV cells and modules were seriously impacted by the decreasing global market prices of PV products and imports from the Asian market. At the same time, the market dominance of c-Si technologies had become clearer, and other PV technologies struggled to compete with it in terms of efficiency and costs. The FP funding portfolio was further extended to include exploration of novel very high-performance PV technologies, as well as new applications areas, like building integrated photovoltaics (BIPV), with the aim to differentiate the EU PV research and give a new boost to EU industry to become competitive at global scale. BIPV was seen as an opportunity to support the EU PV industry, since it generates local jobs and demand for local materials due to its links with the construction industry. R&D efforts were oriented towards new solutions for combining PV power generation technology to building elements and overcoming a number of challenges related to cost reduction, architectural and aesthetic considerations, and smart interaction with the grid. The FP7 period also introduced sustainability considerations (in terms of material and rare metal use, recycling) and life-cycle assessment as an integral part of the EU research agenda, and the current H2020 framework programme continues seeking novel approaches e.g. for recycling and reutilising end of life PV modules (see project spotlight box CABRISS as an example). Also, projects aimed at optimising the PV system and downstream PV technologies such as integration of PV technology into the grid received more attention (see examples in project spotlight boxes PVCROPS and PERFORMANCE PLUS).

The current H2020 framework programme (2014-2020) continues to support a wide spectrum of PV technologies. On one hand, a significant proportion of the funding is dedicated to exploration of novel, emerging PV technology development avenues. Projects supporting discovery of innovative materials and PV concepts such as perovskite solar cells, c-Si tandem cells, bifacial cells, and a number of other higher performance c-Si architectures are currently on-going with very promising results (see project spotlight boxes NANO-TANDEM, DISK and CHEOPS). On the other hand, H2020 has set focus on closer to market, and higher TRL level R&I activities. This is especially true for c-Si technology, where H2020 supports a large pilot project AMPERE to accelerate the heterojunction bi-facial solar cell technology market uptake (see project spotlight box for more details), but also in respect to advancing the BIPV technology towards large-scale manufacturing in projects like PVSITES or ADVANCED-BIPV (see project spotlight boxes). The overarching target of H2020 is to seek new sources of industrial competitiveness and to regain large-scale PV manufacturing in Europe.

2.1.2 Top recipients

The top 10 recipients of EU funding for solar PV technologies include 6 research institutes, 3 universities and 1 manufacturer (see Table 2.2). These organisations have received 25% of the EU funding over the most recent years (H2020 and part of FP7), showing that solar PV is a field of research which is not concentrated in the hands of a few organisations but has many participating organisations instead[7].

The research institutes in the top 5 are all globally renowned for their contribution to the development of the technology and have been active in the field since 2000. They are still recognised as leading research institutions and are an important asset for the future of the solar PV sector in the EU.

The only private company in the top 10 is the Italian manufacturer 3SUN, owned by ENEL. They opened an assembly line for the production of bifacial crystalline silicon panels in 2018 and are planning to open an assembly line for bifacial heterojunction panels[8]. Both are innovative technologies for which manufacturing is pioneered by 3SUN.

Apart from 3SUN, there are no private companies in the top 10. The next private companies in the full list are Onyx Solar and Aixtron at rank 30 and 31. Part of the reason for the absence of private companies is the overall decline of the EU PV industry, which has not retained its leading position.

Table 2.2 Top 10 recipients of EU funding by organisation (2008 to mid-March 2018, in 2016 euros)

Rank	Organisation	Type of organisation	Funding
1	Fraunhofer Gesellschaft zur Foerderung der angewandten Forschung e.V.	Research institute	27 442 613
2	Commissariat a l energie atomique et aux energies alternatives (CEA)	Research institute	18 929 295
3	Interuniversitair micro-electronica centrum (IMEC)	Research institute	17 959 827
4	Ecole Polytechnique Federale de Lausanne	Research institute	17 697 468
5	Stichting Energieonderzoek Centrum Nederland (TNO, former ECN)	Research institute	10 691 348
6	The chancellor, masters and scholars of the University of Oxford	University	10 393 175
7	3SUN SRL	Manufacturer	9 195 652
8	Technion - Israel Institute of Technology	Research institute	7 358 909
9	Technische Universiteit Eindhoven	University	7 286 299
10	Universidad Politecnica de Madrid	University	7 198 618

Source: CORDIS (2018)
The source data covered H2020 funding and FP7 funding from 2008, which includes 66 % of total funding for solar PV identified in section 2.1. No data was available for recipients of FP5, FP6 and part of the FP7 funding. Projects under 'multiple RES technologies' are not included in this table.

The main recipients of EU funding in terms of countries are Germany, United Kingdom, Spain, Italy, Netherlands and France (see Table 2.3). These countries received 66 % of the total EU funding available for solar PV, with Germany receiving 20 % of all EU funding.

[7] In RE sectors such as ocean (44%), geothermal (53%) and hydro (71%), the top 10 organisations attract a relatively large share of the total funding. For bioenergy (14%), solar PV (25%), wind (26%), biofuels (31%) and solar thermal (32%), the top 10 organisations attract much lower shares of the total funding available.
[8] Enel, 2018, 3SUN 2.0: Production Launch for Cutting Edge Bifacial Photovoltaic Panels

Table 2.3 Top 10 recipients of EU funding by country (2008 - mid-March 2018, in 2016 euros)

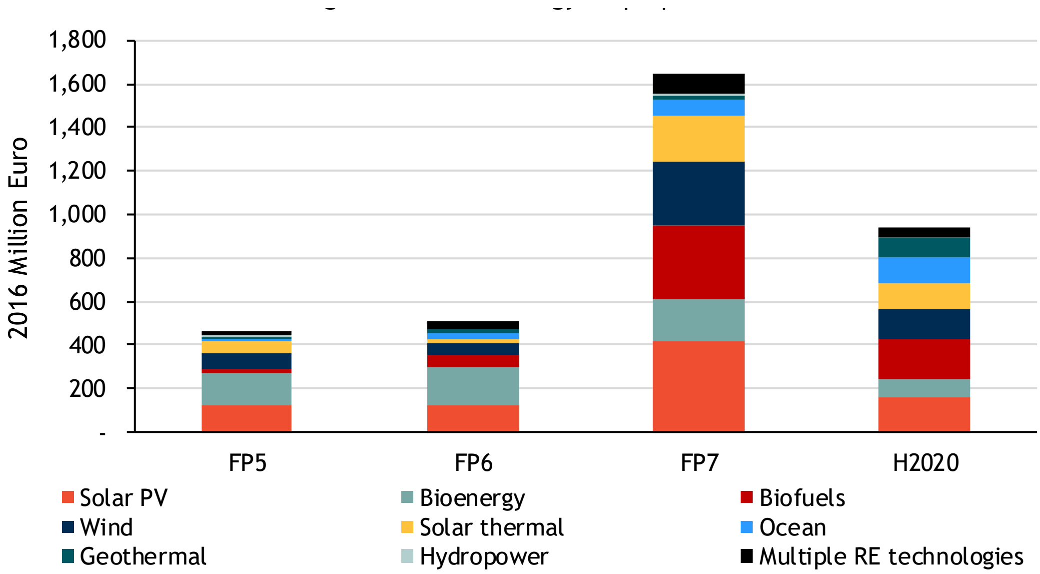
Rank	Country	Funding
1	Germany	109 613 552
2	United Kingdom	55 628 337
3	Spain	52 062 791
4	Italy	50 318 772
5	Netherlands	46 956 353
6	France	45 907 938
7	Switzerland	35 407 804
8	Belgium	32 368 105
9	Israel	17 194 705
10	Sweden	15 074 982

Source: CORDIS (2018)
The source data covered H2020 funding and FP7 funding from 2008, which covers 75 % of total funding for solar PV identified in section 2.1. No data was available for recipients of FP5, FP6 and part of the FP7 funding. Projects under 'multiple RES technologies' are not included in this table.

2.1.3 Share of total RE technology funding

Overall, solar PV projects received 23 % of the EUR 3 600 million awarded to all RE technologies[9] through the FP5, FP6, FP7 and H2020 programmes. In FP5, FP6 and FP7, it received around 25 % of the available funding, but its share has been lower in the first years of H2020, at around 17 %. Still, solar PV is the second highest recipient of funding under H2020 so far (after biofuels) and has been among the top 2 technologies throughout all four FPs reviewed.

Figure 2.3 Share of funding for each technology sector in proportion to overall funding (H2020 only up to mid-March 2018)



Source: CORDIS (2018)
Notes: The area 'multiple RES' includes projects of multiple RES technologies.

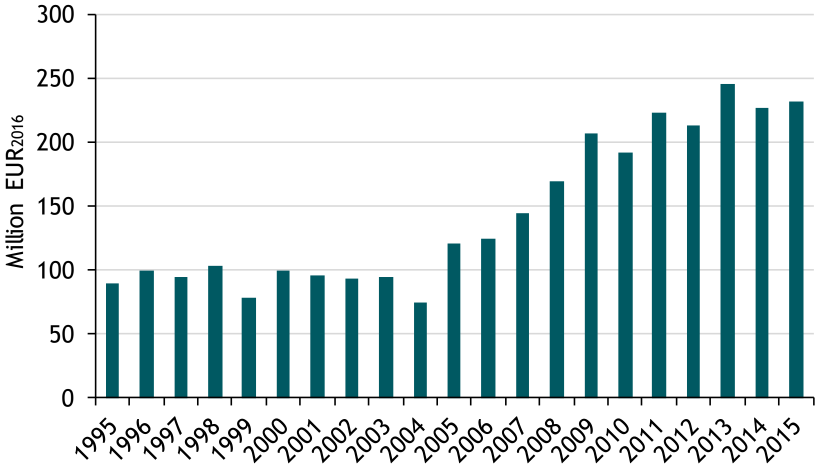
[9] 'All RE technologies' refers to all renewable energy technologies in the scope of this study: solar PV, solar thermal, wind, hydro, bioenergy, biofuels, geothermal and ocean energy.

2.2 Member State R&D funding

2.2.1 Evolution over time

R&D funding for solar PV through national budgets of Member States has more than doubled between 1995 and 2015 (see Figure 2.4). Between 1995 and 2004 funding by MS has remained at or slightly below EUR 100 million per year. After that it quickly grew and has received over EUR 200 million a year from 2011 onwards. MS funding for solar PV is three to four times as large as EU funding for solar PV through the FPs.

Figure 2.4 Annual MS R&D funding in the EU for solar PV

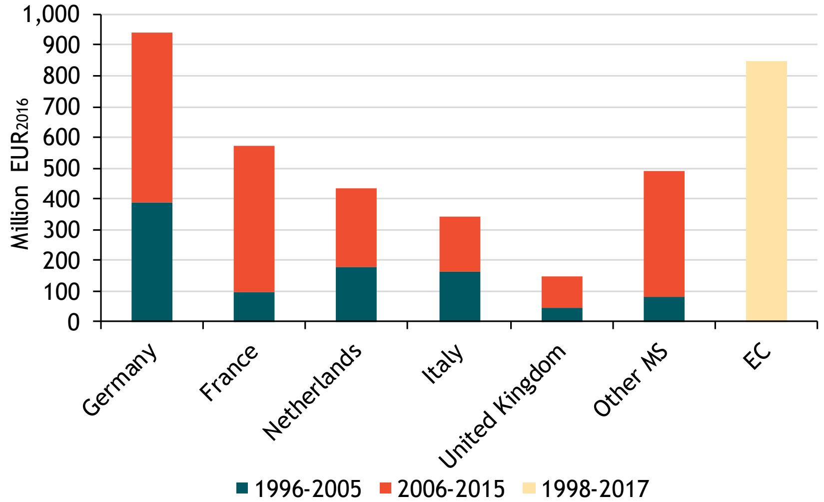


Source: Based on data from OECD/IEA (2018)
Note: Data for 20 EU countries was available in this source: The EU15 plus Czech Republic, Estonia, Hungary, Poland, Slovakia from the New Member States (NMS-13). Data from the source's larger category 'Solar Energy', was grouped according to the definition of solar PV and solar thermal in this study: solar PV data included sub-category 'Solar PV', while solar thermal data included sub-categories 'Solar heating and cooling' and 'CSP'. Budget from the unallocated category 'Unallocated solar energy' that were higher than EUR 1 million were split between solar PV and solar thermal technologies using a using a 5-year ratio of the historic budgets of the respective MS. When no historical ratio was found for a MS, the average EU ratio was used to allocate the budgets. This was the case for 10 MS: Austria, Denmark, Finland, France, Italy, Netherlands, Poland, Slovakia, Spain and UK. Data for the sub-category 'solar PV' was not available for Poland during all the years in the period analysed, for Finland for years 2007 to 2015, for Italy for years 2011 to 2014, for Slovakia for years 2011 and 2012, for Spain for years 2010-2012 and 2014-2015, and for the UK for years 2006-2007, 2010-2012, and 2014. During those years the MS' budgets derived solely from unallocated funding. Data for the overall category 'Solar Energy' was not available for Italy for 1999, 2010 and 2015, and data for the UK was not available for 2008.

2.2.2 Largest MS funders

The largest MS funders of R&D for solar PV are Germany, France, Netherlands and Italy (see Figure 2.5). Together they have provided 79 % of total MS funding. EC funding has been at a level comparable to the main Member States, ranking below Germany but above the other main Member States.

Figure 2.5 Solar PV energy R&D budgets of the Member States with the largest budgets for solar PV (1996-2015) and the EC (1998-2017)

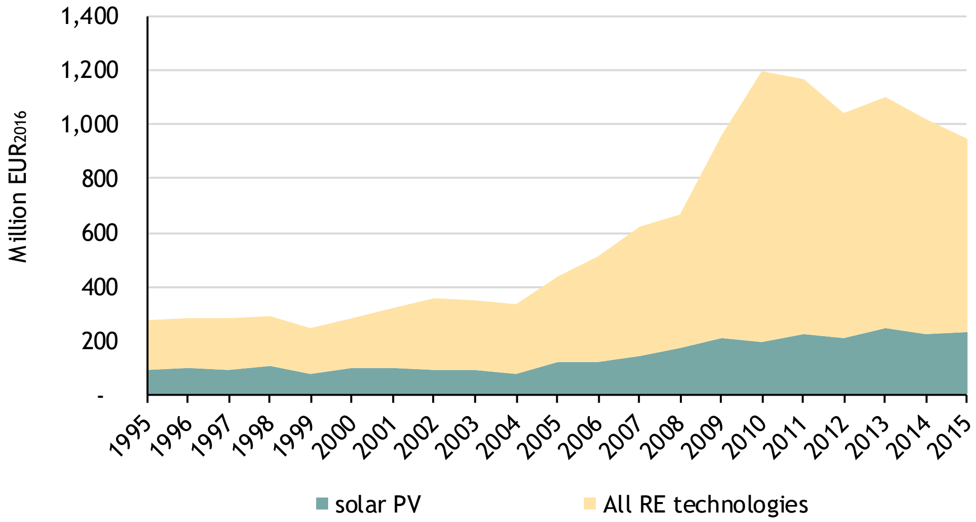


Source: Own elaboration based on data from OECD/IEA and CORDIS (2018). Data for Italy was not available for 2010 and 2015, and data for the UK was not available for 2008.
Note: Time window of comparison between MS and EC funding is shifted 2 years due to data availability of MS budgets for the scope of analysis (FP5-H2020).

2.2.3 Share of total RE technology funding

During the period 1995 to 2015, Member States allocated 24 % of their National RD&D funding for Renewable Energy technologies to solar PV. From 1995 to 2001 the share of solar PV was particularly high at between 30 % to 35 % of the overall budgets. In 2002, the share of solar PV declined to 26 % and has remained at comparable levels until 2008. From 2009 onwards, the share has been lower with values around 20 % in most years. Overall, solar PV received EUR 3 billion of MS funding from 1995 to 2015, which makes it the number 1 RE technology in terms of MS funding.

Figure 2.6 Share of National R&D funding for solar PV in proportion to the overall funding for all RE technologies



Source: Based on data from OECD/IEA (2018)
Note: Data for 20 EU countries was available in this source: The EU15 plus Czech Republic, Estonia, Hungary, Poland, Slovakia from the New Member States (NMS-13). Data for Italy was not available for 2010 and 2015, and data for the UK was not available for 2008.

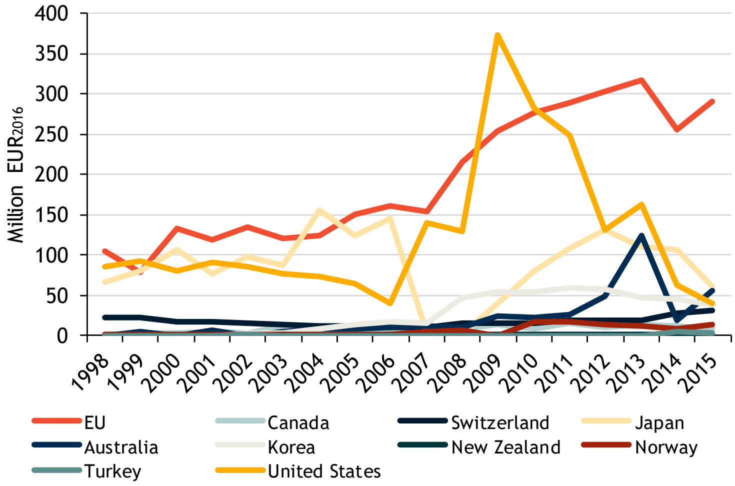
2.3 Private and international R&D funding

2.3.1 International public R&D funding

Funding from the EU and MS for solar PV technologies is larger than in other countries, with spending at an average of EUR 180 million per year between 1998-2015. The United States provided EUR 121 million on average between 1995-2015, followed by Japan who provided EUR 83 million on average. Other countries with significant R&D budgets for solar PV are Korea, Australia and Switzerland.

Traceable figures[10] of Chinese public R&D spending for solar are in the order of EUR 70 million in total between years 2000 and 2015, accounting for central and provincial levels[11]. Another EUR 200 million were found in a combination of government and corporate sources during the whole 2005-2015 period, however the details of how much of this figure came from public spending are not available[12]. On an annual basis, these estimates would translate to R&D spending of roughly EUR 25 million/year, which is significantly lower than the EU funding levels. But due to the lack of traceable data, these figures should be treated with caution.

Figure 2.7 Comparison of international R&D funding for solar PV



Source: OECD/IEA (2018)
Note: EU: European Commission and Member State budgets combined. National budgets for 2016 were excluded from the analysis because they are early estimates and lack reliability/coverage. Data covers 20 EU countries: the EU15 and Czech Republic, Estonia, Hungary, Poland, Slovakia and the European funding programmes FP5, FP6, FP7 and H2020. For countries outside the EU, national budgets were available for Australia, Canada, Japan, Korea, New Zealand, Norway, Switzerland, Turkey and the US. Data for Italy was not available for 2010 and 2015, and data for the UK was not available for 2008.

2.3.2 Private R&D funding

There was no data available for private R&D funding of solar PV in the selected source. Solar PV and solar thermal were aggregated under the category 'Solar' and could not be disaggregated reliably.

[10] As noted by the source, it is very difficult to obtain accurate data on Chinese government solar R&D spending. The traceable sum of Chinese R&D spending included only those amount that could be verified by the source, based on reviews of publicly available documents and on interviews. The presented figure is incomplete and the total sum of solar R&D spending in China is probably underestimated by a large amount. Obtaining accurate data on Chinese government solar R&D spending is difficult.
[11] Ball et al., 2017, The New Solar System; China's Evolving Solar Industry And Its Implications for Competitive Solar Power In the United States and the World
[12] Ibid.

2.4 Conclusions

Solar PV has been one of the main RE technologies funded through the EU Framework Programmes, receiving 23 % of the total funding. Similarly, EU Member States have also allocated substantial budgets to solar PV R&D with 24 % of the total available R&D funding for RE technologies being allocated to Solar PV over the past 20 years. However, these shares have been declining for EU and MS R&D budgets from shares between 25 % and 35 % before 2000 to less than 20 % in recent years. Nevertheless, the combined EU and MS budgets are at a world-leading level, providing a solid basis for EU leadership in PV.

The research topics supported through the Framework Programmes clearly reflect the research priorities and industry requirements throughout the past 20 years. At the time of FP5, the focus was on both c-Si and thin film technologies and the transfer of laboratory results to industrial scale manufacturing in order to bring the costs of PV technology down. Once the PV industry started to gain momentum during FP6, important issues such as the high polysilicon costs were addressed and lower cost technologies such as several thin film technologies were supported. Besides lower cost PV technologies, the FP6-7 period also explored expensive but very high-efficiency PV technologies such as multi-junction PV and concentration photovoltaic systems (CPV) to further expand the EU PV technology portfolio beyond the silicon-based technologies. Towards the end of the FP7 period, the EU manufacturers of c-Si PV cells and modules were seriously impacted by the decreasing global market prices of PV products and imports from the Asian market. At the same time, the market dominance of c-Si technologies had become clearer, and other PV technologies struggled to compete with it in terms of efficiency and costs. The FP funding portfolio was further extended to include exploration of novel very high-performance PV technologies, as well as new applications areas, like building integrated photovoltaics (BIPV), with the aim to differentiate the EU PV research and give a new boost to EU industry to become competitive at global scale. The current H2020 framework programme continues to support a wide spectrum of PV technologies with the objective of seeking new sources of industrial competitiveness and to regain large-scale PV manufacturing in Europe.

3 Research effectiveness

R&D projects can lead to patents, publications, spin-offs and several other, less concrete but potentially important direct outputs such as standardisation and knowledge exchange. Such impacts are the most direct impacts of R&D funding and therefore provide the cleanest view on the effectiveness of research budgets spent. In this section we discuss patents, publications, spin-offs and other direct research outputs, and their relation to R&D funding for the solar PV sector.

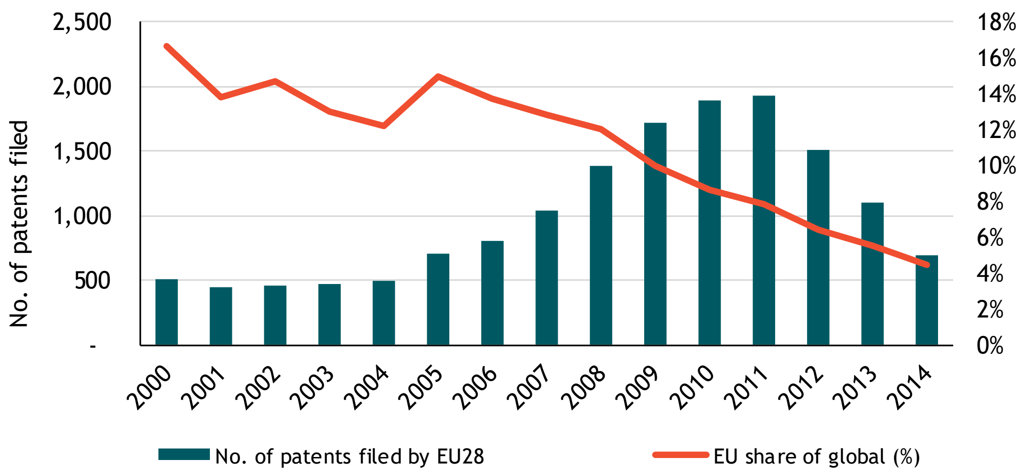
3.1 Patents

Patents are a commonly used indicator to measure the output of R&D funding as they provide a direct measurement of the impact in terms of novel knowledge generated. Furthermore, patent data are readily available, in a standardised form. However, some limitations have to be taken into account, such as the fact that filing a patent is not an objective of all research projects and that the economic value of patents differs significantly.

3.1.1 Evolution over time

Figure 3.1 shows the evolution of patents filed for solar PV technologies in the EU. The number of EU patents increased until 2011, after which it decreased again to pre-2006 levels.

Figure 3.1 Evolution of solar PV patents filed by EU countries



Source: IRENA INSPIRE (2017)

There is a downward trend in EU's share of global patents, from 17 % in 2000 to 4 % in 2014. The global number of patents follows the same trend as the EU, with a peak in 2011 of almost 25 000 patents, and thereafter decreases again. The main exception of this downward trend was China, the only major country that did not experience a decline in patenting activity. The number of filed patents per year is clearly linked to the number and position of existing companies in the solar PV value chain: companies in the upstream (raw materials, ingots, wafers, cells, modules, inverters) tend to protect their knowledge by filing patents. Unfortunately, Europe has been losing market shares and companies in the upstream solar PV value chain since 2011 and this has been reflected in the number of patent applications. Furthermore, several EU industry experts mentioned that the effectiveness of patents for protecting intellectual property has diminished, as innovations are often copied anyway and courts do not rule in favour of the owners of the patent.

In the EU, more than half of all patents have been filed in Germany, reaching nearly 8 000 between 2000 and 2015. France is second with 12 % of all EU patents, followed by Spain (9 %) the UK (8 %), and Austria (6 %). Germany, France and the UK also have large R&D budgets allocated to solar PV. The other two large funders, the Netherlands and Italy, have a more modest share of patents filed (3 % and 4 %, respectively) than could be expected based on their R&D budgets.

The reduced number of patents filed alone does not indicate a decline in innovation activities as shown by the improved conversion efficiency in the last years. World records of PV cells efficiency have been broken frequently, almost every year since 2010, and alternative technologies have also shown fast progress[13]. The countries driving these product innovations are the United States, the EU (mainly Germany), Japan and Australia[14] (see Table 3.1). Several EU projects have contributed to these efficiency records through incremental innovations to crystalline silicon cells or by developing new manufacturing processes for thin-film technologies, as illustrated in the 'project spotlight' boxes on the HETSI (in Section 4.1), HIPOGICS and R2R-CIGS projects (in Section 3.2.3). The FULLSPECTRUM project (see project spotlight box below) is an example of a project that achieved multiple world records for multi-junction solar cells efficiencies, while project X10D improved the efficiency of Organic PV ('project spotlight' box in Section 3.1.3). On the other hand, even though there is a high patenting activity observed in China, Chinese firms tend to file more patent applications for a similar innovation output (they patent minor inventions intensively)[15].

Table 3.1 Best-in class product innovations by PV cell type and country from 1976 to 2017.

Region	Crystalline silicon cells	Thin-film technologies	Multi-junction cells (two-terminal, monolithic)	Single-junction GaAs	Emerging PV	Total
United States	23	72	36	10	20	161
EU	9	16	9	6	9	49
Japan	12	7	6		7	32
Australia	16					16
Rep. of Korea		1		2	5	8
Canada					7	7
Switzerland		1			6	7
China	2	3	0	0	1	6
India		3				3

Source: Carvalho, M. et al. 2017.
Notes: EU aggregates best-in class product innovations from Germany, France, Netherlands, Austria and Spain.

[13] NREL, 2018, Best research cell-efficiencies. See: https://www.nrel.gov/pv/assets/pdfs/pv-efficiencies-07-17-2018.pdf
[14] WIPO, 2017, World Intellectual Property Report 2017: Intangible capital in global value chains
[15] De la Tour, A. et al., 2011, Innovation and international technology transfer: The case of the Chinese photovoltaic industry

Project spotlight: Make use of the full solar spectrum - FULLSPECTRUM

The FULLSPECTRUM project (A new PV wave making more efficient use of the solar spectrum; FP6-2002-ENERGY-1/IP; November 2003 to October 2008; EC funding: EUR 8.3 million; Coordinator: Universidad Politecnica de Madrid, Spain) tested new materials and components to achieve solar cells with efficiencies above 35 %. The project developed multi-junction solar cells, and explored also thermophotovoltaics (TPV) using special wafers taking advantage of solar heat through specifically conceived emitters. The project dedicated considerable efforts also to improve the use of the wider solar spectrum by applying materials that enhance light absorption, molecular-based concepts, dye cells and up-and-down converters for solar cells. The project resulted in industrial prototypes of multi-junction solar cells with compact concentrators, achieving five world records in terms of cell efficiencies, including 37.6 % efficiency using monolithical triple-junction solar cells at high concentration, 28.6 % for concentrator GaAs (gallium arsenide), 32.6 % for dual-junction cells, 3.96 % for fuel-fired TPV systems, and 7.1 % luminescent solar concentrator cells. The triple-junction cells, compact high concentration modules and concentrator characterisation tools were available for mass production at the end of the project. In general, the project was internationally acknowledged as very successful collaboration and led to, apart from world-record PV efficiencies, a number of publications, patents, and follow-up projects.

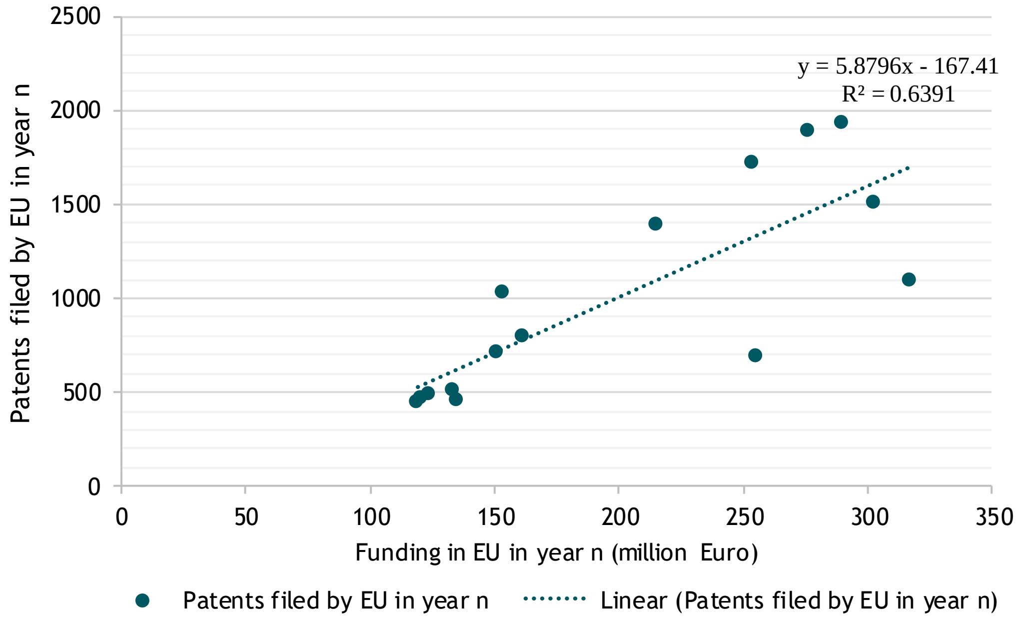
Source: EC, 2018, Community Research and Development Information Service.

3.1.2 Effectiveness of R&D funding in producing new patents

In theory, higher R&D budgets in a region are expected to lead to an increase in the number of patents filed from that region. The extent to which this relation exists in the solar PV energy sector provides insight into the objectives of the research (is it targeted at technology development, so more likely to result to a patent application?) and the effectiveness of the research (was it successful in developing the technology so resulting in a patent application?).

Figure 3.2 compares the total amount of patents filed to the amount of EU R&D funding (MS + EU combined), accounting for a time lag between the moment of funding and the patent application. The highest correlation is visible without a time lag. Even then, there is only a moderate correlation between the number of patents and the amount of EU funding. This is in line with the findings for other RE sectors and underlines that patent applications are generally not a primary objective of a research project.

Figure 3.2 Patent effectiveness



Notes: We tested a delay of 0, 1, 2, 3, 4 and 5 years for the patents filed from year 2000-2014. 2015 data of patents was excluded because the source (IRENA) mentioned it is common to have delays of 3 years from a patent application and the year is reflected in the database. The correlation went up when 2015 data was excluded. A delay of 0 years between funding year and patents filed showed the highest correlation (R^2 = 0.6391).

3.1.3 Contribution of EU funding

To capture data on the impact of EU funding through the Framework Programmes (FP5 to H2020), a questionnaire was sent to all project coordinators of EU-funded R&D projects. 462 solar PV projects were identified for this study. It was not possible to contact all project coordinators (due to missing contact links on CORDIS), but 363 project coordinators were contacted with a request to participate in the questionnaire. The overall response rate was 14 % (51 out of 363 projects). Project coordinators of FP7 and H2020 provided the majority of responses.

Based on the questionnaire, about one third of the projects (18 out of 51, ~35 %) reported a patent application as a result of their project indicating that EU funding contributes to the patenting activity in the EU. For instance, project X10D is an example of an EU-funded project that delivered multiple patent filings (see project spotlight box below).

Project spotlight: Towards more efficient organic PV - X10D

The X10D project (Efficient, low-cost, stable tandem organic devices; FP7-ICT-2011-7/CP; October 2011 to September 2014; EU funding: EUR 8.6 million; Coordinator: IMEC, Belgium) was set-up to support competitiveness of organic photovoltaics (OPV) by uniting forces of the key actors along the OPV value chain. The objective of the project was to develop efficient, low-cost, stable tandem organic solar cells by applying new designs, materials and manufacturing technologies. The project developed new highly efficient small molecule and polymer donor materials, and reached over 6 % efficiencies in single junction solar cells, and with the polymers they measured more than 7 %. Among the explored new materials and fabrication processes, tandem cells stood out and the project achieved record multi-junction devices with efficiencies of 8.9 % and 9.6 %, and an externally certified world record tandem cell with a 12 % power conversion efficiency cell on 1 cm^2 accomplished by the project partner Heliatek (Germany). The project also explored new ways to OPV encapsulation and achieved promising results based on low-cost, flexible polymer encapsulation system with high H2O-barrier properties. In addition, the project resulted in 49 peer-reviewed publications in conferences and journals, and to four patent filings. After the project, the project partners IMEC, Holst Centre, ECN, and TU Eindhoven established a joint research alliance called Solliance in the field of thin-film photovoltaics. Heliatek has enhanced its OPV world record efficiency to 13.2 %, and continues the work towards market launch of OPV solar films in the application areas of buildings and automotive industry.

Source: EC, 2018, Community Research and Development Information Service; Final Report of the project and Heliatek webpage available at www.heliatek.com.

3.2 Publications

Publications of research papers are a useful indicator to measure the output of R&D funding, as there is enough data available to make a comparison between the EU's performance and the rest of the world. Moreover, publications have a close relation with public R&D funding, allowing us to differentiate the effect of public R&D funding from private R&D funding. Publications are categorised by country on the basis of the address of the author. If it has authors from different regions, the publication is counted for both regions.

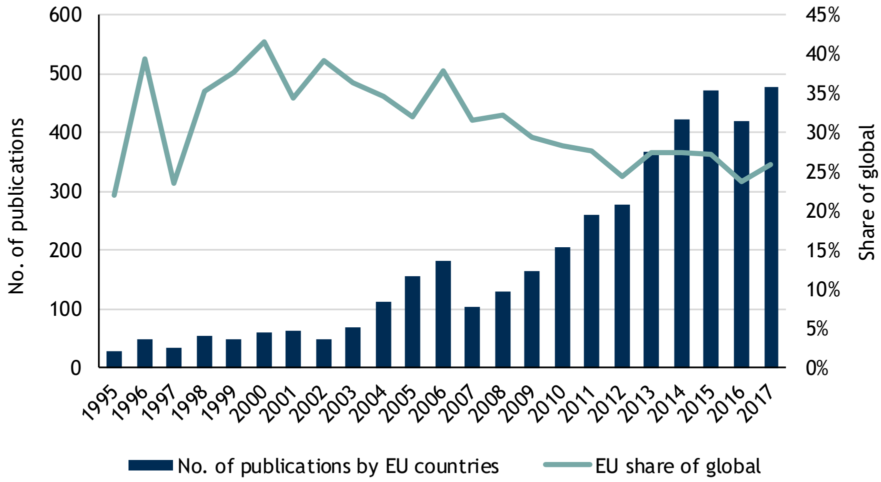
3.2.1 Evolution over time

Figure 3.3 shows the profile of solar PV publications by EU-based authors over the years. The number of publications on solar PV had an upward trend over the years, with a slight decrease in 2007-2008.

EU-based authors were involved in a quarter of the global publications between 1995 and 2017. Overall, the EU has maintained a leading position in PV publications, but authors from China and the USA follow closely, contributing to 19 % and 18 % of global publications respectively (see Figure 3.4). Japan and South Korea have also authored a significant number of publications, accounting for 8 % of global publications each.

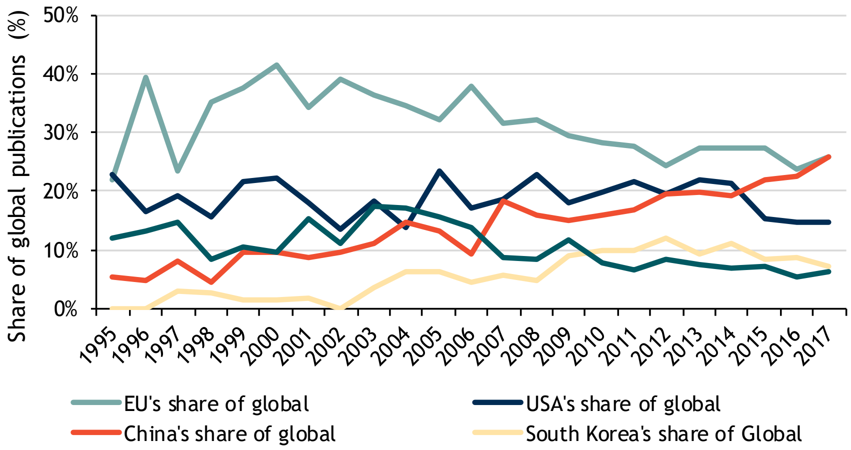
In the EU, most publications had authors from the UK (827), followed by Germany (731), Spain (614), France (555), Italy (549) and the Netherlands (226). This corresponds with the MS that had the largest R&D budgets, with the notable exception of Spain, which has a relatively small R&D budget but still manages to produce a significant number of publications and patent applications (see section 3.1).

Figure 3.3 Evolution of solar PV publications by EU countries



Source: Web of Science (2018)
Notes: keywords used are: 'photovoltaic' not 'therm*' not 'heating' in the title, topics and abstract of articles between 1995-2017. The results were refined to include the publications of the top 6 research areas: physics, materials science, energy fuels, chemistry, engineering and science technology other. The share of global refers only to those publications with an address listed. 0.3 % of the global publications had no address listed in that period of time. One article can have multiple authors (therefore, also multiple countries). The count is the number of articles in which at least one author listed an EU MS as their address.*

Figure 3.4 Comparison of the share of solar PV global publications between key countries



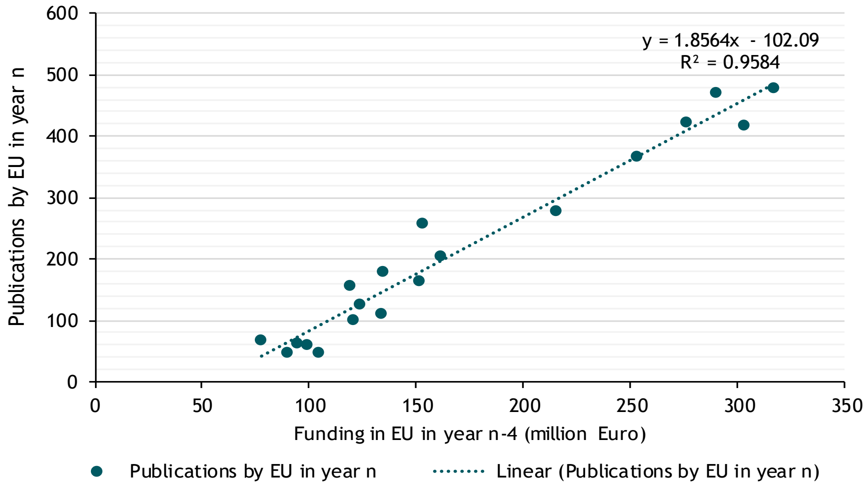
Source: Web of Science (2018)
Notes: The shares of the different countries/regions are not cumulative since one article can have multiple authors (therefore, also multiple countries).

3.2.2 *Effectiveness of R&D funding in producing publications*

In theory, higher R&D budgets in a region are expected to lead to an increase in the number of publications from that region. The extent to which this relation exists in the solar PV energy sector provides insight into the objectives of the research (does it aim for a publication?) and the effectiveness of the research (is it successful in realising a publication?).

Figure 3.5 compares the total amount of EU publications to the amount of EU R&D funding (MS + EU combined), accounting for a time lag between the moment of funding and the publication. The number of publications correlates more closely to R&D funding than the number of patents does, indicating that publicly funded R&D projects in the solar PV sector have a higher focus on publishing and/or are more effective at publishing. This is in line with the findings for other RE sectors and underlines that publishing is often one of the primary outputs of an EU-funded research project.

Figure 3.5 Publication effectiveness



Notes: We tested the publication effectiveness of R&D funding for the period 1995-2017. Funding in EU includes EU funding and MS funding. We tested different delays (0, 1, 2, 3, 4 and 5 years) to evaluate which one had the highest correlation. After two years of delay, for each year of delay, the sample size was reduced by one number (e.g. with 0, 1 and 2 years of delay the sample size was 21 years, with 3 delay the sample size was 20 years).
With no delays (n-0), the R^2 is the lowest of all the ones tested (0.7471). The highest R^2 was found using 4 years of delay (0.9584).

3.2.3 Contribution of EU funding

Between 2008 and 2017, 531 publications explicitly reported benefitting from EU funding sources, which is 13 % of the total number of EU publications in those years. Not all publications report their sources of funding, therefore it is likely that the real figure is higher. The EU funding sources are not always specified and may therefore include funding from other instruments than the Framework Programmes for research and technological development, such as funding from the EIB and FET.

From the 51 projects that completed the questionnaire, 37 reported to have publications as one of the outputs of their project. In general, publications tend to be one of the most frequently reported outputs of research across different RE technologies. The HIPOCIGS, NANOTANDEM and CHEOPS projects (see project spotlight boxes below) are examples of projects that delivered many publications. Overall, these figures indicate that the Framework Programmes clearly play an important role in maintaining the EU's leading academic position in solar PV.

Projects spotlight: Flexible, low-cost CIGS solar cells – HIPOCIGS and R2R-CIGS

The HIPOGICS project (New concepts for high efficiency and low cost in-line manufactured flexible CIGS solar cells; FP7-ENERGY-2009-1; January 2010 to December 2012; EU funding: EUR 3.6 million; Coordinator: ZSW, Germany) resulted in material modifications and adaptation of manufacturing processes of copper indium gallium selenide (CIGS) thin-film solar cells. The project tested various low-cost materials to optimise the solar cells quality and costs, and achieved a world record efficiency of 18.7 %. The project led to an advancement of roll-to-roll (R2R) manufacturing of CIGS cells and the industrial partner Flisom (Switzerland) established a prototype production line. The CIGS manufacturing equipment provider Manz (Germany) had plans to exploit the project results by constructing appropriate production equipment for flexible CIGS modules, whereas Tata Steel and Pemco expressed interest in the further development of substrates for CIGS PV applications. The project also resulted in more than 20 publications, and led to a follow-up project R2R-CIGS (below).

The R2R-CIGS project (Roll-to-roll manufacturing of high efficiency and low cost flexible CIGS solar modules; FP7-NMP-ENERGY-2011; April 2012 to September 2015; EU funding: EUR 7 million;

Coordinator: TNO, Netherlands) project developed and scaled-up R2R processes to manufacture CIGS alloy based PV modules on a polymer substrate. These flexible and lightweight modules can be installed to irregular surfaces such as building walls. At the end of the project, thirteen key exploitable results were identified with a high technology readiness level (TRL) (6 to 7) including a fluor-free weatherproof polymer front sheet, and a R2R laser scribing technology for making monolithic interconnected modules. Thanks to the project, the participating companies Beneq (Finland), VDL Flow (Netherlands) and Mondragon Assembly (Spain) were able to improve their R2R module manufacturing equipment and tools. Furthermore, manufacturing equipment providers Manz and Flison were able to explore new manufacturing methods, possibly replacing the current manufacturing lines in future.

Source: EC, 2018, Community Research and Development Information Service.

Project spotlight: Novel nanowire based high efficiency PV cells - NANOTANDEM

The NANO-TANDEM project (Nanowire based Tandem Solar Cells; H2020-LCE-2014-1/RIA; May 2015 to April 2019; EU funding: EUR 3.6 million; Coordinator: University of Lund, Sweden) aims to develop very high efficiency nanowire tandem solar cells based on semiconductor materials III-V that use very little material, and a manufacturing technology to produce them in cost-efficient manner. The project aims to demonstrate an experimental proof of a tandem solar cell composed of a top pn-junction formed in III V nanowires and series connected to a bottom pn-junction formed in silicon. These cells are fabricated either by direct growth of the nanowires on silicon layer or by transferring a film of nanowires embedded in a polymer onto a silicon bottom cell. The project has made a significant contribution to the number of publications from the EU with 25 peer-reviewed papers published so far, 9 of them in journals with impact factors of more than 10. Furthermore, project partner Sol Voltaics expects to take some of the developed technologies to the market by 2019-2020.

Source: EC, 2018, Community Research and Development Information Service; Project website available at https://nano-tandem.ftf.lth.se; Interview with the project coordinator.

Project spotlight: Taking perovskite PV towards market - CHEOPS

The CHEOPS (Production technology to achieve low Cost and Highly Efficient phOtovoltaic Perovskite Solar cells; H2020-LCE-2015-1-two-stage/RIA; February 2016 to January 2019; EU funding: EUR 3.3 million; Coordinator: CSEM, Switzerland) is an on-going H2020 project aimed at developing very low-cost but highly performing photovoltaic (PV) devices based on the emerging perovskite (PK) technology and advance the potentially game-changing PK technology towards the market. So far, the results of the project have been promising. A team of researchers from EPFL and CSEM partially supported by the CHEOPS project have achieved an efficiency of 25.2 % with a combined silicon and perovskite-based tandem cells. The research also demonstrated how the perovskite deposition process is fully compatible with existing industrial monocrystalline silicon manufacturing lines, and the efficiency could eventually rise to above 30 %. The findings of the study has led to 9 publications, some of them in high impact journals like *Nature Materials*, and 22 conference posters and presentations. The project has also developed a unified standard for measurement and testing of perovskite-based photovoltaic devices and gathered the European perovskite community together to discuss the main challenges.

Source: EC, 2018, Community Research and Development Information Service; Project website available at www.cheops-project.eu.

The top EU organisations in terms of publications are listed in Table 3.2. It shows that almost all of the top EU organisations in terms of publications received considerable funding through the EU framework programmes. This substantiates the conclusion that EU funding plays an important role in maintaining academic leadership, which is also recognised by the industry experts interviewed for this study.

Table 3.2 Top organisations in the EU contributing to solar PV publications (1995-2017)

Rank	Institutions	Country	No. Publications	EU funding rank
1	Centre National de la Recherche Scientifique CNRS	France	321	11
2	University of Cambridge	UK	137	20
3	Helmholtz Association	Germany	123	13
4	Consiglio Nazionale delle Ricerche CNR	Italy	117	25
5	Imperial College London	UK	114	15
6	Fraunhofer Gesellschaft	Germany	90	1
7	Universidad Politecnica de Madrid	Spain	88	10
8	Commissariat à l'énergie atomique et aux énergies alternatives (CEA)	France	87	2
9	Universidad de Jaen	Spain	81	29
10	Universite Paris Saclay Comue	France	77	30+

Source: Web of Science (2018)
Note: The count is the number of articles in which at least one author listed the European organisation as their address.

3.3 Start-ups and spin-offs

The creation of start-ups and spin-offs is another potential impact of research projects, which can function as an important link between the research and the development of a European industry. Start-ups and spin-offs are not reported consistently, however. Therefore, questionnaire results are used to provide insight into these impacts.

4 projects (Crystal Tandem Solar, VaporPV, PRINTSolar and SBskin) out of those who responded to the questionnaire (~ 8 %) reported the creation of a start-up or spin-off as a result of participating in an EU-funded project. Apart from the creation of new start-ups, the EU has also funded 32 SMEs in the solar PV sector through the SME instrument which aims to support ground-breaking innovative ideas developed by small and medium-sized companies[16] and is part of the Framework Programmes. This way, the start-ups that emerge across the EU are supported in the development of their technology.

Aside from the projects mentioned before, R2M-SI is an example of a research project that ultimately resulted in a spin-off (see project spotlight box below).

Project spotlight: Towards novel solar wafer manufacturing technology – R2M-SI

The R2M-SI project (Roll to Module processed Crystalline Silicon Thin-Films for higher than 20 % efficient modules; FP7-ENERGY-2010-FET/CP; October 2010 to September 2013; EC funding: EUR 2.8 million; Coordinator: FhG-ISE, Germany) is an example of an EU-funded project that led to the creation of a spin-off. The project had the objective to overcome the cost-reduction barriers of PV technologies by implementing so called crystalline silicon (c-Si) thin-film lift-off approach. The project coordinator Fraunhofer-ISE developed this technology further; the ProConCVD (Production Continuous Chemical Vapor Deposition Reactor) produces high quality crystalline silicon layers specifically meeting the needs

[16] European Commission, n.d., Horizon 2020 ; SME Instrument. Available at: https://ec.europa.eu/programmes/horizon2020/en/h2020-section/sme-instrument

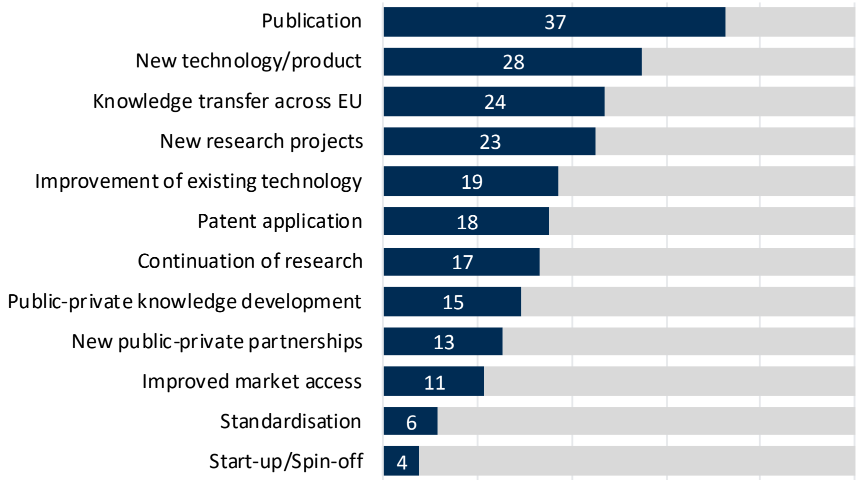
of c-Si thin-film solar cells. In 2015, Fraunhofer launched a spin-off company NexWafe to take the technology towards mass production.

Source: EC, 2018, Community Research and Development Information Service; Fraunhofer, 2015, NexWafe GmbH – Fraunhofer ISE Starts a New Spin-Off Company – Kerfless Wafer Technology to Bring Cost of Photovoltaics Down and Reduce Waste.

3.4 Other research outputs

While patents, publications and start-ups/spin-offs are often the most tangible and easily quantifiable outputs of EU-funded research of RE technologies, there are many other outputs that contribute to the development of a leading sector. To get a better understanding of the other impacts, a questionnaire was sent out to project coordinators of EU-funded R&D projects. The results of the questionnaire are presented in Figure 3.6.

Figure 3.6 Impacts of EU funding based on questionnaire results (out of 51 responses in total)



Source: Own elaboration based on questionnaire conducted as part of this study.

After publications, new technology or product development is the most frequent outcome of EU-funded research in the solar PV sector. More than half of the projects (28 out of 51, ~55 %) that participated in the questionnaire reported the creation of new technologies or products as research outputs. These developments are spread across different PV technologies as indicated before in the analysis of research topics (see section 2.1.1). Examples include:

- Novel materials, concepts and components that enhance light absorption, thus widening the use of solar spectrum (e.g. multi-junction solar cells) and leading to enhanced efficiency (e.g. the FULLSPECTRUM project).
- Organic PV devices through the use of new materials (see X10D project), and new solar cells combining traditional materials and nanotechnology-enabled materials such as nanowires. The NANOTANDEM project is a prime example of this.
- Novel concentrating PV systems with increased efficiency, reliability and lower environmental impact, as illustrated in the HICONPV, APOLLON and NACIR project highlight box (chapter 5).

Furthermore, about one third of the projects reported cost reductions as one of the outputs of their project. Many of these projects were focused on reducing the costs of crystalline silicon-based cells and modules (discussed in more detail in chapter 4). Other projects explored cost reductions in thin-film technology. This is the case for ATHLET, a FP6 project that accelerated the development of thin-film PV technologies by proving reduced costs through efficiency improvements and the improvement of manufacturing equipment. These responses illustrate that many of the projects contributed to advances in the performance and costs of PV technology, leading to increasingly competitive technology.

Knowledge-transfer across Europe was also frequently reported (24 out of 51, ~47 %) as an outcome of EU-funded projects. By bringing together different organisations throughout the EU, projects contribute to knowledge transfer and stimulate further innovation and cross-fertilisation. The MOLLYCELL project, summarised in the 'project spotlight' box below, is an example of a project that contributed to the enhanced collaboration between the European research and industrial PV community. Moreover, the EU has supported the establishment and consolidation of the activities of the European Technology and Innovation Platform Photovoltaics[17], and the EERA Joint Programme Photovoltaic Solar Energy[18].

Project spotlight: Towards large-scale production of OPV - MOLYCELL

The MOLYCELL project (Molecular orientation, low-band gap and new hybrid device concepts for the improvement of flexible organic solar cells; FP6-2002-ENERGY-1/STREP; January 2004 to June 2006; EU funding: EUR 2.5 million; Coordinator: CEA, France) had the objective to take organic solar cells towards large-scale production. The project developed two device concepts: the 'all-organic' solar cells concept and the nanocrystalline metal oxides/organic hybrid solar cells. The project demonstrated polymer/fullerene blend devices with certified efficiencies of 4.8 %, solid state dye-sensitised solar cells with efficiencies of 4.2 %, and strong progress on the development of organic photovoltaic modules on plastic substrates, including demonstrating of 10 cm^2 module with efficiency of 3 %. The project advanced significantly the TRL of OPV, led to many publications and to a patent, and most importantly brought together the European OPV community for the first time, and established a joint roadmap for future research and development.

Source: EC, 2018, Community Research and Development Information Service; EC, 2009, Photovoltaic Solar Energy: Development and current research; and Technopolis, 2014, Evaluation of the impact of projects funded under the 6th and 7th EU Framework Programme for RD&D in the area of non-nuclear energy.

The creation of new research projects and the continuation of existing research were reported as outcomes by 23 and 17 project coordinators out of 51 respectively. These figures underline how EU R&D funding contributes to continuity in EU solar PV research.

Joint knowledge development with the private sector, the creation of new public-private partnerships and improved market access for project participants were reported as outcomes by 15, 13 and 11 projects (out of 51) respectively. These indicators are important as cooperation between private and public entities suggests interest in the technology for private investment and commercialisation. Such interest could in turn lead to the market uptake of the technology and job creation (see chapter 5).

[17] European Technology & Innovation Platform Photovoltaics (n.d.). ETIP PV: Homepage. Available at: http://www.etip-pv.eu/
[18] European Energy Research Alliance (n.d.). See https://www.eera-set.eu/eera-joint-programmes-jps/photovoltaic-solar-energy/

Standardisation and the creation of start-ups/spin-offs (see discussion above) are the least frequently reported outcomes of EU funding in the solar PV sector.
EU funding also had an impact on other factors not listed in the figure above. The CABRISS project described in the 'project spotlight' box below is an example of such a project that has contributed to the European Solar PV field in ways other than those already discussed (e.g. by incorporating principles of the circular economy in the area of solar PV).

Project spotlight: Recycling, recovering and reusing PV materials - CABRISS

The CABRISS project (Implementation of a CirculAr economy Based on Recycled, reused and recovered Indium, Silicon and Silver materials for photovoltaic and other applications; H2020-WASTE-2014-two-stage/IA; June 2015 to May 2018; EU funding: EUR 7.8 million; Coordinator: CEA, France) developed technologies for recycling, recovering materials from end-of-life PV modules and PV production waste, and re-use silicon waste in PV cell manufacturing process. The main results of the project included:

- A new technology and equipment for automated dismantling and delamination the PV cells layer-by-layer, enabling the glass to be removed undamaged.
- A novel cost-efficient technology for recycling silicon kerf from diamond wire cutting processes resulting in high purity silicon powders suitable for melting in furnaces.
- Technology for purification of silicon recovered from different sources (kerf, demetallised broken cells, wafers or demetallised silicon from end of life panels).
- Process for utilising secondary silver recycled from PV waste to produce conductive pastes and inks used for PV manufacturing, and secondary indium recycled from thin film PV waste tested in thin film PV manufacturing or in the production of indium tin oxide (ITO) targets.

The use of recycled silicon from different sources of PV waste has been tested in several conventional production processes, resulting to second life silicon solar cells based on 100 % recycled silicon, reaching efficiencies comparable to commercial PV cells.

The project resulted in four patent applications, 22 publications in peer-reviewed journals and conferences, and contributed to related standardisation processes. The work carried-out is currently continued in a number of new projects.
More information on the project is available as a case study in the annex of this report.

3.5 Conclusions

The significant MS and EU budgets for solar PV have been effective in establishing and maintaining a leading academic position globally. The EU is number 1 in terms of publications and has been able to preserve this leading position irrespective of the increased efforts from China in particular. The contribution of EU funds to EU research leadership is clearly visible with the majority of the EU-funded projects reporting 1 or more publications as the output of their project, and virtually all top publishing EU organisations receiving substantial funding through the EU Framework Programmes.

The conversion of R&D budgets to patents has been less successful with a consistently declining share of global patents and in recent years also a decline in the absolute number of patents from the EU. This can be attributed to the decline of the EU industry, with less EU companies left to participate in patenting activities. Nevertheless, there is evidence that the EU was one the drivers of solar PV innovations in terms of demonstrating world record solar cell efficiencies.

In addition, EU-funded research projects have contributed to the development of several new technologies such as organic PV, multi-junction cells and CPV. Some of these have led to new products being launched to the market. Several new companies have been founded thanks to EU-funded projects and several start-ups have been supported in their growth. EU projects also contributed to cost reductions of crystalline silicon and thin-film technologies through the exploration of new materials and improved manufacturing processes, and have also facilitated closer cooperation between the private and public sector. Overall, this signals that EU-funded research has been able to deliver market-relevant knowledge.

4 Technology development

One of the core objectives of R&D funding on RE technologies is to contribute to the development of the technology to make it cost competitive and allow for increased uptake of the technology. The impacts on technology development can be assessed technologically, or from an economic point of view, looking at the costs, performance and competitiveness of the technology. This section focuses on key indicators that assess technology development from an economic point of view: capex, opex and Levelised Cost of Energy (LCOE).

4.1 Capex

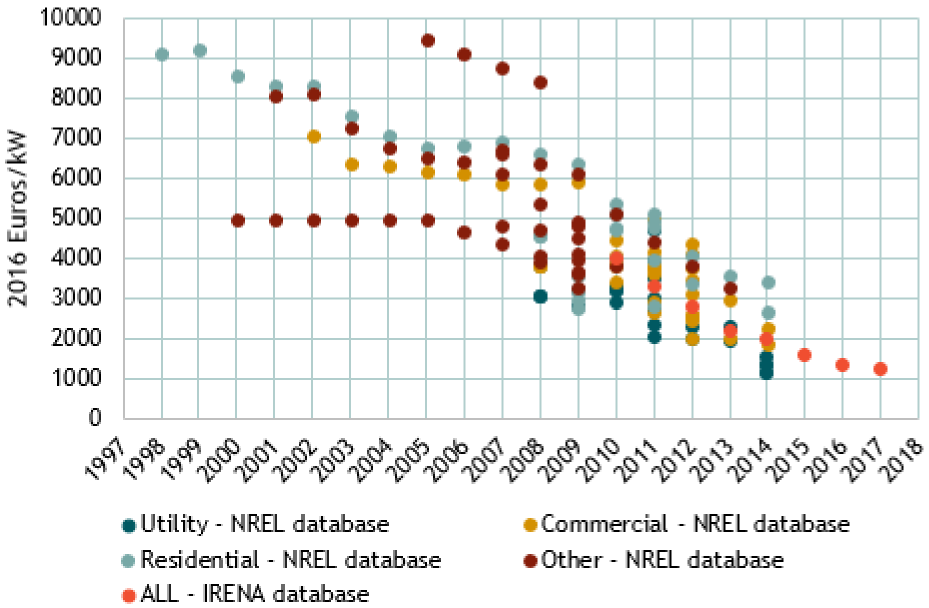
Capex (capital expenditure) refers to the initial investment costs of the solar PV projects. Cost-reducing innovations can contribute to a downward trend in capex, which in turn can make the sector more cost competitive and allow for increased uptake of the technology. One of the main limitations of this indicator is that capex is highly dependent on installation size and technology, and will therefore vary between projects. To be able to provide an overview of the evolution of the capex over time, we consider global historical estimations of capex, including the estimations of regions outside the EU.

Capex in this context includes the all-inclusive turnkey PV system price to be paid upfront. The main cost components considered for PV are the module, inverter, tracker/structure, rest of the balance-of-system (BOS) elements and the cost of installation. Within the BOS, different elements are also considered, some of them efficiency-related (e.g. cabling, structures and logistics) and others non-efficiency related (e.g. combiner box, transformers, fuses, protections and monitoring tools). Within the installation cost component, at least the following costs should be considered:

- administrative costs (e.g. permissions, local taxes and documentation);
- planning, engineering and project management;
- PV plant construction (mounting, cabling, installation) and development;
- installer’s margin.

Average capex costs for solar PV technology have significantly fallen over the last decades (see Figure 4.1). For residential and commercial systems, the capex has decreased from EUR 8 000/kW and higher in the 2000s to less than EUR 2 000/kW in recent years. Utility scale plants saw capex falling from EUR 3 000/kW in 2008 to below EUR 1 000/kW in 2016, cutting costs by two thirds in only eight years. Interestingly, the average capex costs remained more or less constant between 2004 and 2008, even though manufacturing technology continued to improve. Feed-in tariffs and expanding markets in Germany and Spain allowed project developers to be profitable at that price level, which in turn alleviated the pressure on lowering capex costs.

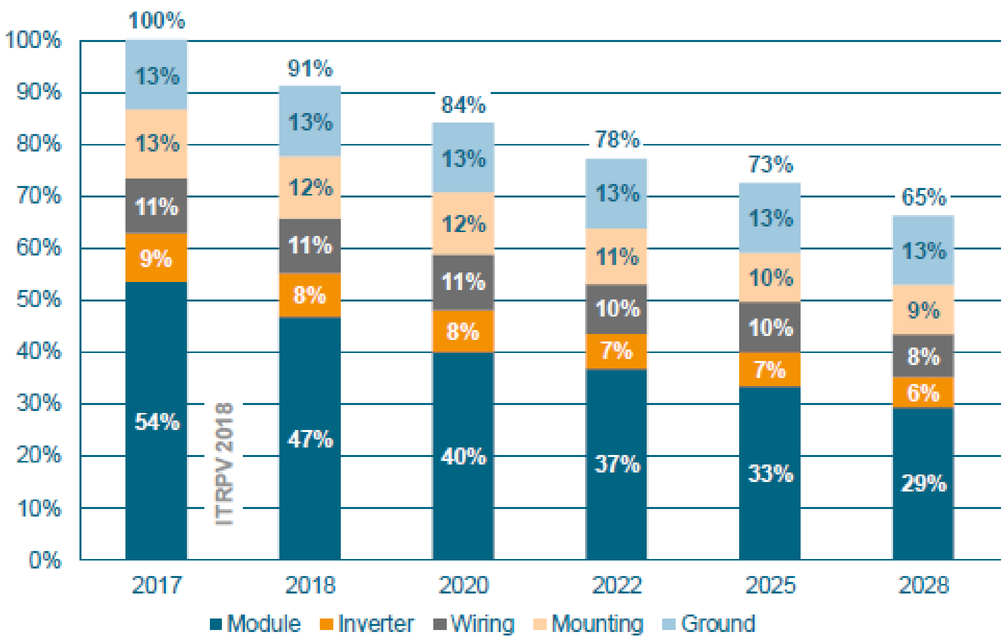
Figure 4.1 Evolution of solar PV capex for electricity generation



Notes:
All figures are global, unless specified otherwise.
For electricity generation, data was taken from NREL database and from IRENA database. IRENA's data is the 'Global weighted average' based on their database with ~15 000 real projects.

Average capex cost for modules decreased the most and now makes up less than 50 % of total capex, compared to 70 % in 2008[19]. If this trend continues, then solar PV modules will account for 25 % or less of the total capex by 2030 (see Figure 4.2) and this would be the main driver for the reduction of the PV installation costs. Although other hardware components (e.g. inverters and cables) are similar worldwide, there are other elements of capex costs that differ between countries including those related to permits, licensing and connection to the grid.

Figure 4.2 Cost breakdown for a PV system in Europe (for systems of more than100 kW)



Source: ITRPV (2018)

[19] JRC (2016) PV Status Report 2016

During the early 2000's there was a temporary shortage of polysilicon, which increased costs and limited silicon cell production[20]. Throughout this period a number of EU projects like SOLSILC, SPURT, SISI, and SOLSILC DEMO resulted in novel methods for reducing silicon cell production costs, see 'project spotlight' box below for their details. However, the emergence of large-scale Chinese cell and module manufacturers in the late 2000's marked a turning point for the industry and consequently enabled rapid cost reductions thanks to economies of scale in addition to the ongoing technological improvements. Notably, the majority of the added PV production lines in China were imported turn-key manufacturing equipment from European suppliers (especially from Germany)[21]. The HERCULES project (see project spotlight box at the end of this section) is an example of an EU-funded project that supported the development of new manufacturing equipment in collaboration with European equipment suppliers (Meyer Burger in this case).

Project spotlight: Novel methods for low cost solar-grade silicon production
SOLSILC, SPURT, SISI, and SOLSILC DEMO

A series of FP5-6 projects supported the discovery, refinement and upscaling of a novel method for manufacturing low cost silicon to ensure reliable and cost-competitive solar-grade silicon feedstock supply in Europe.

The SOLSILC project (A direct route to produce solar grade silicon at low cost; FP5-EESD/CSC; March 2000 to February 2003; EU funding: EUR 1.1 million, Coordinator: Scanarc Plasma Technologies, Sweden) developed a new low-cost and more energy-efficient process for solar grade silicon production. The Solsilc process is based on forming silicon metal in a two-step process: 1) in a rotary plasma furnace, pellets of quartz and carbon black are reacted to form silicon carbide and 2) in an electric arc furnace, the reaction of quartz and silicon carbide leads to the formation of silicon melt. The resulting silicon melt is saturated with carbon, which is removed in a subsequent purification process.

The SPURT project (Silicon purification technology for solar cells at low costs and medium scale; FP5-EESD; January 2002 to March 2004; EC funding: EUR 988 000; Coordinator: S'ENERGY, Netherlands) was focused on up-scaling, reliability and cost-effectiveness of this purification process (i.e. removal of carbon left from the process used to reduce the quartz and metals from the silicon).

The SISI project (Silicon for solar cells at low costs on an intermediate scale; FP6-2002-SME-1; September 2004 to November 2011; EC funding: EUR 0; Coordinator: S'ENERGY, Netherlands) picked-up the results of SOLSILC and SPURT, and worked towards a scale-up of the Solsilc technology and demonstrated that the method is feasible for industrial-scale production of solar-grade silicon. The project also resulted in a detailed plan for the development and realisation of a pilot facility.

The FOXY project (Development of solar-grade silicon feedstock for crystalline wafers and cells by purification and crystallisation; FP6-2004-ENERGY-3/STREP; January 2006 to December 2008; EC funding: EUR 2.7 million; Coordinator: SINTEF, Norway) had the objective to further develop and optimise refining, purification and crystallisation processes for solar grade silicon feedstock. In addition, the project also looked at the possibilities of recycling silicon.

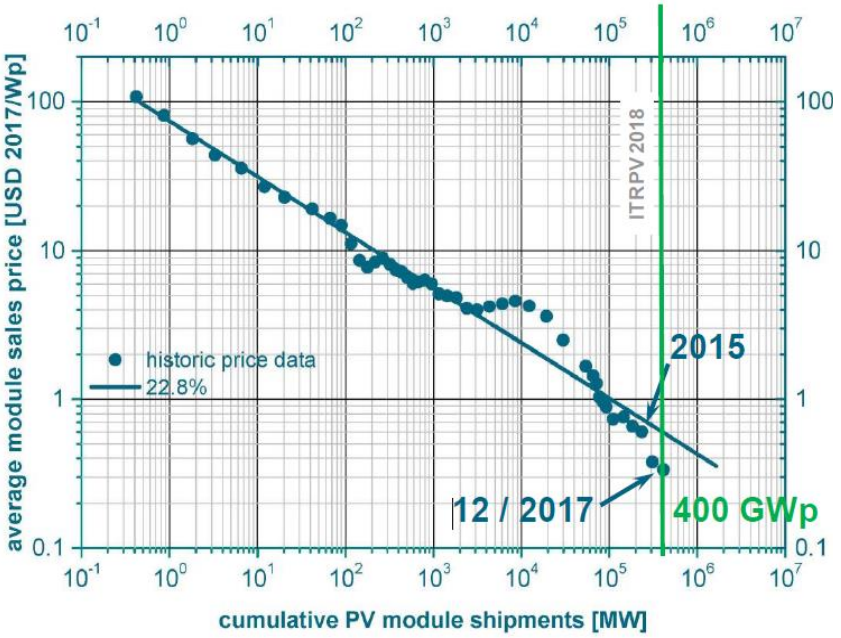
[20] JRC (2016) PV Status Report 2016
[21] Huang et al., 2016, How China became a leader in solar PV: An innovation system analysis

The SOLSILC DEMONSTRATOR project (Validation of a direct route for production of solar-grade silicon feedstock for crystalline wafers and cells; FP6-2005-TREN-4/STREP; June 2007 to May 2009; EU funding: EUR 1.5 million; Coordinator; SUNERGY INVESTCO BV, Netherlands) contributed towards building a pilot-scale plant in Trondheim based on Solsilc process. The pilot factory was built in 2009 by a Fesil-Sunergy, a company formed by Sunergy (a Dutch investment company, part of a Dutch utility company Delta) and Fesil (Norwegian ferrosilicon manufacturer). The company had plans for industrial-scale production. However, before these plans were realised, the global market price of solar-grade silicon decreased significantly, and as a result the Solsilc process was assessed not to be cost competitive. In 2011, Fesil-Sunergy and Solsilc assets were sold to Evonik Solar Norge AS, a subsidiary of Evonik Industries AG (Germany).

Source: EC, 2018, Community Research and Development Information Service; Ceccaroli, B., Ovrelid, E. and Pizzini, S., 2016, Solar Silicon Processes: Technologies, Challenges, and Opportunities.

The relation between the module price and the cumulative module shipments is an important parameter for the analysis of cost evolution. This relation is often explained with the 'learning curve (LC)', also called 'learning rate (LR)'. In the case of PV technology, the learning rate for the period 1976-2017 was 22.8 %, with more than 400 GW of cumulative module shipments. This means that every time that the cumulative PV module shipments doubled, the price was reduced by the 22.8 %. If the period between 2006 and 2017 is considered, the learning rate is even greater at 39.1 %. The EU funding played an important role in the cost reduction of PV modules by consistently supporting projects that improved the efficiency of PV cells and modules, as in the case of consecutive projects HETSI, HERCULES and DISC (se project spotlight below).

Figure 4.3 Learning rate for PV modules as a function of the installed capacity



Source: ITRPV (2018). Presentation by Markus Fischer.

Project spotlight: High efficiency PV cells – HETSI, HERCULES and DISC

The HETSI project (Heterojunction Solar Cells based on a-Si c-Si; FP7-ENERGY-2007-1-RTD/CP-FP; February 2008 to January 2011; EC funding: EUR 3.4 million; Coordinator: CEA, France) aimed to boost the competitiveness of crystalline silicon PV technology by tackling the most critical issues including reduction of silicon material consumption, increase of solar cell efficiency, and improved integration of solar cells into modules. The project resulted in a record cell efficiency of 20.7 % on large area n-type crystalline silicon wafers, and design and development of a dedicated module process based on conductive adhesive curing at low temperatures led to very low power losses (1 %) when the solar cells were incorporated into PV modules. Moreover, the findings of the projects were further explored in successive projects HERCULES and DISC.

The HERCULES project (High efficiency rear contact solar cells and ultra-powerful modules; FP7-ENERGY-2013-1/CP; November 2013 to October 2016; EC funding: EUR 7 million; Coordinator: CEA, France) took the promising results of HETSI project towards industrial-scale pilots and was set-up to reinforce PV industry in Europe. The project resulted in the development of large area heterojunction bifacial (SHJ) solar cells reaching an efficiency of almost 23 % at the laboratory scale. Project partners Meyer Burger (Switzerland) and CEA-INES (France) developed pilot lines with capacity of producing 2 400 wafers per hour. They have also demonstrated industrial readiness by scaling-up to the production of more than 100 000 SHJ cells with efficiencies over 22 %. In addition, they have worked towards novel solutions to connect solar cells into panels more efficiently.

The ongoing DISC project (Double side contacted cells with innovative carrier-selective contacts; H2020-LCE-2016-RES-CCS-RIA; October 2016 to September 2019; EU funding: EUR 4.7 million; Coordinator: Institut fur Solarenergieforschung, Germany) is partially based on the results of projects HETSI and HERCULES. The objective is to develop new generation high-efficiency solar cells with target efficiency above 25.5 % and module-level efficiency of 22 %. So far, the project has already developed 200 cell precursors, with very promising test results.

Source: EC, 2018, Community Research and Development Information Service; Ribeyron, P.J. et al., 2011, Record European efficiency amorphous silicon heterojunction solar cells: final results from the HETSI project; and Interview with DISC's project coordinator. DISC's project website available at www.disc-project-h2020.eu.

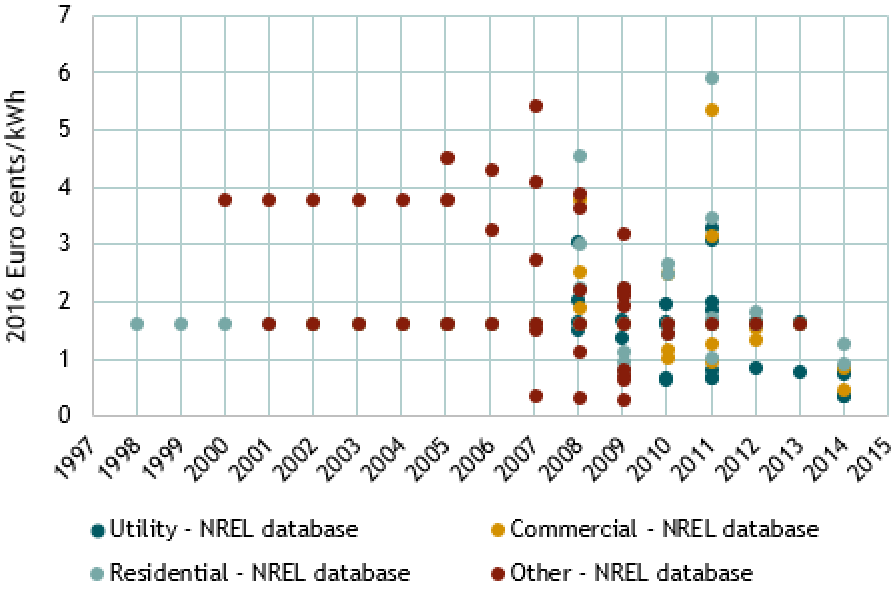
4.2 Opex

Opex (operational expenditure) includes fixed and variable costs for operation and maintenance (O&M) of the plants. Similar to capex, cost-reducing innovations and similarly, innovations that improve the system degradation and energy production of PV systems, and reduce the O&M tasks, can contribute to a downward trend in opex, which in turn can make the sector more cost competitive. Only global figures were available for the opex.

Opex is usually associated with O&M costs as there are no fuel costs related to PV generation. Within the opex, the following costs can be distinguished: cost for O&M (fixed costs: preventive and predictive O&M; and variable costs: corrective O&M); other costs for operation including asset management, insurance, security, billing, monitoring, land/roof cost or rental price, network access fee; and dismantling and recycling cost.

Figure 4.4 shows the evolution of the opex for solar PV. Depending on the technology and scale, the opex ranges from 0.3 EURct/kWh to 2 EURct/kWh in recent years.

Figure 4.4 Evolution of solar PV opex for electricity generation



With system prices at the level of EUR 6 000/kWp before 2010, opex costs were largely considered irrelevant in the economic assessment of a given PV plant. Recently, the reduction in capex and further pressure to reduce the costs for solar PV electricity has clearly contributed also to the reduction of opex costs. For example, in Germany the O&M costs for large systems is already below EUR 10/kWp a year. Total opex costs of EUR 17.5/kWp a year were also reported for the smaller market segments (residential, commercial, industrial) in 2017, whilst opex costs for utility-scale (more than 50 MWp) system are 25 % less (EUR 13/kWp a year).

In most opex analyses, it is assumed that 50 % of opex is area-dependent, and thus will reduce as module efficiency improves. By 2050, this is expected to lead to a 30 % reduction of average opex costs. It is also anticipated that standardisation, more efficient processes and competition will result in a further 30 % reduction in average opex costs by 2050 compared with 2015 levels.

Several EU-funded R&D projects contributed to the reduction of opex costs for solar PV systems. Examples include PVCROPS and PERFORMANCE PLUS, which developed hardware, software and guidelines to optimise the design of PV systems, and to enhance the integration of PV technology into the grid (see project spotlight box below). Through these contributions, energy production by PV systems can be increased and O&M costs can be reduced.

Projects spotlight: Cost reductions through PV system design and operation

PVCROPS and PERFORMANCE PLUS

The PVCROPS project (Photovoltaic cost reduction, reliability, operational performance, prediction and simulation; FP7-ENERGY-2012-1-2STAGE/CP; November 2012 to October 2015; EU funding: EUR 3.8 million; Coordinator: Polytechnic University of Madrid, Spain) developed solutions aimed at minimising levelised cost of energy (LCOE) and enhancing integration of PV technology into the grid. The results of the project included an open-source modelling simulation tool (SISIFO) for estimating and optimising the design of grid-connected PV systems. The project also developed a toolbox for predicting PV power fluctuations and hardware and software solutions to manage PV energy flows and optimise control strategies. The project also resulted in a solution kit for testing and commissioning of PV plants and a web platform that provides hourly solar irradiation data all over Europe aimed at ensuring quality of PV plant design and operations. One of the most important results of the PVCROPS was the development of a free and open-source simulation toolbox, called SISIFO, for robust design of PV systems. The design tools developed in the project can improve the performance ratio of PV systems by 6.8 %, and the tools for automatic detection of power failures lead to an additional 3.1 % increase in performance. As the application of these tools does not imply any additional costs, the performance increase can be translated into an equivalent (~10 %) decrease of LCOE. In addition, the power prediction tool and grid connection solutions involving integration of batteries in PV systems, both studied in the project, were each estimated to lead to an additional 10 % reduction in LCOE.

The PERFORMANCE PLUS project (Tools for Enhanced Photovoltaic System Performance; FP7-ENERGY-2012-1-2STAGE/CP; November 2012 to October 2015; EU funding: EUR 3.1 million; Coordinator: 3E, Belgium) focused on improvements that can be achieved on a PV system level in the design and operation phases. The project developed more economical and reliable sensor prototypes for measuring direct and indirect solar irradiation. These sensors were tested and validated at five different locations in Europe. The project also developed a model-based predictive control framework to optimise the grid integration of PV systems and published a series of best practice guidelines for grid-connected PV modelling and monitoring based on data of 25 PV systems distributed across Europe.

Source: EC, 2018, Community Research and Development Information Service; PERFORMANCE PLUS Project website available at www.perfplus.eu. More information about the PVCROPS simulation toolbox: https://www.sisifo.info/.

4.3 LCOE

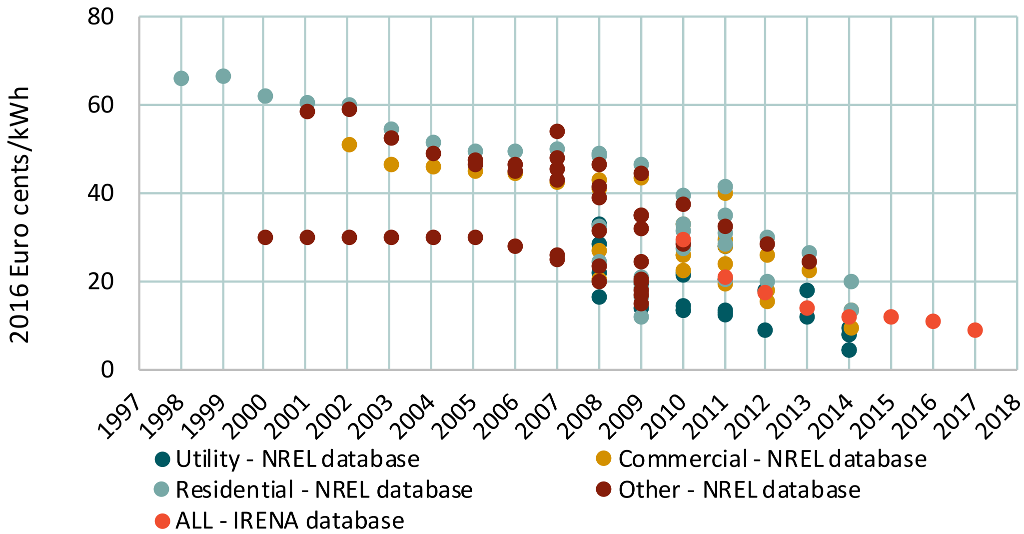
The Levelised Cost of Electricity (LCOE) is an indicator to compare the project costs of different power generation technologies[22]. Similar to capex and opex, cost-reducing innovations can contribute to a downward trend in LCOE, which in turn can make the sector more cost competitive. While LCOE is a relatively comprehensive measure of the technology's costs, it does not include all the costs for delivering energy, such as ancillary services and transmission and distribution costs.

Driven by the substantial reductions in capex cost and module efficiency improvements, the LCOE of solar PV has experienced a rapid decrease during the past 20 years from more than 50 EURct/kWh to less than 10 EURct/kWh (see Figure 4.5). The LCOE for utility scale PV projects has reached a level that is competitive with conventional electricity sources, with an LCOE close to or below 3 EURct/kWh in the latest PPA (Power Purchase Agreements) in Chile and the United Arab Emirates. While these prices are encouraging, it should be mentioned that these bids by JinkoSolar (China) and Marubeni (Japan) are only possible by the combination of high solar resources, a favourable debt to equity ratio and very low debt costs. Hence, such low prices are in most cases not yet typical, as for example, in Germany, contracts were awarded for prices between 6.9 and 7.8 EURct/kWh[23].

[22] There are different ways of calculating the LCOE; the method applied here is explained in the methodology document.
[23] JRC (2016) PV Status Report 2016

Apart from the efficiency improvements of solar modules, one of the primary drivers of the LCOE reductions is the decreased capex, as shown in section 4.1. Hardware costs of PV systems have decreased drastically due to a combination of research activities and market development. Technical installation costs have decreased as well, driven by best practices and increasing competition between installers. As a result, the share of capex in the LCOE has decreased significantly (currently less than 40 %), while opex and the cost of capital became relevant components of LCOE costs.

Figure 4.5 Evolution of solar PV LCOE for electricity generation (all data points)



Notes: For electricity LCOE was calculated for the NREL database values using the values reported from the original source, and for the cases where this information was not available, the market values of NREL were used (16 % capacity factor, and 20 years of plant lifetime). A discount rate of 7.5 % was used, taken from IRENA's methodology, and the capex was annualised using the Capital Recovery Factor Method. LCOE from IRENA was taken directly from the database and converted to EUR_{2016}.

While it is hard to isolate the impact of individual projects on the historical cost reduction of solar cells and modules, there are examples of EU projects that advanced the cost reductions of crystalline silicon PV technology, including the CRYSTALCLEAR and CHEETAH projects (see project highlight boxes below).

Project spotlight: Cost-cutting of crystalline silicon PV modules – CRYSTALCLEAR

The CRYSTALCLEAR project (Crystalline silicon photovoltaic: low-cost, highly efficient and reliable modules; FP6-2002-ENERGY-1/IP; January 2004 to July 2009; EC funding: EUR 16 million; Coordinator: ECN, Netherlands) advanced crystalline silicon PV technology with a holistic approach covering the whole value chain from silicon feedstock to PV modules and their environmental sustainability. The project developed state-of-the-art PV manufacturing technologies, resulting to significantly reduced production cost of solar modules to around EUR 1 for each watt of electricity generated. The project looked at the cost-efficiency of each step: silicon feedstock, wafering technologies, and advances in PV cell technology and production processes that decreased processing costs by 40 percent. These included novel processes for achieving thinner cells, low-cost substrates and next generation cell concepts with record efficiencies: i-PERC (passivated emitter rear contact), MWT (metal wrap through), and PERC solar cells with laser fired contacts (PERC-LFC). The project made efforts to implement these concepts into an industrial process and achieved excellent results. The project also made updates on the lifecycle assessment (LCA) of current crystalline silicon production technology, leading to decreased environmental impacts for the multi-crystalline and mono-crystalline silicon demonstrator modules.

Source: EC, 2018, Community Research and Development Information Service; Beaucarne, G. et al., 2010, A review on 5 years cell development within the European integrated project Crystal Clear.

Project spotlight: Cost reduction of PV modules - CHEETAH

The CHEETAH project (Cost-reduction through material optimisation and Higher EnErgy outpuT of solAr pHotovoltaic modules - joining Europe's Research and Development efforts in support of its PV industry; FP7-ENERGY-2013-IRP/IRP-CSA; January 2014 to December 2017; EU funding: EUR 9.7 million; Coordinator: ECN, Netherlands) aimed to achieve reduced costs in three PV technologies: wafer based crystalline silicon, thin film PV and organic PV(OPV).

- The project aimed to develop a module manufacturing process suitable for ultrathin crystalline silicon wafers. A process for wafers as thin as 80 microns was achieved, with 100 % yield in the process and cell-to-module (CTM) loss less than 1 %. This process was demonstrated to lead to an improved Energy Payback Time (EPBT) by 30 %, and cost reductions up to ~20 % compared to the state of art.
- For thin film solar modules, the project developed 3D device design and micro-concentrators, which led to proven feasibility of 16 % module efficiency, and allowing for simpler and low-cost encapsulation.
- The project also explored alternative and low-cost packaging solutions (e.g. based on polyethylene terephthalate (PET)) and improved the intrinsic stability of OPV.

The resulting technologies ranged from TRL 3 to 6/7 and their relevance was contrasted with industry. The new approach to manufacture thin wafers was considered a revolutionary jump for the PV cell producers, although the current market situation, investment costs and lack of proof of the technology in mass production hinders the commercial introduction. The results of the thin film technology were interesting for the industry, but further away from industrial application due to not high enough module efficiency. From industry perspective, the OPV technology advancement were relevant for niche applications, and especially for advancing the currently booming perovskite PV. CHEETAH contributed significantly to consolidate the EU PV network by developing tools for enhanced collaboration (e.g. e-learning platform, webinars, education and training activities, actions related to mobility of researchers, database of PV experts in Europe) and strengthened the European PV community.

More information on the project is available as a case study in the annex of this report.

4.4 Conclusions

The costs of Solar PV technology have decreased considerably over the past 20 years, leading to a situation where PV is competitive with other electricity sources. Early R&D efforts of the EU, US and Japan increased the performance of solar PV technology, as shown by the analysis on international R&D budgets and the world record cell efficiencies achieved by these countries.

From 2008 onwards, Germany and Spain created a sizeable market that allowed for cost reductions through economies of scale. During this period there was a shortage of silicon, and the EU responded to it by funding research projects focused on reducing the costs of solar grade silicon through the exploration of new materials and processes. Once the Chinese manufacturers started to build large-scale factories, capex costs and LCOE started to decrease rapidly. These new capacities were mostly added using imported turn-key PV manufacturing equipment from European suppliers, which enhanced the performance of the production lines and reduced the cost of producing PV modules. EU-funded R&D supported these European equipment suppliers through several projects and thereby also contributed to cost reductions in the sector.

Nowadays, EU-funded R&D projects continue to look for cost reductions and performance improvements and thereby still contribute to LCOE reductions. When capex decreased and significant capacities were installed, the importance of opex started to increase and cost reductions in opex started to be realised. EU-funded projects have also contributed to reduce these costs through better PV plant designs and automated tools to detect failures, improving the performance of PV systems.

Overall, the main conclusion of this analysis is that the combination of continuous R&D by the Western world, market incentives in the EU and industry development in China created the right conditions for PV to become a competitive source of electricity.

5 Social, economic and environmental impacts

Public R&D funding for RE technologies is justified by several social, economic and environmental impacts. In this section we evaluate a range of indicators that provide insight into these impacts: installed capacity, annual generation, industry turnover, imports/exports, jobs and share of energy consumption.

A direct link between these indicators and R&D funding is hard to establish, as the impact of R&D funding is confluent with numerous other factors that drive or prevent deployment. Still, the indicators presented in this section are relevant indicators to assess the evolution of the solar PV sector over time.

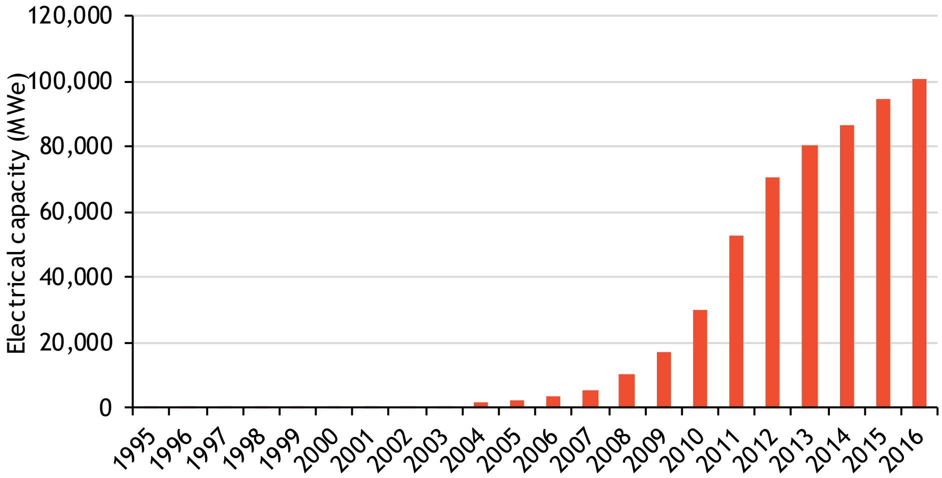
5.1 Installed capacity

As installed capacities for RE technologies provide (near) carbon free energy that prevents the need for fossil fuel-based energy, they contribute to reducing greenhouse gas emissions and can be considered a measure of the environmental impacts. Installed capacity refers to the maximum installed generation capacity. This is expressed in MWe for electricity production.

Installed capacity of solar PV expanded rapidly in the EU, growing from 600 MW in 2003 to over 100 000 MW in 2016, becoming the third largest RE technology installed in the EU for electricity generation (see Figure 5.1).

Two of the main funders of R&D for solar PV also have the largest installed capacity. Germany leads with 40 % of total EU capacity, followed by Italy. Interestingly, the United Kingdom has the third largest capacity, even though it had a smaller R&D budget than France and the Netherlands. France has 7 % of total capacity, and the Netherlands stays behind with only 2 %, making it the 9th MS in terms of installed capacity.

Figure 5.1 Installed capacity of solar PV plants in the EU



Source: Eurostat (2018)

EU installed capacity has been traditionally driven by favourable support schemes. The growth of global PV installation capacity is dependent on country-specific policies. It has been common for countries to have record years for new installations of solar PV, after which they go back to a situation with almost no increase in solar PV capacity. This was the case in Spain (in 2008), Italy (2011), Czech Republic, and UK (2014-2015), amongst others. The Spanish PV market boomed in 2008, installing the first utility scale PV plants, thereby adding 2 650 MW installed capacity in one year. The bubble burst one year later and only modest number of installations took place thereafter. Aided by the Energiewende, Germany's installed capacity rose quickly, from 18 MW in 1995 to over 40 000 MW in 2016. But also in Germany growth peaked in 2009-2010 and slowed down substantially after 2012.

With the current levels of capex (below EUR 0.8/Wp for large-scale PV plants) and PV electricity prices (LCOEs below 4 EURct/kWh are common in South Europe), the driver for PV installation has moved from support schemes to profitability, as PV has become the cheapest way of electricity production in many countries.

EU-funded R&D projects have contributed to growth in installed capacities in several ways. Firstly, the contributions of EU-funded projects to performance improvements and cost reductions as described in the previous chapters, have contributed to making the technology more competitive and thereby increased the installation rates. Additionally, EU-funded projects have contributed to the growth in installed capacity by removing barriers to investment, such as the perceived investment risks of PV projects (see project spotlight on SOLAR BANKABILITY below).

Project spotlight: Assessment of PV risks - SOLAR BANKABILITY

Solar Bankability is a H2020 project (Improving the Financeability and Attractiveness of Sustainable Energy Investments in Photovolatics: Quantifying and Managing the Technical Risk for Current and New Business Models; H2020-EE-2014-3-MarketUptake/CSA; March 2015 to February 2017; EC funding: EUR 1.4 million; Coordinator: Accademia Europea di Bolzano, Italy) funded under 'Market uptake and energy innovation – building on Intelligent Energy Europe' (EU.3.3.7.). The main objective of the project was to reduce the risk associated with investing in sustainable energy projects with a focus on solar PV installations. This goal was achieved by establishing common practices for risk assessment focused on technical and financial rigour. The project developed a methodology for calculating the technical risks in PV projects which may become best practice in the sector. By doing so, the project improved the case for investing in solar PV capacities and thus contributed to the growth of EU installed capacities.

Source: EC, 2018, Community Research and Development Information Service. Further information on the project is available at: http://www.solarbankability.org/home.html

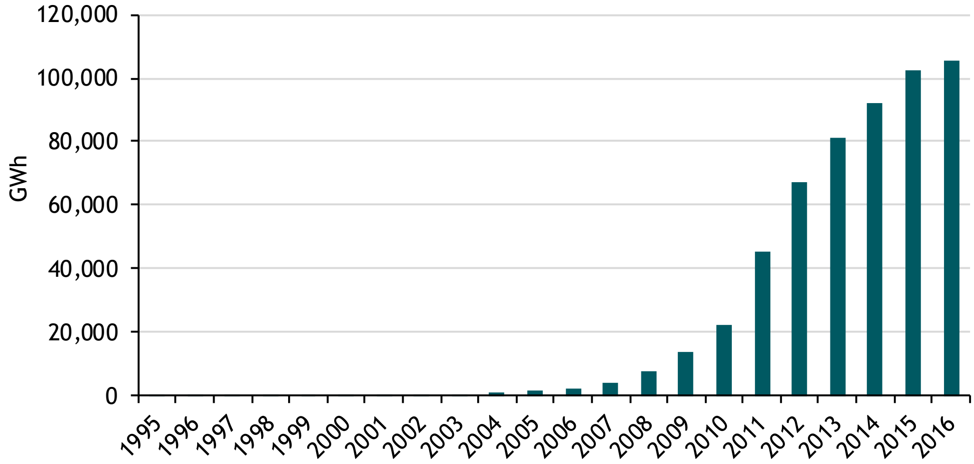
5.2 Annual generation

While installed capacity is a commonly used indicator to measure the progress in deploying RE technologies, it can be somewhat misleading due to differences in capacity factors. Annual generation includes the effects of these differences and is therefore a valuable indicator to complement the statistics on installed capacities.

Annual generation from solar PV has been rising along with the increased capacity. As a result, solar PV is becoming an important source of renewable electricity in the EU. Generation grew by a factor of five between 2010 and 2016, from 22 500 MWh to over 100 000 GWh.

The shares between MS are similar to that of installed capacity, although the southern countries generate relatively more because of the higher solar irradiation rates. These differences in production can be considerable: 1 MW of installed capacity in Seville (Spain) produces almost twice as much electricity as 1 MW installed capacity in Stockholm (Sweden).

Figure 5.2 Annual electricity generation in the EU from solar PV



Source: Eurostat (2018)

5.3 Share of energy consumption

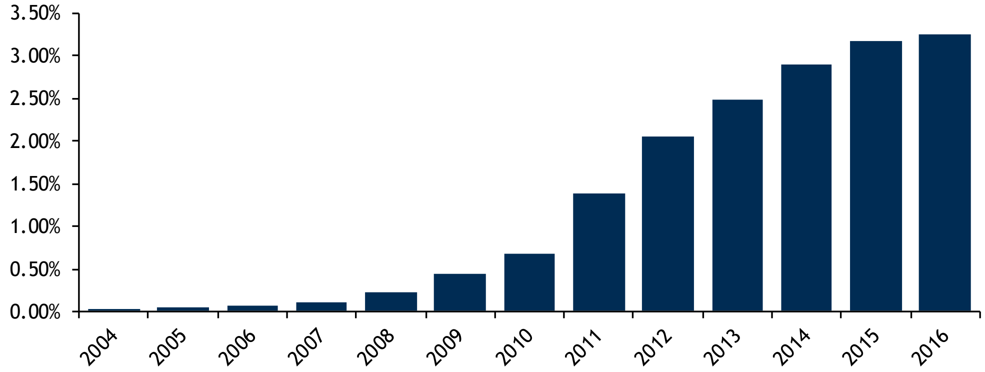
Share of energy consumption refers to the participation of solar PV energy in the gross final energy consumed in the electricity market sector. This indicator allows us to analyse the participation of the solar PV sector in the overall target of increasing the share of energy from RES in the EU's gross final energy consumption.

The share of gross final electricity consumption from solar PV in the EU has increased over the years, from less than 0.1 % before 2007 to 3.3 % in 2016. This can be attributed to the growing installed capacity and generation of solar power in the EU. After rapid growth between 2008 and 2014, growth has slowed down in recent years.

The top three European PV electricity producers are Italy, Greece and Germany which each obtain more than 6 % of their electricity consumption from PV power generation. Globally, solar PV supplies

2.1 % of the global electricity demand, and several countries have surpassed the 1 % milestone in terms of solar PV contribution to the electricity demand[24], including 19 EU MS.

Figure 5.3 Share of gross final electricity consumption from solar PV in the EU



Source: Eurostat (2018)

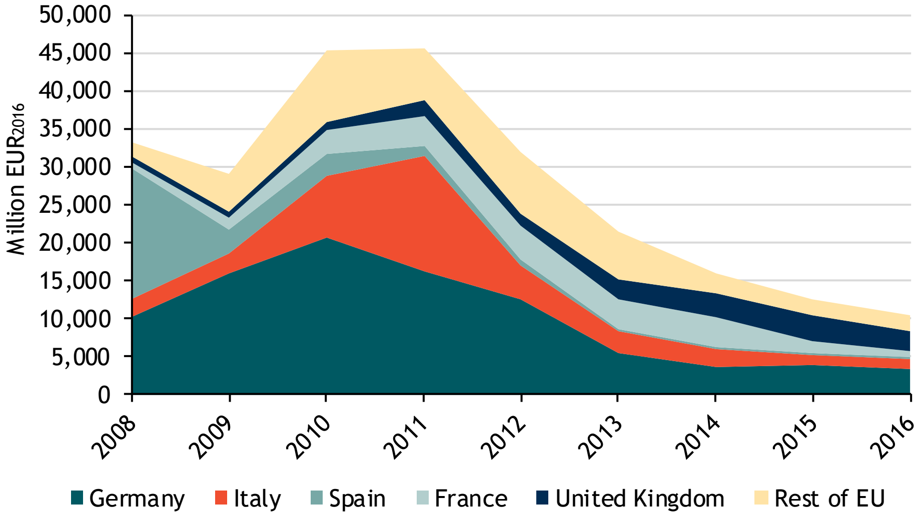
5.4 Industry turnover

Industry turnover is the total amount invoiced from the market sales of goods and/or services supplied to third parties by all sellers in the solar PV sector. Following the definition in EurObserv'ER, it focuses on the main economic activities of the supply chain including manufacturing, installation of equipment and operation and maintenance (O&M).

Driven by strong market growth and leading R&D, the EU solar PV industry turnover grew rapidly to its peak of EUR 45 billion a year in 2010-2011 (see Figure 5.4). The largest turnover was in Germany, which on average generated over a third of the total turnover in the EU. Germany is a leader in manufacturing equipment for solar PV production and exports the majority of their products outside Europe, mainly to factories in China[25]. The EU actions have contributed to the improvement of PV manufacturing processes, which are then commercialised by equipment manufacturers. Examples include the spin-off NexWafe, which commercialises manufacturing equipment resulting from the R2M-SI project (see project spotlight in section 3.3), and the 20PLμS project, which developed innovative crystalline silicon cells, together with a pilot production line (see project spotlight box below).

[24] International Energy Agency (IEA) (2018). Snapshot of Global PV Markets 2018
[25] See https://www.pv-magazine.com/2018/04/24/strong-sales-for-germanys-equipment-makers-in-q4-2017-vdma/

Figure 5.4 Solar PV industry turnover in the EU



Source: EurObserv'ER reports 2010-2017.
Notes: Data is missing for Croatia on years 2008-2011.

Project spotlight: Thin wafer based solar cells – 20PLµS

The 20PLµS project (20 percent efficiency on less than 100 µm thick industrially feasible c-Si solar cells; FP7-ENERGY-2010-1/CP; October 2010 to September 2013; EC funding: EUR 4.9 million; Coordinator: Universitat Konstanz, Germany) developed very thin solar cells and built the entire production chain from wafering to module integration, including a mass-production pilot compatible high-yield process. The process was developed and transferred to the industrial pilot production line of Hanwha Q CELLS (Germany). The pilot showed that it is feasible to fabricate 100 µm thin cell with a median cell efficiency of 20 %. In addition, the pilot line achieved a breakage rate of 4.5 % after process and handling adjustments.

Source: EC, 2018, Community Research and Development Information Service.

Other Member States with significant turnover were Spain, Italy, France and the United Kingdom. The Spanish market boomed in 2008, supported by the high Spanish feed-in tariff but collapsed once the support measures were withdrawn. Numerous PV manufacturers based in Spain had to close or merge. For example ISOFOTON, a pioneering company that once was the largest European PV manufacturer[26], was acquired in 2010 by Korean investors[27]. Surviving companies either expanded to the international market, or reduced their operational capacity. The company ATERSA is one example of the latter (see company spotlight below). Italy saw rising turnover figures up to EUR 15 billion in 2011, creating a strong market in the production and sales of solar PV components. The market started to contract in 2013, as the EUR 6.7 billion feed-in tariff programme 'Conto Energia' started to run out. France saw a similar trend as that of Germany, with large growth in 2009 due to major installations and BIPV activity, followed by a declining domestic market in 2011.

[26] Instituto de Energía Solar Universidad Politécnica de Madrid (IES-UPM), 2018, History
[27] Del Rio, P. and Mir-Artigues, P., 2014, A Cautionary Tale, Spain's Solar PV Investment Bubble

Company spotlight: ISOFOTON and ATERSA

The Spanish PV companies ISOFOTON (founded in 1981) and ATERSA (funded in 1983) were among the pioneering companies of the sector. Both companies experienced the rise and fall of the EU PV industry.

ISOFOTON was established by Professor Dr. Antonio Luque from the Technical University of Madrid (Universidad Politécnica de Madrid, UPM), and initially based on the bifacial silicon solar cells invented at the UPM's Institute of Solar Energy. The company grew fast, and at the beginning of 2000's ISOFOTON was among the largest solar cells manufacturers in Europe, employing 800 persons in 2010. As a research-oriented company, ISOFOTON was a frequent participant in European funded research projects in FP5, FP6 and FP7 (including FOXY, CRYSTAL CLEAR, FULLSPECTRUM and NACIR described in this report). ISOFOTON developed a new business line in the field of high-concentration PV (HCPV) using GaAs based cells, and invested in a large production facility, opened in 2006, including crystalline silicon and HCPV production lines. Few years later, the company was faced with fierce competition from low-cost PV products entering in the market, which eventually led the company to file for bankruptcy in 2013, after being previously acquired by a South Korean company in 2010.

Unlike ISOFOTON, ATERSA is still an active company, and is dedicated to development, manufacturing and commercialising of PV system components, having its own production line in Valencia, Spain. The company is currently a 100 % subsidiary of Elecnor, a large Spanish multi-national engineering company. ATERSA also participated in several EU projects funded under FP5, FP6 and FP7, which was very important in supporting the development of the company. In 2008, the company had a turnover close to EUR 500 million, and 450 employees. Afterwards, the company went into a similar decline as the full EU industry, and is currently operating only at a fraction of their manufacturing output during the 2008 peak.

Sources: Interviews with industry experts, IES-UPM webpage 'History' and newspaper El País, 2013, Isofotón despide a toda la plantilla y cierra tras más de 30 años de historia.

For the EU industry as a whole, the decline started in 2012. The main reasons are the fierce competition from China and the reduction in annual installed capacity in the EU. Notwithstanding the continued R&D efforts and the minimum import prices for Chinese cells and modules, EU industry has not managed to reverse the decline until now. The industry faces severe barriers to rebuild capacities as the Chinese value chain operates at a much larger scale that leads to lower prices for many components, which makes it hard for EU manufacturers to become competitive. Additionally, the EU financial sector is reluctant to finance solar PV factories due to bad experiences in the past, which makes it difficult to obtain sufficient funds to establish new manufacturing capacities.

When facing the decline of the PV industry in Europe, EU R&D funding support has contributed towards identifying and supporting the development of new paths for PV technology by focusing on the large-scale market uptake of higher value added products. This way, EU activities develop niche technologies that could give rise to a new European PV industry. For instance, CPV research has been supported through numerous projects, including HICONPV, APOLLON and NACIR, while the project AMPERE aims to achieve large-scale market uptake of heterojunction PV in Europe (see project spotlight boxes below). Furthermore, the development of perovskite technology was supported (see CHEOPS project spotlight in section 3.2.3) and Oxford PV was awarded a EUR 15 million loan through the EU InnovFin EDP instrument to continue the demonstration of its perovskite solar technology[28]. This year the company obtained a cell efficiency world record of 27.3 %, the highest certified efficiency for a single-junction silicon solar cell[29].

Projects spotlight: Development of concentration PV systems – HICONPV, APOLLON and NACIR

A series of EU-funded projects supported the development and demonstration of cost-effective and reliable CPV systems, and explored applications of the technology in potential new markets. The HICONPV project (High Concentration PV Power System; FP6-2002-ENERGY-1/STREP; January 2004 to December 2006; EU funding: EUR 2.7 million; Coordinator: Solucar Energia, Spain) developed and tested a new cost-effective high concentration PV system with a large area receiver (100 cm^2) utilising semiconductor materials Ill-V. The project results were commercially exploited by the start-up Zenith Solar, established in 2006. In 2009, an assembly facility was opened at Kiryat Gat, Israel and Zenith solar launched a commercial solar array of 240 kW combined heat and power system, shifting its 3-year old prototype into a serially produced product. The company was ultimately acquired in 2013 by Suncore Photovoltaics (US, owned by San'an, the largest LED chip manufacturer in China).

The APOLLON project (Multi-APprOach for high efficiency integrated and inteLLigent cONcentrating PV modules (Systems); FP7-ENERGY-2007-1-RTD/CP-IP; July 2008 to June 2013; EU funding: EUR 7.7 million; Coordinator: RSE, Italy) addressed optimisation of CPVs technology by improving the different technologies along the CPV development chain: from the improvement of the Metal-Organic-Chemical-Vapor Deposition (MOCVD) technique, to the final construction of a prototype CPV system including receiver, optics, tracking, etc. Many of the technologies developed were patented, and the project made a significant contribution to standards on CPV testing methodologies. APOLLON also contributed towards enhanced competitiveness of the CPV technology by reducing the costs of CPV systems and their environmental impact significantly.

The NACIR project (New applications for CPVs: a fast way to improve reliability and technology progress; FP7-ENERGY-2008-1/CP-SICA; January 2009 to December 2012; EU funding: EUR 7.1 million; Coordinator: Universidad Politecnica de Madrid, Spain) brought together the leading European CPV technology actors including UPM (Spain) and Fraunhofer (Germany) with industrial partners Soitec (Germany), Isofoton (Spain) and ISFOC (Spain), with the aim to explore new applications for CPV systems in environments outside the European market. The project resulted in the installation of a stand-alone CPV system in Egypt and a grid connected CPV system in Morocco providing valuable lessons of CPV application in harsh environments and high altitudes. These developments led to two patents, a number of publications, conference presentations and to new commercial scale CPV modules and components.

The CPV research has been further supported by FP7 projects CPV4ALL, ECOSOLE, NGCPV and a H2020 project CPVMATCH.

Source: EC, 2018, Community Research and Development Information Service; Chayet, H. et al., 2010 ; Faiman, D. et al., 2007; and Interview with the project partner.

[28] European Investment Bank, 2017, EU bank grants EUR 15m to Oxford Photovoltaics Germany
[29] Oxford PV, 2018, Oxford PV sets world record for perovskite solar cell

Project spotlight: Towards a large-scale manufacturing of heterojunction PV in Europe - AMPERE

The AMPERE project (Automated photovoltaic cell and Module industrial Production to regain and secure European Renewable Energy market; H2020-LCE-2016-RES-IA; May 2017 to April 2020; EU funding: EUR 15 million; Coordinator: 3SUN, Italy) will implement a fully automated 100 MWp pilot line based on silicon heterojunction technology (HJT) bifacial PV cells and modules. This technology is characterised by a high conversion efficiency (target efficiency 22.5 % at first, 23.5 % later) and through fully automated manufacturing, it is expected to be cost competitive, leading to a 10 % decrease of the LCOE. The pilot line is installed in 3SUN fab located in Catania, Sicily. Apart from the pilot line built, 3SUN is simultaneously installing 100 MWp capacity extra (apart from the AMPERE project), paving the way towards a GWp factory. The project started in May 2017 and is running until April 2020, and involves the key European research actors and companies covering the whole PV value chain (i.e. wafer preparation, automation, metrology on the front-end side and PV fields installation on the end-user energy generation companies). The expected impact of AMPERE is not less than regaining competitiveness of the EU PV value chain.

Source: EC, 2018, Community Research and Development Information Service, Project website (www.ampere-h2020.eu); Interview with the project coordinator

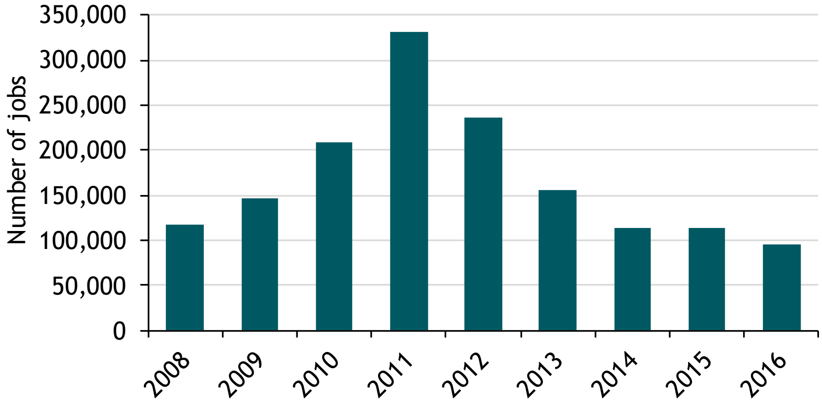
5.5 Jobs

Employment is an important indicator to understand the socio-economic impact of RE technology deployment. Linking jobs to R&D funding is difficult due to the number of confounding factors, but it is possible to make a connection between RE deployment and jobs. Different methods exist for estimating employment figures. A consistent time-series was only available for 2008-2016.

Similar to industry turnover, a peak of 330 000 jobs can be observed in 2011 (see Figure 5.5). The number of jobs rapidly declines afterwards, due to increasing competition from Asian companies and lowered policy support in several large MS (see also Section 5.4). The decline of EU jobs in the PV sector directly reflects the limited installed capacity over the last years and the lack of competitiveness of the EU manufacturing companies in the global PV market. It has been estimated that in 2016 a major part, up to 75 %, of the EU jobs were in downstream activities (engineering, installation and O&M)[30].

[30] Ernst and Young (EY), and Solar Power Europe (SPE), 2017, Solar PV Jobs & Value Added in Europe

Figure 5.5 Evolution of EU jobs in solar PV



Source: EurObserv'ER reports 2010-2017.
Notes: Data is missing for Croatia for years 2008-2011.

Germany had the most jobs between 2008 and 2014. Even in 2008, when estimated turnover was highest in Spain, Germany still topped the list with twice as many jobs (over 60 000 compared to 30 000 in Spain). This can be associated to the fact that the European PV manufacturing industry and jobs are largely located in Germany, and a large part of German PV installations were rooftop PV associated with higher labour intensity compared to utility scale PV. In the peak year of 2011, Germany had an estimated 111 000 jobs, followed by France (63 000) and Italy (55 000). Germany saw a rapid decline afterwards, and is now surpassed by the United Kingdom, who had an estimated 29 000 jobs in 2016 (compared to 27 000 in Germany). The German equipment manufacturing jobs are expected to remain stable in the near future, based on the latest forecasts of the national industry[31]. Other MS with a relatively large number of workers are Italy, France, the Netherlands and Belgium.

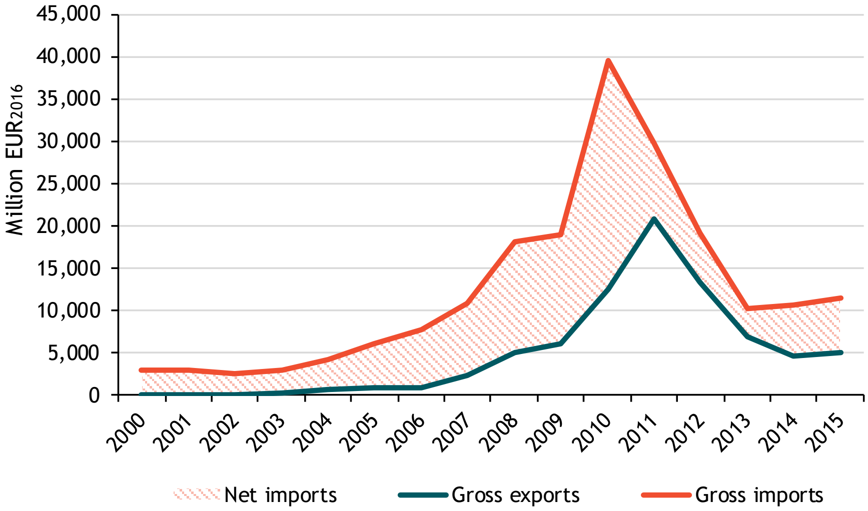
5.6 Imports/exports

International trade can provide a measure of the market uptake of solar PV technologies and development of the solar PV sector itself. It allows us to examine the extent of the external market for these goods, with increasing exports leading to increased growth of the domestic sector. Similarly, increased activity in the sector will lead to an increase in demand for intermediate goods used in the manufacture of RE technologies, a proportion of which may be imported. Increasing imports of these intermediate goods also provide an indication of the growth within the technology sectors.

EU solar PV imports and exports grew continuously from 2000 to 2011, thanks to the increased market penetration of solar PV (see Figure 5.6). While the EU industry was in a much stronger position than nowadays, the EU has always been a net importer of solar PV components. In the early years, this was due to the rapid increase of PV capacities in the EU, which could not be serviced by EU companies alone. In later years (after 2011), the EU market slowed down, but EU manufactured modules could not compete with Asian modules, leading to a sustained trade deficit.

[31] VDMA, 2018, VDMA Photovoltaic Equipment: Order situation is weakening

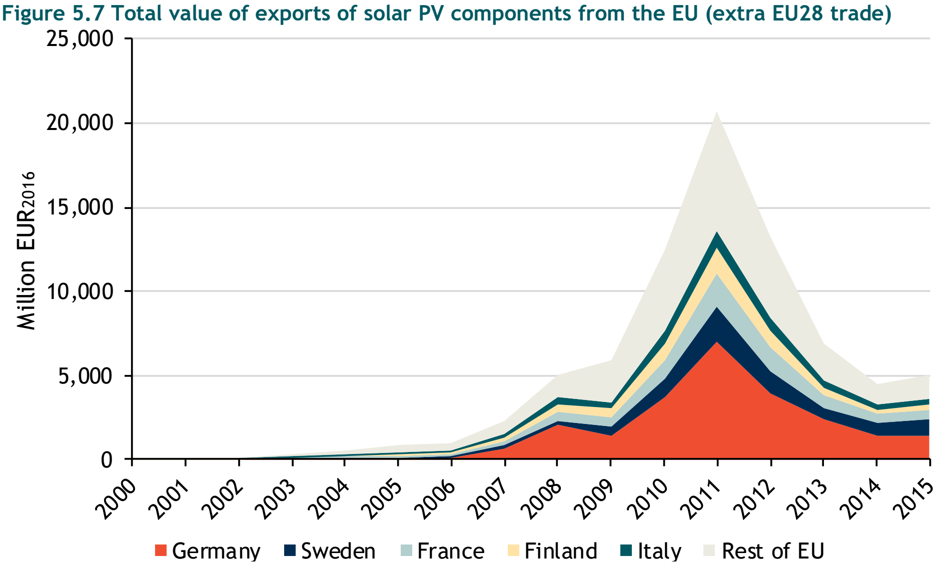
Figure 5.6 Trade balance for solar PV in the EU



Based on Comext (2018), Lako, P. (2008), Wind, I. (2009), and Jha, V (2009).
Notes: For an explanation of the methodology used, see Annex C.

Most EU exports to the rest of the world originate from Germany (see Figure 5.7), consistent with the relatively high industry turnover and number of jobs in Germany. The other main exporters include France and Italy, also consistent with the high industry turnover in these countries, but also Sweden and Finland. For countries like Sweden and Finland, the overall industry turnover is not as high due to the lack of a large local solar PV market, but some industrial players such as Swedish inverter manufacturer ABB do supply their products to customers across the world, leading to a relatively high export volume for Sweden. Recently, various H2020 projects are focusing on developing BIPV solutions that meet the requirements of the building sector worldwide. This path is proving successful for the ADVANCED-BIPV and PVSITES projects (detailed in project highlight boxes below).

Figure 5.7 Total value of exports of solar PV components from the EU (extra EU28 trade)



Based on Comext (2018), Lako, P. (2008), Wind, I. (2009), and Jha, V (2009).
Notes: For an explanation of the methodology used, see Annex C.

Project spotlight: Taking BIPV towards large-scale market uptake – ADVANCED BIPV and PVSITES

The ADVANCED-BIPV project (New generation of BIPV-glass with advanced integration properties; H2020-SMEINST-2-2014/SME2; April 2015 to March 2017; EU funding: EUR 1.9 million; Coordinator: Onyx Solar, Spain) aimed to increase the competitiveness of BIPV technology by developing a new generation of photovoltaic glazing, meeting the specified building architectural requirements and market trends. A prototype was developed, demonstrated and industrialised and a certification process was carried out that facilitated access to the US market. Thanks to the project results, the project coordinator Onyx Solar could expand its activities, increase its turnover from EUR 2.5 million to EUR 8 million and more than double its number of employees. Onyx Solar's PV glass has been installed in over 150 projects globally, with the US as its main market accounting for 40 % of their exports. Other markets that the company is exporting to include Australia, Mexico, Bangladesh and Kenya. In this way, EU funding made a clear contribution to increasing the export volumes of EU manufacturers. Moreover, Onyx Solar is currently participating in the PVSITES project.

The PVSITES project (Building-integrated photovoltaic technologies and systems for large-scale market deployment; H2020-LCE-2015-2/IA; January 2016 to June 2019; EU funding: EUR 5.5 million; Coordinator: Tecnalia, Spain) started from the premises that BIPV technology has reached a certain level of technological maturity but that its commercial application remains limited, despite a huge market potential. Hence, the project aims to analyse and tackle the barriers preventing BIPV from becoming a mainstream solution and offers a portfolio of solutions to achieve large-scale market uptake of BIPV. At this stage, several solutions are tested in 7 demonstration sites across the EU and are expected to reach the market in the near future, supporting the future growth in installed capacities in the EU and worldwide. One product, glass to glass module with back-contact c-Si cells, is already commercialised by the project partner Onyx Solar, with a flagship example of the installation of this product at the Balenciaga storefront in Miami, US. The CIGS product manufacturer, Flisom, is also commercialising one of the products developed within the project, a roof element with CIGS solar module, which has been already installed in a real building in South Africa. Other successful examples are in the beta testing phase, including the design software for BIPV systems based on building information modelling (BIM), developed by Swiss company Cadmation, having already a broad acceptance and over 300 users. The project has received a lot of attention and interest from research and industry communities, and has led to a follow-up project (BIPVBOOST, 'Bringing down costs of BIPV multifunctional solutions and processes along the value chain, enabling widespread nZEBs implementation', Contract 817991, coordinated by Tecnalia, started in October 2018) aimed at automation of BIPV manufacturing processes with the target of lowering the extra costs of BIPV products up to 75 % by 2030, compared to the cost level in 2015.

Source: EC, 2018, Community Research and Development Information Service; PVSITES project website (www.pvsites.eu); Interview with the PVSITES project coordinator.
More information on the ADVANCED BIPV project is available as a case study in the annex of this report.

5.7 Conclusions

The EU PV sector experienced rapid growth between 2008 and 2012, enabled by the continued R&D efforts in the preceding decades and favourable support schemes in countries like Germany, Spain and Italy. Installed capacities grew from negligible amounts to more than 60 000 MW, supplying 2 % of EU electricity consumption in 2012. The EU industry also grew rapidly, to more than EU 45 billion turnover and more than 300 000 jobs. From 2012 onwards, capacity additions slowed down due to the lack of support schemes and the EU industry went into decline. Apart from a declining local market, the industry suffered from a lack of competitiveness versus the Chinese manufacturers who were leading in terms of economies of scale.

When facing the decline of the PV industry in Europe, EU R&D funding has supported several pathways for rebuilding the EU industry, focusing on less mass-produced and higher value added products. Through these efforts, technologies such as CPV, perovskite and BIPV were further developed, market barriers were addressed and new opportunities for developing a competitive EU industry were created. Furthermore, continued support for European equipment manufacturers remained in place to retain their leading position.

6 Conclusions

Solar PV has been one of the main technologies in terms of R&D funding, receiving 23 % of EU funds and 24 % of MS funds for RE technologies over the past 20 years. Internationally, the EU has a strong position in research with leading R&D budgets and EU authors contributing to 25 % of all publications worldwide. The EU Framework Programmes made a clear contribution to the EU's research and technology leadership by funding projects that delivered many publications and stimulating collaboration and knowledge sharing across the EU.

As a result of continuous research efforts and wide-scale market uptake, the costs of solar PV technology have decreased considerably over the past 20 years, leading to a situation where PV is fully competitive with other electricity sources. Early R&D efforts of the EU, US and Japan increased the performance of solar PV technology, as shown by the analysis on international R&D budgets and the world record cell efficiencies achieved by these countries. EU projects also contributed to cost reductions of crystalline silicon and thin-film technologies through the exploration of new materials and improved manufacturing processes, and have also facilitated closer cooperation between the private and public sector.

The EU solar PV sector experienced rapid growth up to 2012 in terms of installed capacities and industry development. Since 2012 the EU solar PV industry has declined however, due to fierce competition from China and a slowdown of capacity additions in the EU. As a result, EU cell and module production capacities have diminished, while equipment manufacturers and in general, downstream capacities still retain a strong position.

When facing the decline of the PV industry in Europe, the EU Framework Programmes focused on less mass-produced and higher added-value products to create new opportunities for the EU industry to grow. Various high-efficiency PV technologies (e.g. CPV), next generation concepts (e.g. organic PV and perovskite) and new applications (e.g. BIPV) were stimulated in addition to continued support for the development of crystalline silicon and thin-film technologies. Thanks to these efforts, new technologies have been introduced to the market and the creation and scale-up of new EU industry has been supported.

Annex 4A - Case studies

Case study: ADVANCED BIPV

Author:	Hanna Kuittinen Eduardo Román	**Approver:**	Teodosio del Caño, Chief Technical Officer (CTO), Onyx Solar
Project title:	New Generation of BIPV-Glass with Advanced Integration Properties (ADVANCED BIPV)		
Lead partner:	Onyx Solar Energy S.L.		
Project location:	Spain		
Technology area/s:	Photovoltaic (PV), Building Integrated Photovoltaic (BIPV)		
Start and end date:	April 2015 to March 2017		
Project cost:	EUR 2 695 887.50	**EC funding:**	EUR 1 887 121.25
Other funding sources:	In-kind contribution and own investments		
Quantifiable outputs and impacts:	Development of a laminator prototype for manufacturing of high-dimensions and high-resistance PV glazing products, and a novel laser etching process to produce high quality vision glass. These manufacturing process improvements led to an introduction of a new product: large format photovoltaic architectural glass panels (8 m^2) responding to market demands on size, robustness, light transmittance, aesthetics and performance.		
Further information:	Project website Company website Chief Technical Officer (CTO) – Dr. Teodosio del Caño, Onyx Solar Energy S.L. Visiting address, Rio Cea, Poligono las Hervencias 1, H6, 05004 Ávila. T +34 920 21 00 50 E info@onyxsolar.com		

Project description

Onyx Solar Energy S.L is an SME established in 2009, based in Ávila, Spain and the single beneficiary of the ADVANCED BIPV project. Onyx Solar focuses on manufacturing transparent photovoltaic (PV) glass for buildings. The PV glass is used as a building material that generates energy, capturing the sunlight and transforming it into electricity. It is made of two or more panes of heat treated safety glass, and it is comparable to conventional architectural glass in terms of providing natural light as well as thermal and sound insulation. The building integrated PV (BIPV) glass offers possibilities to incorporate photovoltaic technology in two ways: either using crystalline silicon (c-Si) cells or thin film amorphous silicon (a-Si) cells, each approach providing different benefits. The former generates greater nominal power capacity per square metre installed, whereas the latter offers higher light transmittance and is more flexible in design and easily customised to building architectural and functional needs. In general, the BIPV glass can be installed in place of conventional glass on building facades, curtain walls, atriums, canopies and terrace floor, among others. The advantage of BIPV glass is in its ability to generate clean, free electricity from the sun, leading to improved building energy efficiency. Nowadays, about 40 % of the energy consumed in the world corresponds to energy consumed in buildings and BIPV is among the solutions to lower the carbon footprint of building and housing sector.

The ADVANCED BIPV project aimed to increase the competitiveness of BIPV technology by developing a new generation of photovoltaic glazing, meeting the specified building architectural requirements and market trends. The project is based on the needs of the building sector (i.e. demand for high-quality glass in terms of transparency, acoustic and thermal insulation being available in more complex geometries and larger formats, and meeting aesthetic requirements). At that time, the main challenges associated with BIPV glass were related to limited dimension of the BIPV glass panels, their fragility and low light transmittance. The project was set to overcome these challenges by developing new generation PV glazing, simultaneously meeting the building sector requirements and aesthetic needs. Thus, the objective was to provide a holistic solution, including:

- novel high-dimensions PV glass-glass based on c-Si and a-Si technologies;
- novel high-resistance PV glass-glass based on c-Si and a-Si technologies;
- new performed see-through patterns for PV glass-glass based on a-Si technology achieving a light transmission up to 50 %.

Outputs and Impacts

The project designed a large format PV laminator prototype (called XL-laminator) capable to manufacture high-dimensions and high-resistance PV glasses. This technology allows larger dimensions (up to 8 square metres compared to state-of-the-art BIPV glazing dimension of 5 square metres), and higher mechanical resistance (up to 30 mm thickness compared to conventional panel thickness of 22-25 mm). This enables the development of various constructive solutions utilising PV glass (such as curtain walls or, skylights). Later, the prototype has been upscaled for full industrial-scale manufacturing. In addition, a laser etching process to produce high quality vision PV glass was developed. This enabled production of PV glass with light transmission at 30 %, 40 % and 50 % see-thru levels.

Apart from advancing the PV glass manufacturing methods, the final PV glazing products were subjects to full testing to ensure the fulfilment of key standards in terms of structural and electrical requirements. The PV glazing products have been certified in accordance with construction glass and photovoltaic standards, and the products were accredited by an external laboratory. This ensured that the developed BIPV products show an excellent manufacturing quality as well as a good life-span as building elements. Regarding photovoltaics the products have the IEC (International Electrotechnical Commission) and UL (Underwriters Laboratories Inc.) certifications. In addition, the BIPV glasses were tested in accordance with the requirements for safety glass in buildings (EN 14449:2006), which ensured full compliance with building sector regulations.

The project also produced two demonstration studies to demonstrate the products and solutions developed in real buildings where they were tested not only in terms of glazing products but as fully integrated multifunctional photovoltaic systems. The solutions chosen for these demonstration studies were 1) a canopy for large dimension and high resistance c-Si solution and 2) a curtain-wall based on high vision 50 % light transmittance a-Si solution.

Onyx Solar has applied intellectual proprietary rights protection for its core technologies related to colour glass, lamination techniques and development of robust photovoltaic floors. It currently has a portfolio of four patents, one of them resulting from the ADVANCED-PV project activities.

Outlook and commercial application of the outputs

The Onyx Solar PV glass has been installed in over 150 projects globally, covering many types of market segments (e.g. commercial buildings, hospitals, schools and sport stadiums). The new technologies developed during the ADVANCED BIPV project allowed the company to expand its activities. At the start of the project, the company's annual turnover was EUR 2.5-3 million, increased to EUR 8 million in 2017, and it is expected to further increase to EUR 10 million by the end of this year. Similarly, the company had a staff of 20 persons in 2014 while currently it employs 49 persons. The company exports 90 % of its production. Approximately 40 % of the production is exported to the US, which is currently the main market, and the remaining 50 % is exported to the rest of the world, with recent projects in Australia, Mexico, Bangladesh and Kenya. The certification process carried-out during the ADVANCED BIPV project facilitated the access to the US market.

'Several of our clients are well-known corporations who have pioneered the adoption of photovoltaic glass within their respective businesses including companies such as Apple Inc. Novartis Pharmaceuticals, Samsung, Coca-Cola, Heineken, Pfizer, and many more', the Onyx Solar CTO Teodosio del Caño explains. The future of the sector looks bright; some market studies foresee that the global BIPV market, which currently falls short of USD[32] 100 million, would exceed USD 1 billion in 2022. According to Mr. del Caño, this is too optimistic, but he concludes that there is a high interest in this technology as demonstrated by the growth of the Onyx Solar project pipeline and the future market growth expectations are strong.

The role of EU Funding

The ADVANCED BIPV project received funding from the European Union's Horizon 2020 Programme for Research and Innovation (H2020). Horizon 2020 funds high-potential innovation developed by SMEs through a dedicated programme called SME Instrument, targeted to support close-to-market activities and boost the SMEs to reach global markets with their highly innovative ideas. The funding programme is organised in two phases: Phase 1 for feasibility assessment (lump sum of EUR 50 000, for a period of 6 months), and Phase 2 for innovation development and demonstration purposes (up to EUR 2.5 million grant with duration 1-2 years). The ADVANCED BIPV proposal achieved a positive evaluation, and the project received Phase 2 funding directly for two years, without going through Phase 1. The EU contribution amounted to EUR 1.9 million representing 70 % of the project's total costs. The project had no delays or amendments, and overall the project implementation was smooth. The final public report received many acknowledgements, and Onyx Solar has since been invited to different events to present the project as a good practice in the field. Winning the SME Instrument grant was an important milestone for Onyx Solar, allowing it to develop the needed capacities faster, and especially the development of the new lamination technology would have been difficult to achieve in timely manner without the support from the EU. The achievement of the SME instrument grant and the successful project execution gave the company extra credibility and visibility. Furthermore, the project results gained wide-range interest from the market and allowed the company to reach to new clients.

Full project participant list

Organisation	Country	Type
Onyx Solar Energy S.L.	Spain	Private company

32 Where USD is the US dollar

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Case study: CABRISS

Author:	Hanna Kuittinen Eduardo Román	**Approver:**	Mr. David Pelletier, CEA Mr. Jean-Patrice Rakotoniaina, CEA
Project title:	Implementation of a CirculAr economy Based on Recycled, reused and recovered Indium, Silicon and Silver materials for photovoltaic and other applications (CABRISS)		
Lead partner:	Commissariat a l'énergie atomique et aux énergies alternative (CEA)		
Project location:	France		
Technology area/s:	Solar photovoltaic (PV)		
Start and end date:	June 2015 to May 2018		
Project cost:	EUR 9 281 682.65	**EC funding:**	EUR 7 844 564.54
Other funding sources:	In-kind contributions, private investments		
Quantifiable outputs and impacts:	Number of recycling technologies to recover indium, silver and silicon for the sustainable PV technology and other applications; A solar cell processing roadmap, which will use silicon waste for the high throughput, cost-effective manufacturing of hybrid silicon based solar cells demonstrating the reusability and recyclability at the end of life of key PV materials.		
Further information:	Project website Project Coordinator – Mr David Pelletier, Laboratoire des Matériaux et Procédés pour le Solaire, Commissariat à l'énergie atomique et aux énergies alternatives (CEA) Visiting address, 50 avenue du Lac Léman, F-73375 Le Bourget-du-Lac. T +33 (0)632 218 691. E david.pelletier@cea.fr		

Project description

Photovoltaics is a fast-growing market and the global installed PV capacity has grown exponentially over the last two decades. The PV installations have an estimated lifetime of 20-25 years. Consequently, a growing amount of PV waste is expected globally over the next decades. Because Europe was a pioneer of installing PV capacity, the first wave of end-of-life PV waste will be faced by Europe. PV waste is also generated in PV manufacturing process when cutting the silicon ingot to bricks, slicing the ingot to wafers, through damage in production of the solar cells and in transport and handling of the modules. The PV waste along the PV value chain is thus a costly challenge affecting the whole PV lifecycle. A well-designed recycling loop would enable the recovery of the raw materials and lead to economic and environmental benefits.

Against this background, the CABRISS project was established to develop a circular economy approach for the photovoltaic industry involving also other industries (such as electronic and glass industry). The circular production value chain consists of two parts: 1) Recycling technologies to recover – from end-of-life PV panels or PV production wastes - indium, silver and silicon for sustainable PV technology and other applications; and 2) A solar cell processing roadmap, which utilises silicon waste for the high throughput and cost-effective manufacturing of hybrid silicon based solar cells and demonstrates the possibility for the re-usability and recyclability at the end of life of key PV materials.

Four main objectives of CABRISS are:

- developing industrial symbiosis by providing raw materials such as glass or silver pastes as feedstock for other industries (e.g. glass, electronics or metallurgy);
- collecting up to 90 % of the PV waste throughout Europe compared to the 40 % rate in 2013 and retrieving up to 90 % of the high value raw materials (silicon, indium and silver) from the PV cells and panels;
- manufacturing PV cells and panels from the recycled raw materials achieving lower cost (25 % less) and at least the same performances (i.e. cells efficiency yield) as the conventional processes;
- engaging the EU citizens and industry with a sustainable and financially viable circular economy approach.

The originality of the project relates to the cross-sectorial approach involving sectors like the powder metallurgy (fabrication of silicon powder based low cost substrate), the PV industry (innovative PV Cells) and recycling (hydrometallurgy and pyrometallurgy), all sharing a common aim: to make use of recycled PV waste materials. The CABRISS project consortium was carefully built to cover the full value chain starting from waste collection and resulting in a closed loop reuse of secondary materials for PV production. It involved five research institutes and 11 companies, all having a specific role along the value chain.

Outputs and impacts

The main results of the project include three technologies based on recycling:

- Processes of dismantling and delamination of end-of-life PV modules for thin film PV panels but also for crystalline silicon-based PV panels. The project achieved to develop a new technology and equipment for automatised dismantling and delamination the PV cells layer-by-layer, enabling the glass to be removed undamaged. This is the first commercially viable solution in the market, which does not shred PV waste but is able to recover undamaged glass. It also allows separation and sorting of several plastics and inorganic materials and hydrometallurgical treatment to recover metals.
- Novel technology to recycle and manufacture low-cost silicon metal powders from waste (crystalline silicon-kerf) and deposited materials, leading to metallurgical grade silicon. The novel technology for recycling silicon kerf from diamond wire cutting processes is cost efficient and results in high purity silicon powders suitable for melting in furnaces.
  Technology for purification of silicon recovered from different sources (kerf, demetallised broken cells, wafers or demetallised silicon from end of life panels). The resulting silicon has a quality sufficient for PV applications or other specialty applications. The purification process is characterised by a low energy consumption and has a low carbon footprint.

In addition, a number of solutions have been developed to reuse recovered materials, including:

- The use of secondary silver recycled from PV waste to produce conductive pastes and inks used for PV manufacturing. Replacing silver by silver-coated copper particles have been successfully tested as a lower-cost alternative.
- The use of secondary indium recycled from thin film PV waste tested in thin film PV manufacturing or in the production of indium tin oxide (ITO) targets. Based on the results achieved, the cost for recycled indium could be lower than virgin material.
- The use of recycled silicon from different sources of PV waste has been tested in several conventional production processes – as for the crystallisation and the cell technology used -

resulting to second life silicon solar cells based on 100 % recycled silicon, reaching efficiencies comparable to commercial PV cells.

The project resulted in four patent applications, one related to new process of delamination of silicon based PV panels, and three related to recovery process of silver from PV waste. In addition, CABRISS project was very active in publishing the results in academic peer-reviewed journals and conferences totalling 22 publications.

The CABRISS project had an active cooperation with European standardisation bodies such as the European Committee for Standardisation (CEN), the European Committee for Electrotechnical Standardisation (CENELEC) and with SEMI, the global industry association serving the manufacturing supply chain for the electronics industry. Altogether, 13 drafts of standard documents were made accessible to all CABRISS' partner institutions for commenting covering aspects of recyclability, product durability, reparability, reusability, recycled content, ability to remanufacture, and product lifespan.

Two new projects have started directly based on CABRISS results. 1. A H2020 project 'Circular business models for the solar power industry' (CIRCUSOL) extending the dismantling and recovery process to other sources of complex waste (e.g. batteries) and 2. 'Second life of silicon' (SELISI) funded by EIT Raw Material[33], to further advance the CABRISS results related to silicon kerf recycling towards market access.

Outlook and commercial application of the outputs

The project made significant technological advancements, achieving a TRL close to market introduction[34] (initially TRL4, end of project TRL 7-8). Consequently, the project has dedicated significant efforts to develop a business plan, and established a professional intellectual property management, expected to lead to further commercial exploitation of the results via direct sales, joint ventures and licensing.

The CABRISS project results have received a lot of industry attention as the PV manufacturers have become more and more interested in recycling, driven by the need to comply with existing regulation and to reduce the carbon footprint of their products. In Europe, the Waste of Electrical and Electronic Equipment directive (WEEE, 2012/19/EU) guides the PV waste use, setting targets to collect 85 % of waste generated, to recover 85 %, and to recycle and prepare for reuse 80 % of the waste[35]. The directive is based on extended producer-responsibility principle (EPR), which ensures that all EU market participants are liable for the cost of collection, treatment and monitoring of PV waste. By 2030, the countries expected to face the highest amount of projected PV waste are China, Germany, and Japan, followed by Italy and France[36]. Although the exact market size of PV waste recycling is difficult to estimate, it is expected to be an important market in the future.

The role of EU Funding

The CABRISS project received funding from the from the European Union's Horizon 2020 Programme for Research and Innovation (H2020). 'Climate action, environment, resource efficiency and raw materials'

[33] EIT RawMaterials, initiated and funded by the EIT (European Institute of Innovation and Technology), is a body of the European Union unites industry, universities and research institutes to conduct R&I activities along the raw materials value chain.
[34] The Technology Readiness Level (TRL) was initially 4 (technology validated in lab), and reached TRL7-8 (system prototype demonstration in operational environment -system complete and qualified) at the end of the project.
[35] These targets are valid from August 2018 when WEEE transitional period is over. The current targets are slightly lower.
[36] CABRISS (2018) H2020 CABRISS Public Business Plan. Available at: https://doi.org/10.5281/zenodo.998558

is one of the seven societal challenges prioritised by the H2020 and provided funding for challenge-based approach bringing together resources and knowledge across different fields, technologies and disciplines. The CABRISS project received the funding under the specific call topic: 'Moving towards a circular economy through industrial symbiosis' (WASTE-1-2014).

The EU contribution of the CABRISS project was EUR 7.8 million, equalling to 85 % of the project total cost. The funding rates varied by participant types; 100 % cost-coverage for non-profit research organisations and 70 % for the private companies. The project started in June 2015 and was finalised in May 2018 celebrating its final conference in June 2018. Despite the large consortium involving different type of actors, the project went smoothly and delivered all the results according the project plan. The project was driven by a real need to develop a solution to make use of recycled PV waste materials: 'One of the success factors of the project were the dedicated partners who knew their role in the project value chain and respected the deadlines', CABRISS project coordinator Mr. Pelletier explained.

The CABRISS project sought to solve a common European challenge and consequently the European funding was critical for the project. The project enabled the partners to enlarge their national networks with European partners, and many of the partners are now also collaborating bilaterally. The CABRISS also resulted in enhanced visibility to PV recycling and reuse technologies. 'Thanks to CABRISS, several partners can address new markets with PV waste reuse', Mr. Pelletier concluded.

Full project participant list

Organisation	Country	Type
Commissariat a l'énergie atomique et aux énergies alternative	France	Research institute
Stiftelsen Sintef	Norway	Research institute
Interuniversitair Micro-Electronica Centrum	Belgium	Research institute
Loser Chemie Gmbh	Germany	Private company
Ferroatlantica I & D SL	Spain	Private company
Uab Soli Tek R&D	Lithuania	Private company
Pyrogenesis SA	Greece	Private company
Rhp Technology GmbH	Austria	Private company
Resitec As	Norway	Private company
Technische Universitaet Wien	Austria	Academic institute
Sunplugged - Solare Energiesysteme GmbH	Austria	Private company
Fraunhofer Gesellschaft zur Foerderung der Angewandten Forschung E.V.	Germany	Research institute
Projektkompetenz.Eu - Gesellschaft fur Projektentwicklung und -Management Mbh	Austria	Private company
PV Cycle France	France	Private company
Inkron Oy	Finland	Private company
ECM Greentech	France	Private company

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Case study: CHEETAH

Author:	Hanna Kuittinen Eduardo Roman	**Approver:**	Dr. Jan M. Kroon, Senior Project Manager, TNO
Project title:	Cost-reduction through material optimisation and Higher EnErgy outpuT of solAr pHotovoltaic modules - joining Europe's Research and Development efforts in support of its PV industry (CHEETAH)		
Lead partner:	Stichting Energieonderzoek Centrum Nederland (ECN, nowdays part of TNO)		
Project location*:	The Netherlands		
Technology area/s:	Photovoltaic (PV)		
Start and end date:	January 2014 to December 2017		
Project cost:	EUR 13 282 037.27	**EC funding:**	EUR 9 696 132.00
Other funding sources:	In-kind contributions		
Quantifiable outputs and impacts:	15 thesis projects funded 7 joint papers (with at least 2 partners) were published 47 peer-reviewed publications/conference proceedings 1.581 external and 577 CHEETAH participants registered to participate in 73 webinars 2 books written More than 240 dissemination and communication actions registered 13 exploitable results reported (2 commercial results) and 1 patent.[37]		
Further information:	Project website Dr. J.M. (Jan) Kroon, Senior Project Manager, PV Modules & Applications, TNO. Visiting address, Westerduinweg 3, NL-1755 LE Petten. T +31 (0)88 866 23 17 E jan.kroon@tno.nl		

Project description

CHEETAH project was initiated by the European Energy Research Alliance (EERA) and its Photovoltaics Joint Research Programme (EERA-PV). The EERA network was established 10 years ago and it brings together the main European research centres and universities working on different RE technologies. The EERA is organised around 17 Joint Research Programmes, of which one focuses on photovoltaics (PV). The aim of the EERA-PV is to join the efforts of the European PV research institutes to overcome the existing fragmentation of PV R&D in Europe, and to intensify the collaboration between research and industry to accelerate the market uptake of research findings. Before the CHEETAH project, the EERA-PV network had already worked towards identifying common research priorities and goals, and thanks to the project funding, the network could start to implement a part of the Joint Research Programme. The CHEETAH project prioritised the following objectives:

1) Developing new concepts and technologies for wafer-based crystalline silicon PV (modules with ultra-thin cells), thin film PV and organic PV (OPV), resulting in reduced cost of materials and increased module performance.
2) Fostering long-term European cooperation in the PV R&D sector, by organising workshops and training of researchers, and by efficient use of infrastructures.
3) Accelerating the implementation of innovative technologies in the PV industry. This is achieved by a strong involvement of Solar Power Europe (SPE) and InnoEnergy.

[37] European Commission (2018) CHEETAH Project Final Report. D1.10 - Final Report, March 2018.

The CHEETAH project consortium was formed by the EERA-PV members, 34 partners located around Europe, including 31 research organisations (universities and research institutes), complemented by Solar Power Europe - the European PV industry association, InnoEnergy - a European company fostering the integration of education, technology, business and entrepreneurship and strengthening the culture of innovation, and a consultancy company Ayming for project management support. The core actors of EERA-PV, ECN (coordinator, the Netherlands), CEA-INES (France), Fraunhofer-ISE (Germany), DTU (Denmark) and Helmholtz Centre (Germany), had also a central role in the CHEETAH project.

Outputs and impacts

CHEETAH project outcomes can be divided into technological achievements, and contributions towards consolidating and fostering the PV research landscape in Europe.

A common goal for the three technology development lines, wafer based crystalline silicon, thin film PV and organic PV, was to achieve reduced costs of PV materials. One of the main technological achievements in this respect was fabrication of very thin kerfless crystalline silicon foils and wafers with lower material use and less waste. The project explored utilising epitaxial growth method, as a substituting technique for wafer sawing. In laboratory-scale, very high electrical and crystalline quality heterojunction cells as thin as 40 microns were demonstrated (on 125 x 125 mm^2 free standing epi foils) achieving 17 % efficiency. This technology is expected to lead 20 % reduction in the total costs. The project demonstrated and validated industrial feasibility of automatic processing for thin wafers down to 80 microns, using chemically thinned wafers and heterojunction technology with record cells having over 22 % efficiency. Demonstrations were carried out in a pilot manufacturing line, and the technology is ready for industrial exploitation. The main advantage of the demonstrated technology is that it can be achieved by optimisation of existing manufacturing lines and therefore no additional equipment investments are needed.

In respect to thin film technology, some very interesting scientific results were attained. The achieved results are still not yet ready industrial application however. Two thin-film PV technologies (liquid phase crystallised silicon and chalcopyrite together with kesterite material) were further developed by reducing absorber dimensions and applying advanced concepts for light management. Top-level research teams were working together and contributed towards more consolidated European research basis, and achieved a number of scientific publications.

In emerging photovoltaics such as organic or perovskite PV, packaging constitutes a significant portion of the total cost of the technology. An extensive collaborative effort was put in place to identify solutions for alternative and low-cost packaging solutions (e.g. based on polyethylene terephthalate (PET)) and improve the intrinsic stability of these technologies. The results of the project were however hindered by the fact that a large part of the OPV research community shift their focus to the emerging perovskite technology, which faces challenges very similar to those of OPV.

The main outcomes related to consolidating the network were related to development of tools and means (e.g. e-learning platform, webinars, education and training activities, actions related mobility of researchers) for knowledge exchange and mutual learning. One of the main achievements is the development of a dynamic database of PV experts and expertise in Europe. Another result was an e-webinar tool to organise short sessions to exchange research results helping to achieve easy and timely knowledge exchange between European researchers. The project also contributed towards enhanced understanding of PV standardisation needs. Overall, although the networking results are difficult to quantify, it is believed that the intensive exchange of ideas and knowledge between the participants has strengthened the entire European PV community, and forms a strong basis for future research projects.

Outlook and commercial application of the outputs

CHEETAH project led to achievement of higher technological readiness levels (TRL), but in general the outcomes are still subject to further development. The main technological results of CHEETAH project were however contrasted together with the European PV industry to assess their feasibility and commercial potential. It was concluded that:

- Thinner crystalline silicon wafers achieved through epitaxial growth method are faced with very low silicon market prices and constantly lowering wafer costs. The current market situation was not however considered to undermine the great technological leap made by the project in wafer technologies. The new approach to manufacture wafers can significantly reduce the environmental footprint of solar cells due to lower material and energy consumption and waste generated.
- Thin wafers can also enable more lightweight and flexible PV products and thus are considered to have commercial opportunities in specialised, higher value-added niche markets such as building integrated PV products, possibly leading to enhanced competitiveness of the technology and eventually a wider market uptake.
- The industrial scale automatic thin wafer processing technology is further developed and applied by CEA-INES in an on-going 3Sun led H2020 project AMPERE, which aims to develop and implement a fully automated PV manufacturing pilot line based on silicon heterojunction technology (HJT)[38].
- In respect to thin film technologies, the results obtained are further away from any potential industrial exploitation. The industry is currently focused to reach the efficiency levels to be competitive with crystalline silicon technology.
- Overall, it was concluded that OPV cannot compete with crystalline silicon technology either, at least in near future, mainly due to lower performance. However, it was considered that the results obtained could be used in niche applications where flexibility and freedom of design are the most important criteria (e.g. indoor energy harvesting, Internet of Things, battery-replacement (low-light), building integrated PV and automotive applications). Also, it was considered that the results obtained in respect to intrinsic stability and packaging of OPV devices are very relevant for the currently booming perovskite PV research.

The role of EU Funding

CHEETAH project was supported by the European Union's Seventh Research and Innovation funding programme (FP7) that was in place in 2007-2013. Alongside with many research and innovation activities, the FP7 Energy programme also launched Integrated Research Programmes (IRPs) as an instrument combining research activities with coordination and support actions. CHEETAH project was among the seven IPR projects funded. The project had a total budget of more than EUR 13 million, out of which 73 % came from the EU. The project started in January 2014 and ran for four years, celebrating the final event in November 2017. Despite that the project had many participants, the division of work was well distributed and the project achieved its goals. The project partner Ayming

[38] http://www.ampere-h2020.eu/project

was responsible for the administrative and financial management allowing research organisation to focus on technical aspects and ensuring smooth progress of the project.

The EU funding was essential for consolidating the EERA-PV network activities, and important in general for keeping European PV research abreast of the global competition. In general, one of the largest benefits of EU funding is about bringing together European PV sector actors and therefore enabling cross-European collaboration. FP funded research should be looked as an integral part of a portfolio of funding and investments that enables European PV sector actors to develop their unique set of technological capacities and competitive position. 'Outcomes of a single project should not be measured alone, they are always resulting from a combination of activities and long-trajectories of cumulative research', remarked Dr. Jan M. Kroon, the coordinator of the CHEETAH project. 'The R&I projects take into account the current industry needs, but their role is also to look further, and create basis for future competitiveness, in a longer-term time perspective', Dr. Kroon concluded.

Full project participant list

Organisation	Country	Type
ECN, Stichting energieonderzoek Centrum Nederland	The Netherlands	Research institute
CEA-INES, Commissariat à l'Energie Atomique et aux Energies Alternatives	France	Research institute
Fraunhofer, Fraunhofer Gesellschaft zur Foerderung der Angewandten Forschung E.V.	Germany	Research institute
DTU, Danmarks Tekniske Universitet	Denmark	Academic institute
Helmholtz-Zentrum Be, Helmholtz-Zentrum Berlin fur Materialien une Energie GmbH	Germany	Research institute
Jülich, Forschungszentrum Juelich GmbH	Germany	Research institute
AIT, Austrian Institute of Technology GmbH	Austria	Research institute
ENEA, Agencia Nazionale per le Nuove Technologi, l'Energia e lo Svilippo Economico Sostenibile	Italy	Research institute
EPFL, Ecole Polythechnique Fédérale de Lausanne	Switzerland	Academic institute
IFE, Institutt for Energiteknikk	Norway	Research institute
Forschungsverbund Be, Forschungsverbund Berlin E.V	Germany	Research institute
IMEC, Interuniversitair Micro-electronica Centrum VZW	Belgium	Research institute
NPL, NPL Management Limited	United Kingdom	Private company
SINTEF, Stiftelsen	Norway	Research institute
Tallinna Tehnikaulik	Estonia	Academic institute
ZSW, Zentrum for Sonnenenergie und Wasserstoff Forschung Baden Wurttembergstiftung	Germany	Research institute
LNEG, Laboratorio Nacional de Energia e Geologia I.P.	Portugal	Research institute
TOR VERGATA, Universita Degli Studi di Roma Torvergata	Italy	Academic institute
METU, Middle East Technical University	Turkey	Academic institute
TECNALIA, Fundacion Tecnalia Research & Innovation	Spain	Research institute
UPM, Universidad Politecnica de Madrid	Spain	Academic institute
CIEMAT, Centro de Investigaciones Energeticas, Medioambbientles y Technologicas	Spain	Research institute
CRES, Center for Renewable Energy Sources and Savings	Greece	Research institute
LU, Loughborough University	United Kingdom	Academic institute

Organisation	Country	Type
EMPA, Eidgenoessische Materialpruefungs und Forschungsanstalt	Switzerland	Academic institute
Imperial, Imperial College of Science, Technology and Medicine	United Kingdom	Academic institute
JRC, Joint Research Centre - European Commission	Belgium	Research institute
TUBITAK, Turkiye Bilimsel ve Teknolojik Arastirma Kurumu	Turkey	Research institute
VTT, Teknologian Tutkimuskeskus	Finland	Research institute
UPVLC, Universitat Politecnica de Valencia	Spain	Academic institute
UNIMIB, Universita' Degli Studi di Milano-Bicocca	Italy	Academic institute
SolarPower Europe	Belgium	Industry association
KIC SE, KIC Innoenergy SE	Netherlands	Private company
Ayming SAS	France	Private company

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Annex 4C - Methodological note on imports and exports

The value of the following components were assessed for solar PV:

Table C.1 HS6 product codes relevant to the solar PV sector

HS6 code	Brief product description
711590	Articles of precious metal or of metal clad with precious metal, N.E.S
830630	Photograph, picture or similar frames, of base metal; mirrors of base metal (excl. optical elements)
841280	Engines and motors (excl. steam turbines, internal combustion piston engine, hydraulic turbines, water wheels, gas turbines, reaction engines, hydraulic power engines and motors, pneumatic power engines and motors and electric motors)
850239	Generating sets (excl. wind-powered and powered by spark-ignition internal combustion piston engine)
850440	Static converters
854140	Photosensitive semiconductor devices, incl. photovoltaic cells whether or not assembled in modules or made up into panels; light emitting diodes (excl. photovoltaic generators)*

Source: Comext database and Jha (2009)
** Single use technology*

Table C.2 NACE2 codes relevant to the solar PV sector

NACE2	Definition
24	Basic metals
25	Fabricated metal products
28	Other machinery and equipment
27	Electrical equipment

Annex 4D - List of EU-funded projects

Table D.1 Solar PV EU-funded projects

Acronym	Rcn	Project title	EC funding (2016 EUR)	Framework Programme	Topic
20PLμS	96221	20 percent efficiency on less than 100 μm thick industrially feasible c-Si solar cells	5283138.2	FP7-ENERGY	ENERGY.2010.2.1-1
2for1-SingletFission	202919	2 for 1: Quantum Dynamics of Singlet Fission	195454.8	H2020-EU.1.3.2.	MSCA-IF-2015-EF
ACTIVRENERGY	187987	Active Balancing Power Converters for Photovoltaic Energy Systems	166735.4	FP7-PEOPLE	FP7-PEOPLE-2013-IEF
ADIOS-RU	105581	Advanced Design and Industrialization of Organic Sensitizers without Ruthenium for Dye Sensitised Solar cells	884950.0	FP7-SME	SME-2012-1
ADVANTAGE	55360	Advanced next generation rear contact module technology for building integration	853087.2	FP5-EESD	1.1.4.-6.
ADVOCATE	59846	Advanced dry processes for low cost, thin multicrystalline silicon solar cell technology-(ADVOCATE)	2268489.3	FP5-EESD	1.1.4.-6.
AFRODITE	55358	Advanced façade and roof elements key to large scale building integration of photovoltaic energy (AFRODITE)	1191263.3	FP5-EESD	1.1.4.-5.
AGATHA	95773	Advanced Gratting for Thin Films Solar Cell	1666951.7	FP7-ENERGY	ENERGY.2010.2.1-2
ALABO	194137	Advanced laser ablation barrier films for organic and large area electronic devices	3947113.2	H2020-EU.2.1.1.1.	ICT-03-2014
AlbaSolar	210400	Developing perovskite-based solar panels	49156.6	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
ALD4PV	98952	ATOMIC LAYER DEPOSITION OF METAL OXIDES FOR PHOTOVOLTAIC SOLAR CELLS	193780.4	FP7-PEOPLE	FP7-PEOPLE-2010-IEF
ALHSOLAR	93309	Advanced Light Harvesting for Organic based Solar Energy Conversion	49732.7	FP7-PEOPLE	PEOPLE-2007-2-2.ERG
ALIGN	92460	Ab-initio computational modelling of photovoltaic interfaces	1082613.4	FP7-IDEAS-ERC	ERC-SG-PE5
ALLOXIDEPV	105882	Novel Composite Oxides by Combinatorial Material Synthesis for Next Generation All-Oxide-Photovoltaics	3068857.2	FP7-ENERGY	ENERGY.2012.10.2.1
ALPINE	92584	Advanced Lasers for Photovoltaic INdustrial processing Enhancement	6520490.5	FP7-NMP	NMP-2008-4.0-4

Acronym	Rcn	Project title	EC funding (2016 EUR)	Framework Programme	Topic
AMETIST	204863	Advanced III-V Materials and Processes Enabling Ultrahigh-efficiency (50%) Photovoltaics	2450672.5	H2020-EU.1.1.	ERC-ADG-2015
AMON-RA	89662	Architectures, Materials, and One-dimensional Nanowires for Photovoltaics - Research and Applications	3571573.1	FP7-NMP	NMP-2007-2.2-3
AMPERE	209763	Automated photovoltaic cell and Module industrial Production to regain and secure European Renewable Energy market	14699858.1	H2020-EU.3.3.2.	LCE-09-2016
APOLLON	88272	Multi-APprOach for high efficiency integrated and inteLLigent cONcentrating PV modules (Systems)	8590681.7	FP7-ENERGY	ENERGY-2007-2.1-03
APPEL	206128	Approaching efficiency limits of perovskite solar cells by overcoming non-radiative recombination losses	195454.8	H2020-EU.1.3.2.	MSCA-IF-2015-EF
ARCIGS-M	206842	Advanced aRchitectures for ultra-thin high-efficiency CIGS solar cells with high Manufacturability	4498700.9	H2020-EU.2.1.3.;H2020-EU.2.1.2.	NMBP-17-2016
ArtESun	110576	Efficient, large-area arbitrary shape solar energy	3711880.5	FP7-NMP	NMP.2013.4.0-2
ASPIS	89736	Active Solar Panel Initiative	3187680.3	FP7-ENERGY	ENERGY.2008.10.1.1
ATHLET	78499	Advanced Thin-Film Technologies for Cost Effective Photovoltaics	12424434.7	FP6-SUSTDEV	SUSTDEV-1.2.4
BATTMAN	201965	Battery Management with Solar Powered Devices	986413.3	FP7-JTI	SP1-JTI-ENIAC-2011-2-1;SP1-JTI-ENIAC-2011-2-3
BFIRST	103645	Building-integrated fibre-reinforced solar technology	3376120.0	FP7-ENERGY	ENERGY.2011.2.1-4
BGCSE	86957	Bulgarian centre of solar energy	241582.5	FP5-EESD	
BI-DSC	107008	Building Integrated Dye Sensitized Solar Cells	2004899.2	FP7-IDEAS-ERC	ERC-AG-PE8
BIOCELL	86896	New design methodology for industrialised, autonomous and low-energy demand cellular buildings	3772081.1	FP5-EESD	
BITHINK	87882	Bifacial Thin Industrial multi-Crystalline Silicon Solar Cells	2471325.1	FP6-SUSTDEV	SUSTDEV-1.1.1
BUILD-DSSC	86533	Large area dssc for building integrated PV tile	778735.7	FP6-SME	SME
CA2PVM	104569	Multi-field and multi-scale Computational Approach to design and durability of PhotoVoltaic Modules	1518205.9	FP7-IDEAS-ERC	ERC-SG-PE8

Acronym	Rcn	Project title	EC funding (2016 EUR)	Framework Programme	Topic
CABRISS	196816	Implementation of a CirculAr economy Based on Recycled, reused and recovered Indium, Silicon and Silver materials for photovoltaic and other applications	7864176.0	H2020-EU.3.5.4.	WASTE-1-2014
CAMBAR07	87857	Large-area ordered arrays of semiconducting oxide nanowires as electrodes for nanostructured hybrid solar cells	189060.8	FP7-PEOPLE	PEOPLE-2007-2-1.IEF
CANTOR	109018	Carbon-nanotube-based terahertz-to-optics rectenna	91418.9	FP7-PEOPLE	FP7-PEOPLE-2013-IRSES
CapTherPV	197495	Integration of Capacitor, Thermoelectric and PhotoVoltaic thin films for efficient energy conversion and storage	2004373.4	H2020-EU.1.1.	ERC-CoG-2014
CASi-CVD	102654	Stable Unsaturated Silicon Clusters as Nucleation Sites in Solution and the Gas Phase	178499.2	FP7-PEOPLE	FP7-PEOPLE-2011-IEF
CDRONE	204384	Towards un-subsidised solar power – Cleandrone, the inspection and cleaning solution	50000.0	H2020-EU.2.3.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
ChalQd	107082	Chalcopyrite Quantum dots for Intermediate band Solar cells	148364.4	FP7-PEOPLE	FP7-PEOPLE-2012-IEF
CHEETAH	111512	Cost-reduction through material optimisation and Higher EnErgy outpuT of solAr pHotovoltaic modules - joining Europe's Research and Development efforts in support of its PV industry	9719400.4	FP7-ENERGY	ENERGY.2013.10.1.5
CHEOPS	199296	Production technology to achieve low Cost and Highly Efficient phOtovoltaic Perovskite Solar cells	3299095.0	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-02-2015
CHESS	103237	Block Copolymers for High Efficient Solar Cells with novel Structures	198059.8	FP7-PEOPLE	FP7-PEOPLE-2011-IEF
CHOIS	103101	Characterisation of hybrid inorganic-organic solar cells by advanced spectroscopic methods	204993.1	FP7-PEOPLE	FP7-PEOPLE-2011-IEF
CHROMTISOL	193604	Towards New Generation of Solid-State Photovoltaic Cell: Harvesting Nanotubular Titania and Hybrid Chromophores	1648491.0	H2020-EU.1.1.	ERC-StG-2014
CIS	57562	The World's First Large Scale Cis Based Photovoltaic Installation at the New Museum of Fine Arts in the City of Leipzig	279879.6	FP5-EESD	1.1.4.-6.5.2
CISLINE	60340	Improved ciscut solar cells, manufactured roll-to-roll in a base line - (CISLINE)	1253910.7	FP5-EESD	1.1.4.-6.

Acronym	Rcn	Project title	EC funding (2016 EUR)	Framework Programme	Topic
Cogem CPVTM	197363	COGEM CPV - An innovative Ceramic Heatsprider within HCPV (High Concentration Photovoltaic) Technology	2103701.8	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014
COLIBRI	206129	Carrier-selective contacts for silicon photovoltaics based on broadband-transparent oxides	175419.6	H2020-EU.1.3.2.	MSCA-IF-2015-EF
CONMAN	60331	Improvement of photovoltaic concentrator systems and technology transfer to a manufacturer (CONMAN)	928294.9	FP5-EESD	1.1.4.-5.
CONSOL	67372	Connection technologies for thin film solar cells (CONSOL)	682682.4	FP5-EESD	1.1.4.-6.
CONSTRUCT-PV	107962	Constructing buildings with customizable size PV modules integrated in the opaque part of the building skin	6967309.5	FP7-ENERGY	ENERGY.2011.2.1-4
CONTREX	200745	Controlling Triplet Excitons in Organic Semiconductors	1499223.0	H2020-EU.1.1.	ERC-StG-2015
CPV/RANKINE	106823	Improving the Performance of Concentrating PV by Exploiting the Excess Heat through a Low Temperature Supercritical Organic Rankine Cycle	959012.1	FP7-SME	SME-2012-1
CPV4ALL	107968	Novel CPV system fit for mass production, for electricity costs beyond grid parity and for applications in B2B, industrial and residential areas	7419571.1	FP7-ENERGY	ENERGY.2011.2.1-3
CPVMatch	193754	Concentrating Photovoltaic modules using advanced technologies and cells for highest efficiencies	4961970.2	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-02-2014
CRYSTAL CLEAR	73971	Crystalline Silicon PV: Low-cost, highly efficient and reliable modules (CRYSTAL CLEAR)	19780490.8	FP6-SUSTDEV	SUSTDEV-1.2.4
Crystal Solar	199602	Organic-Inorganic perovskite and organic semiconductor films with improved crystal properties via reel-to-reel solution coating; application to photovoltaics and field effect transistors	251857.8	H2020-EU.1.3.2.	MSCA-IF-2014-GF
Crystal Tandem Solar	200874	Single-Crystal Perovskite Tandem Solar Cells For High Efficiency and Low Cost	265305.9	H2020-EU.1.3.2.	MSCA-IF-2015-GF
cSiOnGlass	199052	Development of high-quality crystalline silicon layers on glass	171889.5	H2020-EU.1.3.2.	MSCA-IF-2014-EF
CU-PV	105212	Cradle to cradle sustainable pv modules	4127957.4	FP7-ENVIRONMENT	ENV.2012.6.3-1
DAMASCO	97977	Preparation and Application of new n-type, Electron Acceptor Materials in Organic Solar Cells	47253.1	FP7-PEOPLE	FP7-PEOPLE-2009-RG

Acronym	Rcn	Project title	EC funding (2016 EUR)	Framework Programme	Topic
DELUMOPV	103354	Delayed Luminescence Spectroscopy of Organic Photovoltaic Systems	190048.0	FP7-PEOPLE	FP7-PEOPLE-2011-IEF
DEMOSOLNOWAT	188536	Testing and up scaling of technology developed under the SOLNOWAT FP7 Project which developed a competitive 0 GWP, dry, atmospheric pressure etching process for use in manufacture of PV solar cells	1298184.9	FP7-SME	SME-2013-3
DEPHOTEX	90294	Development of Photovoltaic Textiles based on novel fibres	3495113.2	FP7-NMP	NMP-2007-4.0-2
Desolenator	201782	Green and Affordable Water Supply for All	50000.0	H2020-EU.3.5.;H2020-EU.2.3.1.	SC5-20-2015-1
Destiny	105583	DyE SensiTized solar cells wIth eNhanced stabilitY	3937732.4	FP7-PEOPLE	FP7-PEOPLE-2012-ITN
DIELECTRIC PV	188164	Advanced light trapping with dielectric micro-particle self-assembled arrays for low-cost and high-performance thin film solar cells	153698.0	FP7-PEOPLE	FP7-PEOPLE-2013-IEF
DISC	205805	Double side contacted cells with innovative carrier-selective contacts	4743518.8	H2020-EU.3.3.2.	LCE-07-2016-2017
DOIT	54162	Development of an optimized integrated thin film silicon solar module (DOIT)	2265503.0	FP5-EESD	1.1.4.-6.
EASE	102728	Energy Transfer in Supramolecular Nanostructures	361733.8	FP7-PEOPLE	FP7-PEOPLE-2011-IOF
EASY Pv	200249	EGNSS high Accuracy SYstem improving PhotoVoltaic plants maintenance	935973.1	H2020-EU.2.1.6.	GALILEO-2-2015
EBFZ	205141	Float zone silicon from electron beam grown rods	50000.0	H2020-EU.2.3.1.;H2020-EU.2.1.1.	SMEInst-01-2016-2017
EC2 CONTACT	60071	Environmentally clean efficient, and easy to contact crystalline silicon solar cells (EC2 CONTACT)	839686.3	FP5-EESD	1.1.4.-6.
ECHELLE	73061	Electrodeposited Chalcopyrite thin film solar cells: High efficiency Limits and Losses Evaluation	184333.2	FP6-MOBILITY	MOBILITY-2.1
ECOCHEM	108255	Development of Low Band Gap Conjugated Polymers by EcoFriendly Synthetic Methodologies for High Performance Organic Photovoltaics	163238.9	FP7-PEOPLE	FP7-PEOPLE-2012-IEF
ECOF	106900	Electroactive Donor-Acceptor Covalent Organic Frameworks	2450796.5	FP7-IDEAS-ERC	ERC-AG-PE5
Eco-Solar	198355	Eco-Solar Factory - 40%plus eco-efficiency gains in the photovoltaic value chain with minimised resource and energy consumption by closed loop systems	5656814.3	H2020-EU.2.1.5.1.	FoF-13-2015

Acronym	Rcn	Project title	EC funding (2016 EUR)	Framework Programme	Topic
ECOSOLE	107964	Elevated Concentration photovoltaic solar energy generator and fully automated machinery for high throughput manufacturing and testing	7159399.0	FP7-ENERGY	ENERGY.2011.2.1-3
ECPM	90562	Computational modelling of electromagnetic control of melt flows and heat/mass transfer during manufacturing of bulk photovoltaic materials	133847.4	FP7-PEOPLE	FP7-PEOPLE-IEF-2008
EDEN PV	86810	Eden project photovoltaic system	635780.9	FP5-EESD	
EGBERT FIGGEMEIER	65055	Tuning of dye-sensitized particles in nano-structured solar cells	192956.8	FP5-HUMAN POTENTIAL	
ELECTPROPOIPC	185813	Atomically thin layers of Organic-Inorganic Perovskite Crystals – Electronic Properties and Application in Solar Cells	275469.7	FP7-PEOPLE	FP7-PEOPLE-2013-IOF
ELSI	92327	Electrochemical Silicon Layers Formation in Fused Salts	272958.7	FP7-PEOPLE	FP7-PEOPLE-IEF-2008
ELSi	202719	Industrial scale recovery and reuse of all materials from end of life silicon-based photovoltaic modules	2529607.0	H2020-EU.3.;H2020-EU.2.	FTIPilot-1-2015
EMM3	96036	Emerging Materials and Methods for 3rd generation solar cells	271077.7	FP7-PEOPLE	FP7-PEOPLE-2009-IOF
EPHOCELL	90161	Smart light collecting system for the efficiency enhancement of solar cells	2763250.4	FP7-ENERGY	ENERGY.2008.10.1.2;NMP-2008-2.6-1
EPIMETSI	67448	High throughput epitaxial reactor development for solar cell manufacturing from mg-silicon (EPIMETSI)	2568488.3	FP5-EESD	1.1.4.-6.
EpiSil-IBC	195423	Epitaxial silicon foil solar cells with interdigitated back contacts	161202.0	H2020-EU.1.3.2.	MSCA-IF-2014-EF
ERG	201952	ENERGY FOR A GREEN SOCIETY: FROM SUSTAINABLE HARVESTING TO SMART DISTRIBUTION. EQUIPMENTS, MATERIALS, DESIGN SOLUTIONS AND THEIR APPLICATIONS	4508836.9	FP7-JTI	SP1-JTI-ENIAC-2010-3
ESA 2.0	208414	Pushing forward irradiation monitoring efficiency in the PV industry	658464.4	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
ESCORT	95774	Efficient Solar Cells based on Organic and hybrid Technology	1451964.3	FP7-ENERGY	ENERGY.2010.2.1-2
ESTABLIS	101561	Ensuring STABiLIty in organic Solar cells	3959555.7	FP7-PEOPLE	FP7-PEOPLE-2011-ITN
ETASECS	185663	Extremely Thin Absorbers for Solar Energy Conversion and Storage	2155159.5	FP7-IDEAS-ERC	ERC-CG-2013-PE8
ETFE-MFM	186992	Development and demonstration of flexible multifunctional ETFE module for architectural façade lighting	2101970.5	FP7-ENERGY	ENERGY.2012.2.1.2

Acronym	Rcn	Project title	EC funding (2016 EUR)	Framework Programme	Topic
ETIP PV - SEC	205614	Support to all stakeholders from the Photovoltaic sector and related sectors to contribute to the SET-Plan	596812.5	H2020-EU.3.3.3.;H2020-EU.3.3.2.	LCE-36-2016-2017
EU HEROES	211441	EU routes for High pEnentration of solaR PV into lOcal nEtworkS	1209800.8	H2020-EU.3.3.7.;H2020-EU.3.3.3.;H2020-EU.3.3.2.	LCE-21-2017
EUROPEAN PV CONFEREN	57749	European Photovoltaic Solar Energy Conference and Exhibition, May 2000- Demonstrating the European Union’s Commitment	93904.7	FP5-EESD	1.1.4.-5.2.3
EURO-PSB	67499	The European polymer solar battery (EURO-PSB)	1839430.5	FP5-EESD	1.1.4.-5.
EUROPV	86967	Euro-conference on photovoltaic devices - target action L	90014.1	FP5-EESD	
EUROPV	70404	Euroconference On Photovoltaic Devices - Target Action L	88281.5	FP5-EESD	1.1.4.-5.2.3
EverClean	209697	EVERCLEAN - A DURABLE SELF-CLEAN COATING FOR SOLAR PANELS TO IMPROVE PV ENERGY GENERATION EFFICIENCY	2229386.2	H2020-EU.3.;H2020-EU.2.	FTIPilot-01-2016
EXCITONIC SOLAR CELL	94857	Photovoltaic Excitonic Solar Cells	198086.6	FP7-PEOPLE	FP7-PEOPLE-2009-IEF
EXTMOC	108337	Exciton Transport in Molecular Crystals: The Role of Dynamic Disorder	223344.1	FP7-PEOPLE	FP7-PEOPLE-2012-IEF
FabriGen	100965	Fabric structures for solar power generation	1240865.5	FP7-SME	SME-2011-1
FACESS	85569	Flexible Autonomous Cost efficient Energy Source and Storage	3794811.8	FP7-ICT	ICT-2007.3.2
FANTASI	61288	Fast and novel manufacturing technologies for thin multicrystalline silicon solar cells - (FANTASI)	2571821.4	FP5-EESD	1.1.4.-6.
Fast Track	109417	Accelerated development and prototyping of nano-technology-based high-efficiency thin-film silicon solar modules	8772520.3	FP7-NMP	ENERGY.2011.2.1-2;NMP.2011.1.2-1
FAST-IQ	51594	Fast inline characterisation tools for crystalline silicon material and cell process quality control in the pv-industry ('FAST-IQ')	2280541.9	FP5-EESD	1.1.4.-6.
FerroHub	205018	A modular power electronic inverter based on a local DC nanogrid for solar, storage and smart grids	1384312.0	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017

Acronym	Rcn	Project title	EC funding (2016 EUR)	Framework Programme	Topic
FERROVOLT	210069	For a better understanding and design of ferroelectric photovoltaics: First-principles study of optical absorption and charge-carrier transport at ferroelectric domain walls in BiFeO3	172899.5	H2020-EU.1.3.2.	MSCA-IF-2016
FIRST	57385	fuel cell innovative remote energy system for telecom ('FIRST')	2280543.3	FP5-EESD	1.1.4.-5.
FIRST STEP	70412	Self-formation Research Towards Stairway To Excellence In Photovoltaic	153398.0	FP5-EESD	1.1.4.-5.2.3
FLASH	59851	Fast Low Thermal Budget Large Area System for High Throughput Solar Cell Production - (Flash)	1926545.0	FP5-EESD	1.1.4.-6.
FLEXCELLENCE	75094	Roll-to-roll technology for the production of high-efficiency low cost thin film silicon photovoltaic modules	3745392.0	FP6-SUSTDEV	SUSTDEV-1.2.4
FLEXISOL	84773	Explorative research on flexible amorphous silicon solar cells	11458947.7	FP6-MOBILITY	MOBILITY-1.3
FLEXSOLCELL	92743	Development of Flexible single and tandem II-VI-Based High Efficiency Thin Film Solar Cells	286460.1	FP7-PEOPLE	FP7-PEOPLE-IRSES-2008
F-LIGHT	103797	Förster resonant energy transfer for high efficiency quantum dot solar cells	200921.4	FP7-PEOPLE	FP7-PEOPLE-2011-IOF
FLOTA	194785	Floating Offshore Photovoltaic systems	50120.0	H2020-EU.2.3.1.;H2020-EU.3.2.	BG-12-2014-1
FOXY	78508	Development of solar-grade silicon feedstock for crystalline wafers and cells by purification and crystallisation	3196823.0	FP6-SUSTDEV	SUSTDEV-1.2.4
FULLSPECTRUM	73976	A new PV wave making more efficient use of the solar spectrum (FULLSPECTRUM)	10518106.7	FP6-SUSTDEV	SUSTDEV-1.2.4
FV-TR-SMS	79058	Time Resolved Single Molecule Spectroscopy Studies of Photoinduced Charge Separation and Charge Transfer in Model Photovoltaic Solar Energy Devices	328147.2	FP6-MOBILITY	MOBILITY-2.2
GO-NEXTS	105884	Graphene doping and texturing in efficient electrodes for organic solar cells	2136154.7	FP7-ENERGY	ENERGY.2012.10.2.1
GOTSolar	199036	New technological advances for the third generation of Solar cells	2993403.5	H2020-EU.1.2.1.	FETOPEN-1-2014
GreenChalcoCell	200930	Green and sustainable chalcopyrite and kesterite nanocrystals for inorganic solar cells	171460.8	H2020-EU.1.3.2.	MSCA-IF-2015-EF
GRIPHOS	87010	Grid-connected Pv systems on roofs of newly built low energy consumptive family houses	315611.1	FP5-EESD	

Acronym	Rcn	Project title	EC funding (2016 EUR)	Framework Programme	Topic
H-ALPHA SOLAR	52720	Development of new production techniques for highly efficient polymorphous solar cells ('H-ALPHA SOLAR')	2673242.1	FP5-EESD	1.1.4.-6.
HAMLET	60056	High efficiency iii-v based solar cell under concentrated sunlight : advanced concepts for mass production and low cost electricity (HAMLET)	1368121.9	FP5-EESD	1.1.4.-5.
HEEC	51938	High efficiency energy convertor ('HEEC')	257926.8	FP5-EESD	1.1.4.-5.
HEINSOL	207898	Hierarchically Engineered Inorganic Nanomaterials from the atomic to supra-nanocrystalline level as a novel platform for SOLution Processed SOLar cells	2444917.3	H2020-EU.1.1.	ERC-2016-COG
HELATHIS	93377	High Efficient Very Large Area Thin Film Silicon Photovoltaic Modules	2282313.6	FP7-ENERGY	ENERGY.2009.2.1.1
HELSOLAR	71077	High-efficiency low-cost solar cells	29535.5	FP5-EESD	1.1.4.-5.
HELSOLAR	67406	High-efficiency low-cost solar cells (HELSOLAR)	1247507.8	FP5-EESD	1.1.4.-5.
HERCULES	110845	HIGH EFFICIENCY REAR CONTACT SOLAR CELLS AND ULTRA POWERFUL MODULES	7054890.9	FP7-ENERGY	ENERGY.2013.2.1.1
HETSI	85740	Heterojunction Solar Cells based on a-Si c-Si	3794325.2	FP7-ENERGY	ENERGY-2007-2.1-06
HICONPV	73974	High Concentration PV Power System (HICONPV)	3337863.9	FP6-SUSTDEV	SUSTDEV-1.2.4
HIFLEX	93273	Highly Flexible Printed ITO-free OPV Modules	3951183.8	FP7-ICT	ICT-2009.3.8
HIGH EFFICIENCY HOES	54399	Holographic optical elements (hoe) for high efficiency illumination, solar control and photovoltaic power in buidings (high efficiency hoe's)	1312620.0	FP5-EESD	1.1.4.-6.
HIGH-EF	85760	Large grained, low stress multi-crystalline silicon thin film solar cells on glass by a novel combined diode laser and solid phase crystallization process	3197195.9	FP7-ENERGY	ENERGY-2007-2.1-06
HIGHSOL	85680	High volume manufacturing of photovoltaic products	1293892.6	FP6-SUSTDEV	SUSTDEV-1.1.1
HIGHSPEEDCIGS	86239	High speed pilot production line for CIGS manufacturing	1331131.0	FP6-SUSTDEV	SUSTDEV-1.1.1
HIGH-VOLTAGE PV	90347	New materials for high voltage solar cells used as building blocks for third generation photovoltaics	202304.4	FP7-PEOPLE	FP7-PEOPLE-IEF-2008
HIMAMIS	107710	Highly mismatched alloys to implement multiband solar cells	231840.4	FP7-PEOPLE	FP7-PEOPLE-2012-IIF
HIPERB	51207	High performance pv in buildings ('HIPERB')	1739028.3	FP5-EESD	1.1.4.-6.
HIPERSOL	92605	Modelling of interfaces for high performance solar cell materials	3757568.0	FP7-NMP	NMP-2008-2.5-2

Acronym	Rcn	Project title	EC funding (2016 EUR)	Framework Programme	Topic
HIPOCIGS	93227	New concepts for high efficiency and low cost in-line manufactured flexible CIGS solar cells	3945899.5	FP7-ENERGY	ENERGY.2009.2.1.1
HIPROLOCO	59856	High productivity and low cost for the encapsulation of thin film solar cells,(HIPROLOCO)	1483508.3	FP5-EESD	1.1.4.-5.
HISICON	51192	High efficiency silicon solar cells concentrator ('HISICON')	1997974.6	FP5-EESD	1.1.4.-5.
HISTORIC	195082	High efficiency GaInP/GaAs Tandem wafer bonded solar cell on silicon	159859.5	H2020-EU.1.3.2.	MSCA-IF-2014-EF
HJSC	95617	Hierarchical Junction Solar Cells: Theory guides Experiements	364942.3	FP7-PEOPLE	FP7-PEOPLE-2009-IOF
HT PHOTO DB	209059	High throughput computing for accelerated photovoltaic material discovery: From materialdatabase to the new generation of photovoltaic materials.	155454.5	H2020-EU.1.3.2.	MSCA-IF-2016
HYBRIDSOLAR	185782	Morphology and Molecular Packing in Polymer-Nanocrystal Hybrid Solar Cells Revealed with Synchrotron X-ray Characterization and Other Techniques	173786.6	FP7-PEOPLE	FP7-PEOPLE-2013-IIF
HybridSolar2010	98568	Development of inorganic/organic hybrid heterojunction solar cells	229696.9	FP7-PEOPLE	FP7-PEOPLE-2010-IOF
HyMoCo	193487	Hybrid Node Modes for Highly Efficient Light Concentrators	1488712.5	H2020-EU.1.1.	ERC-StG-2014
HYPER	100261	Hybrid Photovoltaic Energy Relays	1963981.2	FP7-IDEAS-ERC	ERC-SG-PE3
HySOL	99010	Inorganic-Organic Hybrid Materials through Controlled Self-Assembly of Nano-Building Blocks	172001.2	FP7-PEOPLE	FP7-PEOPLE-2010-IEF
HySPOD	105781	Hybrid Solution Processable Materials for Opto-Electronic Devices	1511762.3	FP7-IDEAS-ERC	ERC-SG-PE4
HY-SUNLIGHT	94778	Optical properties of hybrid organic/inorganic nano-particles for photovoltaic applications: toward a predictive computational approach	240635.1	FP7-PEOPLE	FP7-PEOPLE-2009-IIF
HyTile	201727	Sensitive integrated Solar Hybrid Roofing for historical buildings.	50000.0	H2020-EU.2.3.1.; H2020-EU.3.3.	SIE-01-2015-1
IBPOWER	85739	Intermediate Band Materials and Solar Cells for Photovoltaics with High Efficiency and Reduced Cost	3894737.1	FP7-ENERGY	ENERGY-2007-2.1-01
IBPV	91417	Innovative battery for photovoltaics applications based on intrinsically conductive rubber	29535.5	FP5-EESD	

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IDEOCONTE	69517	Identification and development of the optimum si-cells concentrator technology for pv power systems (IDEOCONTE)	1928869.9	FP5-EESD	1.1.4.-5.
IDSC	104175	Indoor Dye Sensitized Solar Cells	151863.6	FP7-IDEAS-ERC	ERC-OA-2011-PoC
IMOTHEE	51195	Improvement of photovoltaic modules - measures for withstanding electrical and thermal effects caused by reverse biasing of cells (IMOTHEE)	475188.8	FP5-EESD	1.1.4.-5.
IMPROV	95445	Innovative Mid-infrared high Power source for resonant ablation of Organic based photovoltaic devices	2630750.5	FP7-ICT	ICT-2009.3.7
IMS	86543	Integrated modular system for energy self-sufficient buildings based on thin film photovoltaic and thermoelectric devices	1304215.5	FP6-SME	SME
INDHI	67373	Industrially scalable high efficiency silicon solar cells (INDHI)	1373257.3	FP5-EESD	1.1.4.-6.
INDUCIS	100187	Development and industrial implementation of cost-effective advanced CIGS photovoltaic technologies	833754.1	FP7-PEOPLE	FP7-PEOPLE-2011-IAPP
INFLATCOM	51588	Industrialisation of ultra-flat concentrator module of high-efficiency ('INFLATCOM')	1001790.3	FP5-EESD	1.1.4.-5.
INNO PV-SWITCH	210653	Innovative Fireman's Switch for Photovoltaic Systems: towards large-scale production	49156.6	H2020-EU.2.1.3.;H2020-EU.2.3.1.;H2020-EU.2.1.5.;H2020-EU.2.1.2.	SMEInst-02-2016-2017
INNOVASOL	109411	Innovative Materials for Future Generation Excitonic Solar Cells	3204452.4	FP7-NMP	ENERGY.2008.10.1.2;NMP-2008-2.6-1
INPHOFLEX	185798	INTEGRATION OF PHOTONIC NANOSTRUCTURES IN FLEXIBLE DYE SOLAR CELLS	173786.6	FP7-PEOPLE	FP7-PEOPLE-2013-IIF
IonBeaTHeteroMat	98525	Ion beam techniques for the sub-nanometric characterisation of advanced energy conversion heterostructured materials	211115.8	FP7-PEOPLE	FP7-PEOPLE-2010-IEF
IQDotPV	107232	All-Inorganic Quantum Dot Films for Photovoltaic Applications	194132.7	FP7-PEOPLE	FP7-PEOPLE-2012-IIF
IQEOPV	108178	Internal Quantum Efficiency limitations in Organic Photovoltaics	127588.5	FP7-PEOPLE	FP7-PEOPLE-2012-IEF
IWM-BIPV	86912	Demonstration of cost-effective building integration of thin film PV	661407.9	FP5-EESD	
JUMPKEST	187967	JUnction iMProved KESTerite based solar cells for cost efficient sustainable photovoltaic technologies	173804.0	FP7-PEOPLE	FP7-PEOPLE-2013-IEF

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KESTCELLS	104698	Training for sustainable low cost PV technologies: development of kesterite based efficient solar cells	3790778.0	FP7-PEOPLE	FP7-PEOPLE-2012-ITN
LAB2LINE	85630	From the laboratory to the production Line	1468953.5	FP6-SUSTDEV	SUSTDEV-1.1.1
LARCIS	78503	Large-Area CIS Based Thin-Film Solar Modules for Highly Productive Manufacturing	5074210.9	FP6-SUSTDEV	SUSTDEV-1.2.4
LARGECELLS	95916	Large-area Organic and Hybrid Solar Cells	1782553.3	FP7-ENERGY	ENERGY.2010.2.1-2
LASSOL	67495	Lightweight amorphous silicon solar panels (LASSOL)	868942.6	FP5-EESD	1.1.4.-5.
LATECS	67114	Large-grain thin-film crystalline si solar cells on ceramics (LATECS)	1542301.8	FP5-EESD	1.1.4.-6.
LC-ENERGY	84737	Photovoltaic materials from novel self-assembling nanostructured liquid crystals	336889.0	FP6-MOBILITY	MOBILITY-2.2
LIFORGANICPV	88051	Investigation of interfacial structure of buried inorganic-organic interfaces in organic photovoltaics - LiF at organic-cathode interface	178388.4	FP7-PEOPLE	PEOPLE-2007-4-2.IIF
LIMA	93007	Improve Photovoltaic efficiency by applying novel effects at the limits of light to matter interaction	2571206.8	FP7-ICT	ICT-2009.3.8
LONGESST	191272	Low Cost Germanium Substrates for Next Generation 4-Junction Space Solar Cells Utilising Dilute Nitride Technology	2504361.5	FP7-SPACE	SPA.2013.2.2-01
LPAMS	75647	Production process for industrial fabrication of low price amorphous-microcrystalline silicon solar cells	752894.9	FP6-INCO	INCO-2002-C.1.3
MAESTRO	211677	MAking pErovskiteS TRuly explOitable	3787464.5	H2020-EU.1.3.1.	MSCA-ITN-2017
MatchForSolar	201488	Mechanochemical Approach to Inorganic-Organic Hybrid Materials for Perovskite Solar Cells	131564.7	H2020-EU.1.3.2.	MSCA-IF-2015-EF
MATHERO	110865	New materials for highly efficient and reliable organic solar cells	3620358.2	FP7-NMP	NMP.2013.4.0-2
MEDITERRANEO	89228	Urban photovoltaic awareness	1599319.8	FP5-EESD	
MESO	110574	Meso-superstructured Hybrid Solar Cells	3567634.2	FP7-NMP	NMP.2013.4.0-2;NMP.2013.2.2-4
MESOLIGHT	93966	Mesoscopic Junctions for Light Energy Harvesting and Conversion	2215027.0	FP7-IDEAS-ERC	ERC-AG-ID1
MESO-SUPERCELLS	107673	Novel MESO-SUPERstructured solar CELLS with enhanced performance and stability	300277.3	FP7-PEOPLE	FP7-PEOPLE-2012-IEF

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METACELLS	103016	Advanced epitaxy of metamorphic semiconductor structures for multijunction solar cells	258215.1	FP7-PEOPLE	FP7-PEOPLE-2011-IOF
METAFLEX	59843	Towards the roll-to-roll manufacturing of cost effecive flexible cis modules - intermediate steps (METAFLEX)	1673218.1	FP5-EESD	1.1.4.-6.
METAPV	94493	Metamorphosis of Power Distribution: System Services from Photovoltaics	6101417.2	FP7-ENERGY	ENERGY-2007-2.1-11
METEOR	60061	Metal-induced crystallization and epitaxial deposition for thin, efficient and low-cost crystalline si solar cells - (METEOR)	1913628.0	FP5-EESD	1.1.4.-5.
MIBCELL	54397	Metallic intermediate band solar cells for high efficiency and low cost in photovoltaics	1358358.0	FP5-EESD	1.1.4.-6.
MIMESIS	92101	Microscopic Modelling of Excitonic Solar Cell Interfaces	1160428.8	FP7-IDEAS-ERC	ERC-SG-PE4
MirrorPV	199262	MirrorPV - Balanced growth photovoltaic generation with Roof PV mirrors	50125.0	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
MLSYSTEM	196662	MLSYSTEM - heatable, integrated photovoltaics with insulated glass units	50125.0	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
MOLEMAT	211796	Molecularly Engineered Materials and process for Perovskite solar cell technology	1846406.0	H2020-EU.1.1.	ERC-2016-COG
MOLESOL	108131	All-carbon platforms for highly efficient molecular wire-coupled dye-sensitized solar cells	2652808.8	FP7-ENERGY	ENERGY.2010.10.2-1
MOLYCELL	73975	Molecular Orientation, Low Band Gap Materials and New Hybrid Device Concepts for the Improvement of Plastic Solar Cells (MOLYCELL)	3090660.9	FP6-SUSTDEV	SUSTDEV-1.2.4
MOPHET	59864	pv module processing based on silicon heterostructure (MOPHET)	1431347.4	FP5-EESD	1.1.4.-5.
MOSPA	82972	Multi-electroactive organic semiconductors for photovoltaic applications	197172.9	FP6-MOBILITY	MOBILITY-2.3
MPerS	194832	Sustainable Mixed-ion Layered Perovskite Solar Cells	195943.4	H2020-EU.1.3.2.	MSCA-IF-2014-EF
MUJULIMA	110575	Innovative Materials for Multiple Junction OPVs and for Improved Light Management	3902056.6	FP7-NMP	NMP.2013.4.0-2
MULTISOLAR	72248	Development of an integrated solar system for buildings	740532.1	FP6-SME	SME-1
NACIR	89954	NEW APPLICATIONS FOR CPV'S: A FAST WAY TO IMPROVE RELIABILITY AND TECHNOLOGY PROGRESS	4860078.2	FP7-ENERGY	ENERGY.2008.2.1.1

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Nano Harvest	193620	Flexible nanowire devices for energy harvesting	1500312.7	H2020-EU.1.1.	ERC-StG-2014
Nano@Energy	100283	Novel Design of Nanostructures for Renewable Energy: Fundamental Questions and Advanced Applications	1575102.1	FP7-IDEAS-ERC	ERC-SG-PE5
NANO2SOLAR	102945	From nanolayers to solar cells: Advanced in-situ optical characterization of thin-film materials	193178.4	FP7-PEOPLE	FP7-PEOPLE-2011-IIF
NANOCIS	98996	Development of a new generation of CIGS-based solar cells	452054.3	FP7-PEOPLE	FP7-PEOPLE-2010-IRSES
NanoCuI	195307	Nano-Copper Iodide: A New Material for High Performance P-Type Dye-Sensitized Solar Cells	195943.4	H2020-EU.1.3.2.	MSCA-IF-2014-EF
NANOENABLEDPV	109539	Novel Photovoltaics Enabled by Nanoscience	1511066.9	FP7-IDEAS-ERC	ERC-SG-PE5
NANOMATCELL	105880	NOVEL ENVIRONMENTALLY FRIENDLY SOLUTION PROCESSED NANOMATERIALS FOR PANCHROMATIC SOLAR CELLS	2743446.8	FP7-ENERGY	ENERGY.2012.10.2.1
NANOMAX	60065	Nanocrystalline dye-sentitised solar cells having maximum performance	1928824.9	FP5-EESD	1.1.4.-6.
NANO-MESO-SOLAR	82204	Inverse Templation of Semiconductor CdSe, CdTe and ZnO Nanorods using Mesoporous Thin Films: Towards High Power Efficiency Hybrid Organic/Inorganic Solar Cells	159065.4	FP6-MOBILITY	MOBILITY-2.2
NanoPhoSolar	106837	Innovative, environmentally friendly nanophosphor down converter materials for enhanced solar cell efficiency that will reduce energy production costs and increase cell lifetime	1943798.8	FP7-SME	SME-2012-2
NANOPHOTO	75382	Nanocrystalline silicon films for photovoltaic and optoelectronic applications	2056975.1	FP6-NMP	NMP-2003-3.4.2.1-2
NANOPV	97983	Nanomaterials and nanotechnology for advanced photovoltaics	4046243.1	FP7-NMP	NMP-2009-1.2-1
nanoPV	99592	Spectroscopic insight with nanoscale resolution on model photovoltaic systems	241544.2	FP7-PEOPLE	FP7-PEOPLE-2010-IOF
NANOSOL	90546	From Femto- to Millisecond and From Ensemble to Single Molecule Photobehavior of Some Nanoconfined Organic Dyes for Solar Cells Improvement	178926.6	FP7-PEOPLE	FP7-PEOPLE-IEF-2008
NanoSol	199291	Accelerating Commercialization of Nanowire Solar Cell Technologies	1740375.0	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015
NANOSOLAR	195040	HYBRID QUANTUM-DOT/TWO-DIMENSIONAL MATERIALS PHOTOVOLTAIC CELLS	158516.9	H2020-EU.1.3.2.	MSCA-IF-2014-EF

Acronym	Rcn	Project title	EC funding (2016 EUR)	Framework Programme	Topic
NANOSPEC	95353	Nanomaterials for harvesting sub-band-gap photons via upconversion to increase solar cell efficiencies	3284479.1	FP7-NMP	NMP-2009-1.2-1
Nano-Tandem	193777	Nanowire based Tandem Solar Cells	3570746.1	H2020-EU.3.3.5.	LCE-01-2014
NASCENT	96716	SILICON NANODOTS FOR SOLAR CELL TANDEM	3229278.8	FP7-NMP	NMP-2009-1.2-1
NEBULES	67550	New buffer layers for efficient chalcopyrite solar cells - target action l (NEBULES)	1946874.2	FP5-EESD	1.1.4.-6.
NEM	105238	New Energy Material	151176.2	FP7-IDEAS-ERC	ERC-OA-2012-PoC
NESSI	69550	N-type solar grade silicon for efficient p+n solar cells (NESSI)	2300026.4	FP5-EESD	1.1.4.-6.
NeutronOPV	195602	New neutron techniques to probe bulk heterojunction solar cells with graded morphologies – understanding the link between processing, nanostructure and device performance	195943.4	H2020-EU.1.3.2.	MSCA-IF-2014-EF
NextBase	205821	Next-generation interdigitated back-contacted silicon heterojunction solar cells and modules by design and process innovations	3800421.3	H2020-EU.3.3.2.	LCE-07-2016-2017
NextGEnergy	201328	Next Generation Power Sources for Self-sustainable Devices – Integrated Multi-source Energy Harvesters	191325.6	H2020-EU.1.3.2.	MSCA-IF-2015-EF
NEXTNANOCELLS	195222	Next generation nanowire solar cells	174291.8	H2020-EU.1.3.2.	MSCA-IF-2014-EF
NGCPV	99115	'A new generation of concentrator photovoltaic cells, modules and systems'	5250338.3	FP7-ENERGY	ENERGY.2011.2.1-1
NIOS	98209	High Efficiency Nanostructured Electrodes for Organic Solar Cells Using Solution Processed LiF	47253.1	FP7-PEOPLE	FP7-PEOPLE-2009-RG
NIRPLANA	102763	Near-Infrared Semiconductor Plasmonic Nanocrystals for Enhanced Photovoltaics	198194.8	FP7-PEOPLE	FP7-PEOPLE-2011-IEF
NLO FOR PV	102684	NonLinear Optics for Photovoltaics	102306.4	FP7-PEOPLE	FP7-PEOPLE-2011-CIG
No-LIMIT	209725	Boosting Photovoltaic Performance by the Synergistic Interaction of Halide Perovskites and Semiconductor Quantum Dots	1965351.8	H2020-EU.1.1.	ERC-2016-COG
NOVA-CI(G)S	93533	Non-vacuum processes for deposition of CI(G)S active layer in PV cells	3761786.0	FP7-NMP	NMP-2008-2.4-2
NoVoSiP	104008	Nano-Voids in Strained Silicon for Plasmonics	325860.7	FP7-PEOPLE	FP7-PEOPLE-2011-IIF
NoVoSiP	104008	Nano-Voids in Strained Silicon for Plasmonics	15036.0	FP7-PEOPLE	FP7-PEOPLE-2011-IIF

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OPTISUN	86349	The development of a new more efficient grid connected PV module	745595.0	FP6-SME	SME
ORGAPVNET	80090	Coordination Action towards stable and low-cost organic solar cell technologies and their application	1420488.2	FP6-SUSTDEV	SUSTDEV-1.2.4
ORION	99307	Optimization of Si solar cells, plastic materials and technologies for the development of more efficient concentRatION photovoltaic systems	2492298.5	FP7-SME	SME-1
OSC-Go	186782	Organic Solar Cells - Go!	100240.0	FP7-PEOPLE	FP7-PEOPLE-2013-CIG
PanePowerSW	210108	Transparent Solar Panel Technology for Energy Autonomous Greenhouses and Glass Buildings	49156.6	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
PAWAME	205276	CONDUCTING A FEASIBILITY STUDY ON THE VIABILITY OF AN INNOVATIVE BUSINESS MODEL FOR BRINGING SOLAR ENERGY TO REMOTE COMMUNITIES AND DEVELOPING COUNTRIES	50000.0	H2020-EU.3.6.;H2020-EU.2.3.1.	SMEInst-12-2016-2017
PBFREEPEROVSKITES	188265	Pb-Free Perovskites for Efficient All-Solid-State Hybrid Solar Cells	162373.7	FP7-PEOPLE	FP7-PEOPLE-2013-IEF
PECQDPV	103488	PLASMONICALLY ENHANCED COLLOIDAL QUANTUM DOT PHOTODETECTORS AND PHOTOVOLTAICS	180113.6	FP7-PEOPLE	FP7-PEOPLE-2011-IIF
PEDAL	193673	Plasmonic Enhancement and Directionality of Emission for Advanced Luminescent Solar Devices	1451028.5	H2020-EU.1.1.	ERC-StG-2014
PEPDIODE	99758	Peptide-based diodes for solar cells	2887651.5	FP7-ENERGY	ENERGY.2010.10.2-1
PEPPER	100464	DEMONSTRATION OF HIGH PERFORMANCE PROCESSES AND EQUIPMENTS FOR THIN FILM SILICON PHOTOVOLTAIC MODULES PRODUCED WITH LOWER ENVIRONMENTAL IMPACT AND REDUCED COST AND MATERIAL USE	6497573.8	FP7-ENERGY	ENERGY.2009.2.1.2
PercIGS	103098	PercIGS	185602.6	FP7-PEOPLE	FP7-PEOPLE-2011-IEF
PERFORMANCE	78501	A science base on photovoltaics performance for increased market transparency and customer confidence	8287987.3	FP6-SUSTDEV	SUSTDEV-1.2.4
PERFORMANCE PLUS	105862	Tools for Enhanced Photovoltaic System Performance	3216018.4	FP7-ENERGY	ENERGY.2012.2.1.1
PerovSAMs	208616	Molecular glues for perovskite materials	167252.0	H2020-EU.1.3.2.	MSCA-IF-2016
PerovskiteHTM	195761	New Hole-Transport Materials to Enhance Perovskite Solar Cells	195454.8	H2020-EU.1.3.2.	MSCA-IF-2014-EF

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PHOTEX	59872	Experience curve analysis of photovoltaic energy systems and components (PHOTEX)	387163.0	FP5-EESD	1.1.4.-6.
PHOTO-EM	96588	Solar cells at the nanoscale: imaging active photoelectrodes in the transmission electron microscope	1495674.8	FP7-IDEAS-ERC	ERC-SG-PE4
PHOTON	188158	Perovskite-based Hybrid Optoelectronics: Towards Original Nanotechnology	199795.9	FP7-PEOPLE	FP7-PEOPLE-2013-IEF
PHOTONVOLTAICS	105925	Nanophotonics for ultra-thin crystalline silicon photovoltaics	2961210.5	FP7-ENERGY	ENERGY.2012.10.2.1
PHOTOPEROVSKITES	209204	Photoexcitation Dynamics and Direct Monitoring of Photovoltaic Processes of Solid-State Hybrid Organic-Inorganic Perovskite Solar Cells	192157.9	H2020-EU.1.3.2.	MSCA-IF-2016
PHOTOQWELL	102997	Photonic optimisation of multiple quantum well structures for single and dual-junction solar cells	201943.0	FP7-PEOPLE	FP7-PEOPLE-2011-IEF
PHOTORODS	94922	Photovoltaic cells based on nano-structured CdTe	248192.6	FP7-PEOPLE	FP7-PEOPLE-2009-IEF
PHOTOSI	100258	Silicon nanocrystals coated by photoactive molecules: a new class of organic-inorganic hybrid materials for solar energy conversion	1209881.1	FP7-IDEAS-ERC	ERC-SG-PE5
PHOTOSURF	109743	Investigating the 2D Self-Assembly of Photo-sensitive Molecules on Semiconductor and Insulating Surfaces	100784.2	FP7-PEOPLE	FP7-PEOPLE-2013-CIG
PHYSIC	206778	Photovoltaic with superior crack resistance	146978.3	H2020-EU.1.1.	ERC-PoC-2016
PINC	195592	Towards p-type conductivity in In0.5Ga0.5N nanocolumns on a Si (100) substrate with GaN buffer layers	170546.9	H2020-EU.1.3.2.	MSCA-IF-2014-EF
PlasmaPerovSol	196104	A full plasma and vacuum integrated process for the synthesis of high efficiency planar and 1D conformal perovskite solar cells	158121.6	H2020-EU.1.3.2.	MSCA-IF-2014-EF
PLATIO	208005	Innovative outdoor solar and kinetic energy harvesting pavement system	49156.6	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
PLE	199339	Perovskite Light Emitters	149983.0	H2020-EU.1.1.	ERC-PoC-2015
POCAONTAS	105229	Polymer - Carbon Nanotubes Active Systems for Photovoltaics	3500406.3	FP7-PEOPLE	FP7-PEOPLE-2012-ITN
POLYGLASS	96901	Development of a new method to produce high efficiency solar concentrators based on polymer casted directly on glass	970846.5	FP7-SME	SME-1

Acronym	Rcn	Project title	EC funding (2016 EUR)	Framework Programme	Topic
POLYMAP	107300	Mapping and Manipulating Interfacial Charge Transfer in Polymer Nanostructures for Photovoltaic Applications	233096.8	FP7-PEOPLE	FP7-PEOPLE-2012-IIF
POLYSIMODE	106051	Improved Polycrystalline-Silicon Modules on Glass Substrates	4897445.7	FP7-ENERGY	ENERGY.2009.2.1.1
POLYSOLAR	194761	A light weight, recyclable, tracking support system, for solar photovoltaic modules based on inflatable polymer membranes	50120.0	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
PORASOLAR	88953	Organic Optoelectronic Device	186878.0	FP7-PEOPLE	PEOPLE-2007-4-3.IRG
POSITS	209562	High Performance Wide Bandgap and Stable Perovskite-on-Silicon Tandem Solar Cells	172460.7	H2020-EU.1.3.2.	MSCA-IF-2016
PREFAB-PV-CLADDING	91418	Application of photovoltaic systems on multifamily residential building to be retrofit combined with prefabricated elements	29535.5	FP5-EESD	
PRIMA	93265	Plasmon Resonance for IMproving the Absorption of solar cells	2490010.8	FP7-ICT	ICT-2009.3.8
PRINTSolar	205636	Printable Perovskite Solar Cells with High Efficiency and Stable Performance	150000.0	H2020-EU.1.1.	ERC-PoC-2016
PROCIS	54151	Production of large area cis modules (PROCIS)	1567137.1	FP5-EESD	1.1.4.-5.
PRODESA	209996	ENERGY EFFICIENCY PROJECT DEVELOPMENT FOR SOUTH ATTICA	1040901.1	H2020-EU.3.3.7.;H2020-EU.3.3.1.	EE-22-2016-2017
p-TYPE	206143	Transparent p-type semiconductors for efficient solar energy capture, conversion and storage.	1474541.1	H2020-EU.1.1.	ERC-2016-STG
PV ACCEPT	58297	Improving PV acceptability through innovative architectural design-development: Demonstration, acceptability study in protected tourist regions	-	FP5-INNOVATION-SME	
PV FINANCING	194454	PV FINANCING	2056066.1	H2020-EU.3.3.7.;H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-04-2014
PV INGRID	57617	Integration Of Photovoltaic generators Into European Insular Grids With A Rational Use Of Energy Managed By A European	546661.0	FP5-EESD	1.1.4.-5.3.1
PV SEC	75716	Strengthen the European photovoltaic sector and support to establish a PV technology platform	786511.8	FP6-SUSTDEV	SUSTDEV-2003-1.2.9

Acronym	Rcn	Project title	EC funding (2016 EUR)	Framework Programme	Topic
PV TP - SEC	91957	Support of the activities of all stakeholders from the PV sector to collaborate together to achieve the 2020 targets	517347.9	FP7-ENERGY	ENERGY.2009.2.1.3
PV TP SEC III	109671	Support of the activities of all stakeholders from the PV sector to collaborate together to achieve the 2020 targets and beyond	493516.8	FP7-ENERGY	ENERGY.2013.2.1.2
PV-CENTER	69514	Photovoltaic center of competence in Poland	231464.9	FP5-EESD	1.1.4.-5.
PVCROPS	105879	PhotoVoltaic Cost reduction, Reliability, Operational performance, Prediction and Simulation	3886214.8	FP7-ENERGY	ENERGY.2012.2.1.1
PV-EC-NET	60346	Network for co-ordination of European an national RTD programmes for photovoltaic solar energy (PV-EC-NET)	1285912.0	FP5-EESD	1.1.4.-6.
PV-EMPLOYMENT	85639	The role of the European PV industry for the Europe's jobs and education today and tomorrow	450497.5	FP6-SUSTDEV	SUSTDEV-1.1.1
PV-ERA-NET	72857	Networking and integration of national and regional programmes in the field of Photovoltaic (PV) solar energy Research and Technological Development (RTD) in the European Research Area (ERA)	3246898.3	FP6-COORDINATION	COOR-1.1
PV-EST	67102	Materials and technologies for photovoltaic applications from Estonia	378338.1	FP5-EESD	1.1.4.-6.
PV-FIBRE	59857	Indoor operation of 1000x multijunction cells by fibre transmission (PV-FIBRE)	918881.8	FP5-EESD	1.1.4.-5.
PVFIFTY	195437	TOWARDS A 50% EFFICIENT CONCENTRATOR SOLAR CELL AND A 40% EFFICIENT SPACE SOLAR CELL	183913.4	H2020-EU.1.3.2.	MSCA-IF-2014-EF
PVFINAL	197410	Photo Voltaic Fully Integrated and Automated Line	50125.0	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
PV-GUM	100465	Manufacturing technologies and equipment to produce low-cost PV bituminous-modified roofing membrane with full integration of high efficiency flexible thin-film silicon PV modules	6749386.5	FP7-ENERGY	ENERGY.2009.2.1.2
PVICOKEST	98074	INTERNATIONAL COOPERATIVE PROGRAMME FOR PHOTOVOLTAIC KESTERITE BASED TECHNOLOGIES	189537.3	FP7-PEOPLE	FP7-PEOPLE-2010-IRSES

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PV-LIGHT	86902	Light weight PV-louvres for multifunctional solar control and day-lighting systems with improved building integration - target action E	1532729.8	FP5-EESD	
PVMINDS	209827	Bottom-up PV module energy yield and integrated reliability model for site-specific design optimization	169885.3	H2020-EU.1.3.2.	MSCA-IF-2016
PV-MIPS	87884	Photovoltaic module with integrated power conversion and interconnection system	5439403.8	FP6-SUSTDEV	SUSTDEV-1.1.1
PV-NAS-NET	67933	Accompanying measures for co-ordination of nas and european union rtd programmes on photovoltaic solar energy (PV-NAS-NET)	504464.7	FP5-EESD	1.1.4.-5.
PVNET	59877	Photovoltaic network for the development of a roadmap for pv (PVNET)	521126.7	FP5-EESD	1.1.4.-6.
PV-NORD	86820	Widespread exploitation of building integrated photovoltaics in the Nordic dimension of the European Union	1387242.3	FP5-EESD	
PV-SALSA	57732	Service Assurance for Large Social Acceptance of Photovoltaic Stand Alone and Grid Connected Systems	1437960.4	FP5-EESD	1.1.4.-5.2.3
PV-SERVITOR	107636	Autonomous cleaning robot for large scale photovoltaic power plants in Europe resulting in 5% cost reduction of electricity	1332153.5	FP7-SME	SME-1
PVSITES	200257	Building-integrated photovoltaic technologies and systems for large-scale market deployment	5467611.8	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-03-2015
PV-STARLET	86831	Photovoltaic standardised tiles attested for roofing with a large European target	2329902.0	FP5-EESD	
PYTHAGORAS	54154	Preparing the market for novel polycrystalline thin film photovoltaic generators by examination and assessment of field performance (PYTHAGORAS)	774725.0	FP5-EESD	1.1.4.-5.
QPorQPcQdaP	186664	The Development of Quinoidal Porphyrins, Quinoidal Phthalocyanines, and Quinoidal Diazaporphyrins for Dye-Sensitized Solar Cells: Into the Red	144822.2	FP7-PEOPLE	FP7-PEOPLE-2013-IIF
QUANTUM BIOTECH	100162	QUANTUM PHENOMENA IN BIOLOGY: THEORY AND EXPERIMENTS TOWARDS NOVEL SOLAR ENERGY QUANTUM TECHNOLOGIES	105006.8	FP7-PEOPLE	FP7-PEOPLE-2011-CIG
Quokka Maturation	195179	A mature Quokka for everyone – advancing the capabilities and accessibility of numerical solar cell simulations	171460.8	H2020-EU.1.3.2.	MSCA-IF-2014-EF

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R2M-SI	96068	Roll to Module processed Crystalline Silicon Thin-Films for higher than 20% efficient modules	3069128.0	FP7-ENERGY	ENERGY.2010.10.2-1
R2R-3G	201060	Towards Roll-to-Roll Production of Third Generation Solar Cells	187419.6	H2020-EU.1.3.2.	MSCA-IF-2015-EF
R2R-CIGS	109418	Roll-to-roll manufacturing of high efficiency and low cost flexible CIGS solar modules	7183441.9	FP7-NMP	ENERGY.2011.2.1-2;NMP.2011.1.2-1
RAMSES	80016	Renewable Energy Agricultural Multipurpose for Farmers	1539211.1	FP6-INCO	INCO-2004-B1.5;INCO
RAYGEN	197028	A unique innovative utility scale solar energy technology that utilises a field of low cost heliostat collectors to concentrate sunlight onto an ultra-efficient multi-junction photovoltaic cell array	50125.0	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
RECHARGE	209226	Photon-recycling for high-efficiency energy harvesting in GaAs photovoltaic devices on silicon	243879.1	H2020-EU.1.3.2.	MSCA-IF-2016
RECLAIM	106540	Reclamation of Gallium, Indium and Rare-Earth Elements from Photovoltaics, Solid-State Lighting and Electronics Waste	4752502.1	FP7-NMP	NMP.2012.4.1-2
REFLECTS	86556	Novel bifacial single-substrate solar cell utilising reflected solar radiation	1123149.9	FP6-SME	SME
REPHLECT	198396	Recovering Europe´s PHotovoltaics LEadership through high Concentration Technology	1637685.4	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015
REPTILE	100305	Repairing of Photovoltaic Wafers and Solar Cells by Laser Enabled Silicon Processing	1080520.1	FP7-SME	SME-2011-1
RE-SI-CLE	60332	Recycling of silicon rejects from pv production cycle (RE-SI-CLE)	1631309.0	FP5-EESD	1.1.4.-5.
RESURGENCE	86837	Renewable energy systems for urban regeneration in cities of Europe	2942655.1	FP5-EESD	
RGSELLS	60069	Cost-effective, high throughput ribbon-growth-on-substrate solar cell technology (RGSELLS)	1917610.4	FP5-EESD	1.1.4.-6.
ROBUST DSC	85752	Efficient and Robust Dye Sensitzed Solar Cells and Modules	4442173.3	FP7-ENERGY	ENERGY-2007-2.1-02
ROD-SOL	89444	All-inorganic nano-rod based thin-film solarcells on glass	2983785.3	FP7-NMP	ENERGY.2008.10.1.2;NMP-2008-2.6-1

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RollArray	204582	A disruptive mobile photovoltaic array that can pack up to 20kWp of generating power into a domestic trailer and 100kWp of generating power into an ISO 20-foot shipping container.	50000.0	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
ROTROT	100254	ROll To Roll production of Organic Tandem cells	3255211.1	FP7-ICT	ICT-2011.3.6
SANDPAPER	100591	Synthesis and Assembly of Nanostructured Devices for Photovoltaic And Photocatalyic Energy Reservoirs	210274.3	FP7-PEOPLE	FP7-PEOPLE-2010-IOF
SANS	97483	Sensitizer Activated Nanostructured Solar Cells	4190884.7	FP7-NMP	NMP-2009-1.2-1
SASOLAR13	188133	Self-assembly strategies towards optimal morphology in small molecule organic solar cells	194512.3	FP7-PEOPLE	FP7-PEOPLE-2013-IEF
SBskin	196525	SBskin. Smart Building skin	50125.0	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
SCALENANO	109419	Development and scale-up of nanostructured based materials and processes for low cost high efficiency chalcogenide based photovoltaics	7715401.2	FP7-NMP	ENERGY.2011.2.1-2;NMP.2011.1.2-1
SECQDSC	189939	Towards Long-term Stable and Highly Efficient Colloidal Quantum Dot Solar Cells	153258.4	FP7-PEOPLE	FP7-PEOPLE-2013-IEF
SEEWHI	202590	Solar Energy Enabled for the World by High-resolution Imaging	2000000.0	H2020-EU.1.1.	ERC-CoG-2015
SELFLEX	85702	Demonstration of self-formation based flexible solar cells manufacturing technology	809867.3	FP6-SUSTDEV	SUSTDEV-1.1.1
SENSE	67931	Sustainability evaluation of solar energy systems (SENSE)	1405768.8	FP5-EESD	1.1.4.-5.
SEPOMO	207004	Spins for Efficient Photovoltaic Devices based on Organic Molecules	3826023.8	H2020-EU.1.3.1.	MSCA-ITN-2016
SE-POWERFOIL	81406	Roll-to-roll manufacturing technology for high efficient multi-junction thin film silicon flexible photovoltaic modules	2604818.7	FP6-SUSTDEV	SUSTDEV-1.2.4
SERPHO	52854	Self rechargeable photovoltaic microbattery coupled system (SERPHO)	1683346.8	FP5-GROWTH	1.1.3.-1.
Sharc25	193776	Super high efficiency Cu(In,Ga)Se2 thin-film solar cells approaching 25%	4574530.6	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-02-2014
SIKELOR	110318	Silicon kerf loss recycling	1412487.9	FP7-ENVIRONMENT	ENV.2013.6.3-1

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SiLaSpaCe	202619	Si based Layer Stacks for Rear-Side Passivation and Enhanced Reflection of GaInP/GaInAs/Ge Triple-Junction Space Solar Cells	997466.3	H2020-EU.2.1.6.	COMPET-03-2015
SILICON_LIGHT	93315	Improved material quality and light trapping in thin film silicon solar cells	6256985.3	FP7-ENERGY	ENERGY.2009.2.1.1
SINANOTUNE	95356	Dopant-surface interactions in silicon nanoclusters	155707.9	FP7-PEOPLE	FP7-PEOPLE-2009-IEF
SINGFISS	92629	Singlet exciton fission as a route to more efficient dye-sensitized solar cells	1326204.4	FP7-IDEAS-ERC	ERC-SG-PE4
SIRACUSA	102622	Study on intermediate band materials with prevailing radiative carrier recombination for superior solar energy applications	204993.1	FP7-PEOPLE	FP7-PEOPLE-2011-IEF
SISI	75354	Silicon for solar cells at low costs on an intermediate scale	-	FP6-SME	SME-1
SiTaSol	209742	Application relevant validation of c-Si based tandem solar cell processes with 30 % efficiency target	4225700.5	H2020-EU.3.3.2.	LCE-07-2016-2017
SLOPETRACK PV	57669	1.2 Mw Photovoltaic Active Tracking System Power Plant Located on slope	4563266.5	FP5-EESD	1.1.4.-5.2.3
SMART-FLEX	185358	Demonstration at industrial scale of the FLeXible manufacturing of SMART multifunctional photovoltaic building elements	2937336.1	FP7-ENERGY	ENERGY.2012.2.1.2
SNAPSUN	95609	Semiconductor Nanomaterial for Advanced Photovoltaic Solar cells Using New concept of nanocrystal and conductive host	2484094.3	FP7-NMP	NMP-2009-1.2-1
SNS PV CELLS	96190	Development of SnS Based Solar Cells	252320.4	FP7-PEOPLE	FP7-PEOPLE-2009-IIF
SOBONA	98991	Solar Cells Based on Nanowire Arrays	317225.6	FP7-PEOPLE	FP7-PEOPLE-2010-IRSES
SOFT-PHOTOCONVERSION	209132	Solar Energy Conversion without Solid State Architectures: Pushing the Boundaries of Photoconversion Efficiencies at Self-healing Photosensitiser Functionalised Soft Interfaces	1473758.3	H2020-EU.1.1.	ERC-2016-STG
SoHo3X	197559	Introducing a novel concept of solar photovoltaic module in the market	50125.0	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
SOLACYLIN	194492	A preparative approach to geometric effects in innovative solar cell types based on a nanocylindrical structure	1943501.6	H2020-EU.1.1.	ERC-CoG-2014
SOLAMON	89442	Plasmons Generating Nanocomposite Materials (PGNM) for 3rd Generation Thin Film Solar Cells	1768215.0	FP7-NMP	ENERGY.2008.10.1.2;NMP-2008-2.6-1

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Solar Beyond Silicon	185808	Nanoengineering High-Performance Low-Cost Perovskite Solar Cells Utilising Singlet Fission Materials	294925.7	FP7-PEOPLE	FP7-PEOPLE-2013-IOF
SOLAR CELL MATERIALS	95628	Electronic Structure Methodology Reveals New Materials for Solar Cells	259544.8	FP7-PEOPLE	FP7-PEOPLE-2009-IOF
SOLAR DESIGN	105949	On-the-fly alterable thin-film solar modules for design driven applications	2737724.0	FP7-NMP	NMP.2012.4.0-1
SOLAR PLOTS	87888	MULTIPLE OWNERSHIP GRID CONNECTED PV SOLAR-PLOTS WITH OPTIMISED TRACKING AND LOW CONCENTRATION REFLECTORS	2225305.2	FP6-SUSTDEV	SUSTDEV-1.1.1
SOLARGE45	196550	Towards a SOLAR enerGy Efficiency of 45 %	50125.0	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
SolarIn	107420	Solar cells based on InGaN nanostructures on silicon	195568.2	FP7-PEOPLE	FP7-PEOPLE-2012-IEF
SOLARNTYPE	82423	Development of n-type polymer materials used as alternative to soluble C60 derivatives and their use in organic solar cells	3865579.4	FP6-MOBILITY	MOBILITY-1.1
SOLARPAT	90305	Self-nanostructuring Polymer Solar Cells	170309.0	FP7-PEOPLE	FP7-PEOPLE-IIF-2008
SOLARPLAS	75458	Development of Plasma-Chemical Equipment for Cost-Effective Manufacturing in Photovoltaics	1014672.8	FP6-SME	SME-1
SOLARPOWER	86996	Development of innovative quality assurance measures to improve the efficiency of solar panel production	399195.0	FP5-EESD	
SolarRevolution	108115	Revolutionizing Understanding of Organic Solar Cell Degradation to Design Novel Stable Materials	167640.5	FP7-PEOPLE	FP7-PEOPLE-2012-IEF
SOLARROK	106234	PHOTOVOLTAIC Clusters Development and Implementation Measures of a Seven Region Strategic Joint Action Plan for Knowledge-based Regional Innovation	2314614.8	FP7-REGIONS	REGIONS-2012-2013-1
SOLARSKIN	70540	Energy sustainable building with integrated thermophotovoltaic solar system and climate control (SOLARSKIN)	704078.8	FP5-EESD	1.1.4.-6.
SolarSoft	100610	Development of Ultra Soft Copper Conductors for Crystalline Silicon Solar Photovoltaic Applications	1056301.3	FP7-SME	SME-2011-1
SOLARTECH	63490	Plasma technologies for solar cell manufacturing, at atmospheric pressure	315563.8	FP5-GROWTH	1.1.3.-1.

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SOLAR-TRAIN	205427	Photovoltaic module life time forecast and evaluation	3576247.6	H2020-EU.1.3.1.	MSCA-ITN-2016
SOLARX	104653	Riddle of light induced degradation in silicon photovoltaics	852402.2	FP7-IDEAS-ERC	ERC-SG-PE8
SOLASYS	90332	Next generation solar cell and module laser processing systems	3884418.0	FP7-ENERGY	ENERGY-2007-2.1-08
SOLGAIN	105027	Competitive stationary low concentrating solar module of novel design	950426.1	FP7-SME	SME-2012-1
SOLNOWAT	100189	Development of a competitive 0 GWP dry process to reduce the dramatic water consumption in the ever-expanding solar cells manufacturing industry	1248828.1	FP7-SME	SME-2011-1
Sol-Pro	194495	Solution Processed Next Generation Photovoltaics	1845542.4	H2020-EU.1.1.	ERC-CoG-2014
SOLPROCEL	110577	SOLUTION PROCESSED HIGH PERFORMANCE TRANSPARENT ORGANIC PHOTOVOLTAIC CELLS	2882864.3	FP7-NMP	NMP.2013.4.0-2
SOLSILC	54403	A direct route to produce solar grade silicon at low cost ('SOLSILC')	1461580.1	FP5-EESD	1.1.4.-6.
SOLSILC DEMONSTRATOR	85669	Validation of a direct route for production of solar-grade silicon feedstock for crystalline wafers and cells	1735337.3	FP6-SUSTDEV	SUSTDEV-1.1.1
Soltile	197392	A roof integrated solar tile system to develop cost-effective distributed solar power generation.	50125.0	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
SolTile	205862	A roof integrated solar tile system to develop cost-effective distributed solar power generation	1542733.0	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
SOPHIA	108132	PhotoVoltaic European Research Infrastructure	9450612.8	FP7-INFRASTRUCTURES	INFRA-2010-1.1.22
SOS-PVI	75088	Security of Supply PhotoVoltaic Inverter: combined UPS, power quality and grid support function in a photovoltaic inverter for weak low voltage grids	1815737.4	FP6-SUSTDEV	SUSTDEV-1.2.3
SPURT	60338	Silicon purification technology for solar cells at low costs and medium scale (SPURT)	1270484.9	FP5-EESD	1.1.4.-6.
SRec BIPV	208696	Smart Reconfigurable photovoltaic modules for Building Integrated PhotoVoltaic applications	169885.3	H2020-EU.1.3.2.	MSCA-IF-2016
STARCELL	206577	Advanced strategies for substitution of critical raw materials in photovoltaics	4750677.1	H2020-EU.2.1.3.	NMBP-03-2016
STILORMADE	207637	Highly efficient non-standard solar modules manufactured through an automated reconfigurable mass production processes delivering 30% reduction in costs	2788198.0	H2020-EU.3.;H2020-EU.2.	FTIPilot-01-2016

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STORM	206796	SMART PLANT MANAGER FOR UTILITY SCALE PHOTOVOLTAIC PLANTS WITH STORAGE SYSTEMS	50000.0	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
STRAPCON	65068	Solar tracking for photovoltaic concentration technologies (STRAPCON)	166639.3	FP5-EESD	1.1.4.-6.
SUBARO	51597	Substrate and barrier layer optimisation for cvd-grown thin-film crystalline silicon solar cells ('SUBARO')	2682760.0	FP5-EESD	1.1.4.-6.
SUGAR	105842	Silicon sUbstrates from an inteGrated Automated pRocess	4024780.9	FP7-ENERGY	ENERGY.2010.2.1-1
SUMMIT	185361	Smart large lightweight long life Multifunctional PV Module Technology for large Power Installations and Distributed Energy Generation	4031335.2	FP7-ENERGY	ENERGY.2012.2.1.2
SUN ON CLEAN	102433	Study of soiling effect and glass surface modification of concentrating photovoltaic (CPV) modules: Climate influence and Comparative testing	54427.0	FP7-PEOPLE	FP7-PEOPLE-2011-IRSES
SUN4GREEN	197576	MAXIMISING SUNLIGHT RESOURCES FOR COST, ENERGY AND YIELD EFFICIENT GREENHOUSES	50125.0	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
SUNFLOWER	100718	SUstainable Novel FLexible Organic Watts Efficiently Reliable	10605654.0	FP7-ICT	ICT-2011.3.6
SUNINBOX	208319	Portable SolUtioN for dIstributed geNeration in a BOX	50125.0	H2020-EU.2.3.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
SUNINBOX	208319	Portable SolUtioN for dIstributed geNeration in a BOX	1383800.5	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
SUNLIGHT	102933	Solution-processed nanocrystal photovoltaics from environmentally benign and earth-abundant elements	100784.2	FP7-PEOPLE	FP7-PEOPLE-2011-CIG
SUNRISE	85690	Strengthening the European photovoltaic sector by cooperation with important stakeholders	752019.6	FP6-SUSTDEV	SUSTDEV-1.1.1
SupraL_SAS	98940	Supramolecular Active Layer, Self-Assembly on Surface	187018.8	FP7-PEOPLE	FP7-PEOPLE-2010-IEF
SUVIL	57604	Solar Urban Village in London	1030134.8	FP5-EESD	1.1.4.-5.2.3
SWEET	69551	Silicon wafer equivalents based on crystalline silicon thin-film solar cells grown epitaxially on low cost silicon substrates (SWEET)	2054119.4	FP5-EESD	1.1.4.-6.
SWInG	196579	Development of thin film Solar cells based on WIde band Gap kesterite absorbers	3262891.9	H2020-EU.3.3.5.	LCE-01-2014

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SYNABCO	98233	Synthesis and Application of Block Copolymers for Interfacial Stability in Organic Solar Cells	219561.7	FP7-PEOPLE	FP7-PEOPLE-2010-IEF
TAQSOLRE	86984	Tackling the quality in solar rural electrification - target action C	626653.9	FP5-EESD	
TEAPUB	87007	Trans European action on Pv integration into public buildings	781202.1	FP5-EESD	
TFQD	199145	Thin film light-trapping enhanced quantum dot photovoltaic cells: an enabling technology for high power-to-weight ratio space solar arrays.	1008376.3	H2020-EU.2.1.6.	COMPET-03-2015
THE REV	51598	A thermophotovoltaic power generator for hybrid electric vehicles (the rev)	3188686.5	FP5-EESD	1.1.4.-6.
ThforPV	196774	New Thermodynamic for Frequency Conversion and Photovoltaics	1503750.0	H2020-EU.1.1.	ERC-StG-2014
THIME	105629	Thinfilm measurements on organic photovoltaic layers	1158801.3	FP7-SME	SME-2012-1
THINSI	106256	Thin Si film based hybrid solar cells on low-cost substrates	4781450.9	FP7-ENERGY	ENERGY.2009.2.1.1
TinPSC	209354	Towards Stable and Highly Efficient Tin-based Perovskite Solar Cells	182722.2	H2020-EU.1.3.2.	MSCA-IF-2016
TONSOPS	201393	Titanium Oxide Nanocomposites for Scalable Optimized Perovskite Solar cells	170121.6	H2020-EU.1.3.2.	MSCA-IF-2015-EF
TOPSICLE	67551	Towards 20 percent mc-si industrial solar cell efficiency	2056665.5	FP5-EESD	1.1.4.-6.
TREASURE	69543	Thin film crystalline silicon solar cell on metallurgical silicon substrate (TREASURE)	1663361.7	FP5-EESD	1.1.4.-6.
TripleSolar	110811	Solar Energy Conversion in Molecular Multi-Junctions	2499569.0	FP7-IDEAS-ERC	ERC-AG-PE5
TWINGO	61187	Fabrication of a 20% efficient silicon solar cell by a cost-effective industrial process (TWINGO)	1816407.6	FP5-EESD	1.1.4.-5.
TwinPV	199595	Stimulating scientific excellence through twinning in the quest for sustainable energy (TwinPV)	1012173.8	H2020-EU.4.b.	H2020-TWINN-2015
ULITES	106819	Ultra-lightweight structures with integrated photovoltaic solar cells: design, analysis, testing and application to an emergency shelter prototype	1053194.4	FP7-SME	SME-2012-1
ULTHEFFCONSYS	83346	Ultra-high efficiency photovoltaic systems with concentrator modules based on Fresnel lenses and multi-junction solar cells	-	FP6-MOBILITY	MOBILITY-2.1
ULTIMATE	90324	Ultra Thin Solar Cells for Module Assembly -Tough and Efficient (ULTIMATE)	4446593.1	FP7-ENERGY	ENERGY-2007-2.1-09
ULTRA PARTICLE	99865	Ultra precise nanoparticles to harvest light	105006.8	FP7-PEOPLE	FP7-PEOPLE-2011-CIG

Acronym	Rcn	Project title	EC funding (2016 EUR)	Framework Programme	Topic
ULTRADSSC	92395	Ultrafast Spectroscopies for Dye Sensitised Solar Cell study and Optimisation	50225.5	FP7-PEOPLE	PEOPLE-2007-2-2.ERG
Uniting PV	208289	Applying silicon solar cell technology to revolutionize the design of thin-film solar cells and enhance their efficiency, cost and stability	1952623.6	H2020-EU.1.1.	ERC-2016-STG
UPCON	91841	Ultra-Pure nanowire heterostructures and energy CONversion	1392240.8	FP7-IDEAS-ERC	ERC-SG-PE5
UPP-SOL	85672	Urban photovoltaics: polygeneration with solar energy	2022216.6	FP6-SUSTDEV	SUSTDEV-1.1.1
UPSSIM	106137	Upgrading Semiconductor Silicon Wafers to Manufacture cheap solar cells (UPSSIM)	1140963.4	FP6-SME	SME-1
VaporPV	201752	Low cost PV cooling system for ground-mounted and rooftop systems - VaporPV	50000.0	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
WATLY	198937	An autonomous and mobile water treatment plant powered by solar energy	1421394.6	H2020-EU.3.5.;H2020-EU.2.3.1.	SC5-20-2015
WELLBUS	73060	Study of Efficiency Enhancement Mechanisms in Quantum Well Solar Cells for Better Utilization of the Solar Spectrum (WELLBUS)	207281.0	FP6-MOBILITY	MOBILITY-2.1
WNSL PV	57746	Wembley National Stadium Photovoltaic System	847415.4	FP5-EESD	1.1.4.-6.1.3
X10D	100721	Efficient, low-cost, stable tandem organic devices	8978082.1	FP7-ICT	ICT-2011.3.6
XLIM	108107	Well-defined Conjugated Block Copolymer Nanofibers and their Applications in Photovoltaic Devices	233096.8	FP7-PEOPLE	FP7-PEOPLE-2012-IIF
XTPL	207116	XTPL - A new generation of TCF layers for use in displays and thin film photovoltaic cells	49156.6	H2020-EU.2.1.3.;H2020-EU.2.3.1.;H2020-EU.2.1.5.;H2020-EU.2.1.2.	SMEInst-02-2016-2017
No acronym	53722	Lightweight amorphous silicon solar panels	30183.7	FP5-EESD	1.1.4.-6.
No acronym	62270	Photoelectrochromic systems and micro storage dye sensitised solar cells	19887.2	FP5-HUMAN POTENTIAL	
No acronym	63095	Towards the control of photoelectric processes in dye sensitised photovoltaic cells.	146944.2	FP5-HUMAN POTENTIAL	
No acronym	64623	Photovoltaic and solar electricity (SOLAREC)	-	FP5-JRC	M04;S10;P01
No acronym	53185	Development of an Efficient Photovoltaic Power Supply in Space	173857.9	FP5-INCO 2	1.2.1.-2.
No acronym	63825	THIN FILM AND NANO-STRUCTURED MATERIALS FOR PHOTOVOLTAÏCS	-	FP5-HUMAN POTENTIAL	1.4.1.-3.1S3

Acronym	Rcn	Project title	EC funding (2016 EUR)	Framework Programme	Topic
No acronym	76058	Thinc-pv	282901.5	FP5-HUMAN POTENTIAL	1.4.1.-3.1.
No acronym	61985	Single-crystalline thin films by direct wafer bondig and hydrogen induced exfoliation	396009.6	FP5-HUMAN POTENTIAL	
No acronym	53985	A challenging solar cell concept- the skilful intercalation of a nanostructured semiconductor by an extremely thin copper (indium) sulphide absorber	1772116.3	FP5-HUMAN POTENTIAL	
No acronym	70959	Solar Electricity	-	FP6-JRC	2.3.2
No acronym	70965	Electricity Storage and Demonstration of Renewable Energy Systems	-	FP6-JRC	2.3.2
No acronym	53974	Photo-induced charge transfer in the novel low bandgap polymer semiconductors and their use in photovoltaic devices	1906265.9	FP5-HUMAN POTENTIAL	
No acronym	62846	European network on thin film technology	366486.0	FP5-HUMAN POTENTIAL	
No acronym	55336	European network on amorphous-silicon-device technology materials science electronics	1895185.8	FP5-GROWTH	1.1.3.-5.
No acronym	54016	A thermophotovoltaic power generator for hybrid electric vehicles 'the rev'	31344.4	FP5-INCO 2	1.2.1.-2.
No acronym	61371	Novel battery for solar home systems	30183.7	FP5-EESD	1.1.4.-6.
Solar Bankability	194639	Improving the Financeability and Attractiveness of Sustainable Energy Investments in Photovolatics: Quantifying and Managing the Technical Risk for Current and New Business Models	1358493.8	H2020-EU.3.3.7.	EE-19-2014

Table D.2 EU-funded projects of multiple RES technologies, where solar PV is one of the funded technologies

Acronym	Rcn	Project title	EC funding (2016 EUR)	Framework Programme	Topic	RES Technologies
Enerbox	197583	Sustainable and Standalone Oxyhydrogen powered heat generator box	50125.0	H2020-EU.2.3.1.; H2020-EU.3.3.	SIE-01-2015-1	Solar PV, bioenergy
EURECONF	57676	European Re Conferences 2001/2002: Integrated Initiative for PV, Wind & Biomass Technologies for European Competitiveness on the World Re Markets	630072.0	FP5-EESD	1.1.4.-5.2.1	Wind, solar PV, bioenergy
EURECONF	86850	European re- conferences 2001/2002: integrated initiative for PV, wind & biomass technologies for European competitiveness on the world re- markets	630072.0	FP5-EESD		Wind, solar PV, bioenergy
EUROCARE	52230	Infrastructure co-operation network in area of combustion and solar energy	201224.4	FP5-HUMAN POTENTIAL	1.4.1.-2.	Solar PV, Solar Thermal
EUROSUNMED	109592	EURO-MEDITERRANEAN COOPERATION ON RESEARCH & TRAINING IN SUN BASED RENEWABLE ENERGIES	5302986.3	FP7-ENERGY	ENERGY.2013.2.9.1	Solar PV, Solar Thermal
INTENSOL	97198	Transparent Fresnel Based Concentrated Photovoltaic Thermal System	1019606.8	FP7-SME	SME-1	Solar PV, Solar Thermal
MED2010	54142	Large scale integration of PV and wind power in Mediterranean countries (MED2010)	743476.4	FP5-EESD	1.1.4.-5.	Solar PV, wind
Omniflow	196470	Next-generation hybrid wind and solar power technology	50125.0	H2020-EU.2.3.1.; H2020-EU.3.3.	SIE-01-2014-1	Solar PV, wind
PV/HP GENERATION	92655	A Micro-generation System Using PV/heat-pipe Roof Modules	200423.5	FP7-PEOPLE	FP7-PEOPLE-IIF-2008	Solar PV, Solar Thermal
REELCOOP	109511	Research Cooperation in Renewable Energy Technologies for Electricity Generation	5211509.8	FP7-ENERGY	ENERGY.2013.2.9.1	Solar PV, Solar Thermal, Bioenergy
RESSOL-MEDBUILD	93381	RESearch Elevation on Integration of SOLar Technologies into MEDiterranean BUILDings	1082553.8	FP7-REGPOT	REGPOT-2009-2	Solar PV, Solar Thermal
RO-SWEET	69513	Solar and wind technology excellence, knowledge exchange and twinning actions Romanian centre (RO-SWEET)	450070.5	FP5-EESD	1.1.4.-5.	Solar PV, Wind
SOLAR-ERA.NET	105893	ERA-NET on Solar Electricity for the Implementation of the Solar Europe Industry Initiative	2046114.6	FP7-ENERGY	ENERGY.2012.10.1.2	Solar PV, Solar Thermal
SOLAR-ERA.NET Cofund	200090	SOLAR-ERA.NET Cofund	5930149.5	H2020-EU.3.3.3.; H2020-EU.3.3.2.; H2020-EU.3.3.4.	LCE-18-2015	Solar PV, Solar Thermal
SOLEURAS	67851	European-central Asian solar energy conference tashkent May 2003	25218.3	FP5-INCO 2		Solar PV, solar thermal, wind
SOLFORRENEW	99608	A comprehensive framework for high-resolution assessment and short-term forecasting of the solar resource for renewable energy applications	223527.6	FP7-PEOPLE	FP7-PEOPLE-2010-IOF	Solar PV, Solar Thermal

Annex 5

Technology Sector Report Ocean energy

(Deliverable D2.5)

Authors:
Onne Hoogland (Trinomics)
Elske Veenstra (Trinomics)
Perla C. Torres Vega (Trinomics)
Fiona Buckley (Tractebel)

1 Introduction

This report is one in a series of eight technology reports for the study *Impacts of EU actions supporting the development of renewable energy (RE) technologies*, prepared for the European Commission. The report has two objectives: 1) describing how EU research and development (R&D) funding for the ocean technologies has impacted the ocean sector in the EU, and 2) describing more broadly the development of the ocean sector to which the EU R&D funding has contributed. It is based on a compilation of data from several databases, a questionnaire sent to coordinators of EU-funded R&D projects, case studies, interviews and literature research. The methodology applied for this study is documented in a separate deliverable.[1] Where relevant, limitations and assumptions are mentioned throughout this report.

Ocean energy technology refers to any technology used to harness energy from ocean currents/tides, waves, salinity gradients and temperature differences. There are different technologies that can use this energy and convert it to renewable electricity, such as tidal currents, ocean currents, wave energy, ocean thermal energy conversion (OTEC) and salinity gradient energy. **Tidal range** plants are sometimes also categorised as ocean energy technology, but will not be considered in this report. It is a mature technology that has not received any EU R&D funding. The 240 MW La Rance tidal barrage in France has been operational since 1966. As this technology has a considerable impact on the environment, no other tidal range plants are currently operational in the EU.

Over the last 10 years, there has been an increased focus on development of technologies to utilise tidal currents and wave power. **Tidal current** technologies have begun to converge on a common design - horizontal axis tidal turbines – which are close to mature development and deployment. There are also a wide range of different **wave** devices being trialled. **Ocean currents, OTEC and salinity gradient** technologies have been the subject of active R&D projects.

Ocean energy is still in its early stages of development and its contribution to global energy production is not significant yet. Tidal current and wave devices are generally small but may eventually be deployed at utility-scale in multi-unit arrays or in smaller groups for off-grid applications. Most technologies have been deployed offshore but some, OTEC and salinity gradient, may work in coastal onshore locations (e.g. estuaries for salinity gradient projects). There are also some close-to-shore and onshore wave and tidal devices.

Ocean energy development has progressed at a slower pace than anticipated. High up-front costs and capital needs is one of the main reasons, together with intrinsic technical challenges connected to the harsh ocean environment. Technologies to harness ocean energy are not mature enough, with some reliability and survivability problems, leading to high costs of energy in comparison to other sources. Nevertheless, the resource is abundant and well distributed around the world, in many cases close to high energy demand in coastal areas. Renewable energy sources (RES) from the ocean have the potential to play a role in the long-term clean energy mix, potentially providing a world-wide energy source located near end users in coastal cities and harbours.

[1] Trinomics (2018) - Study on impacts of EU actions supporting the development of renewable energy technologies – Literature review and methodology (Deliverables D1.1 and D1.2)

The impacts of ocean energy lie in the future, as we are currently experiencing a moment of growth for ocean energy, with several devices being deployed and demonstrated. Though on a national level, there are only few countries with strong national incentives for the development of ocean energy schemes. On sector and EU level, there is a clear vision of what should be done on the technical, financial and consenting aspects. For example, the Ocean Energy Forum presented a detailed plan to build up ocean energy in Europe. It covers everything from initial R&D to the industrial roll-out, stating the importance of testing technologies in real conditions while introducing a phase-gate scheme to validate sub-systems and early prototypes.

2 Historical R&D funding

2.1 EU R&D funding

The European Commission has supported research and development in ocean energy technologies with EUR 225 million of funding for 72 R&D and demonstration activities in the framework programmes (FPs). Another EUR 73 million was provided to 20 projects that focused on ocean in combination with other RE technologies, of which 19 were combined with wind technology and one with hydro technology (see Table 2.1 and see Annex C for a full list of projects). In total, ocean energy projects received 6 % of all funding to RE technologies through the FP5, FP6, FP7 and H2020 programmes.

Table 2.1 EU funding per framework programme (1998 to mid-March 2018, 2016 million euros[2])

	Ocean		Ocean and other RES	
Framework programme	EU funding	Number of projects	EU funding	Number of projects
FP5	3.73	6	-	0
FP6	24.80	13	-	0
FP7	72.60	22	46.23	13
Horizon 2020[3]	123.42	31	26.32	7
Total EU funding	224.55	72	72.55	20

Source: CORDIS (2018)

2.1.1 *Evolution of research topics*

There are many different ocean energy sub-technologies, most of which have received some EU funding (see Figure 2.1). Tidal and wave technologies are the most advanced and have received the most funding. Funding from FP5 and FP6 focused on wave technologies. Presently, most funding goes to tidal technologies, receiving EUR 106 million under FP7 and Horizon 2020 (H2020) (until the end of 2017).

Tidal technologies are at demonstration stage and are thus more advanced than other ocean technologies. As can be seen in Figure 2.3, 90 % of the funding went to demonstration projects, followed by funding for component design and component demonstration. The next step that the tidal sector needs to take is to move towards multiple 'real size' turbine parks in real conditions. EU support enabled technologies to increase their TRL level (from TRL 2-3 to TRL 5-6) via different means, for example:

- by testing and improving components (e.g. PowerKite for its PTO, see project spotlight below);
- by testing and improving turbines (e.g. DirectDrive TT with its horizontal axis tidal turbine, see Chapter 4);
- by demonstrating integrated solutions for the offshore tidal plants (e.g. InToTidal with its small tidal turbines, see Chapter 4).

[2] Historical values have been inflation adjusted to arrive at 2016 constant values. This has been done to show the values of budgets, prices and other monetary indicators without the impact of varying price levels over the years so that they can be compared over time more accurately.
[3] Funding from H2020 is still ongoing. The tables and graphs presenting EU R&D funding in this section include funding until mid-March 2018 (unless specified otherwise).

EU support enabled, for high resource sites, a technology convergence towards 3 bladed horizontal axis turbines. It also enabled the development of different technologies (smaller, different design, etc.) targeting medium and low resource sites (e.g. Minesto and Nova Innovation) which will be the second-generation locations and projects. EU and National funding enabled Europe to be the leader in device development and first mover on single device testing (e.g. FP4 SeaGen) and first array projects (e.g. FP7 Clearwater with Meygen 1A and H2020 Demotide Meygen 1B, see Chapter 4).

Project spotlight: PowerKite

The H2020 funded PowerKite project aims to design, build and deploy a power take-off system (PTO) for novel tidal energy collector concept, the Deep Green subsea tidal kite. The overall objective of the PowerKite project is to gather experience in Open Sea conditions to enhance the structural and power performance of the PTO for a next generation tidal energy converter, to ensure high survivability, reliability and performance, low environmental impact and competitive cost of energy in the (future) commercial phases. One of the key deliverables of the project was to create a concept for a grid connected power system design. A base case array design was defined and developed in steps of 3 MW, 12 MW and 80 MW. This first conceptual design study has identified a number of key design issues – for array and the kite. These are being addressed in the current project and/or will be fed into to the future development. Alternative technological solutions are explored for future performance improvement and reduced costs of the kite and the system.

Source: EC, 2018, Community Research and Development Information Service

Wave technologies are less advanced and need to overcome issues linked to components, such as power take off (PTO). In the past, they received significant funding for demonstration projects (over 50 % of the EU R&D funding went to demonstration projects), but several of these were unsuccessful which caused the sector to take a step back. The most well-known example of this is the Pelamis device that received EU-funding (FP7) and completed over 200 hours of full-scale, grid-connected demonstration only to have the device disappear from circulation, as the company failed to secure further investment and ceased trading. Nevertheless, via leanings and financial support, the EU enabled technologies to increase their TRL level (from TRL 2-3 to TRL 5-6) via different means, including:

- by allowing a better understanding of the environment (e.g. SOWFIA). Wave conditions, though continuous, are complex (matrix based) and non-predictable (at least not on the long term);
- by enabling the testing of specific components and more specifically the PTO to gain in knowledge and overcome the current knowledge barriers.

EU funding also supported research projects that have benefitted both tidal and wave technologies:

- by developing a series of technology evaluation protocols for marine energy, specifically wave and (kinetic) tidal current energy extraction systems (for instance FP7 EQUIMAR);
- by developing design tools (FP7 DTOCEAN, H2020 DTOCEAN-plus);
- by allowing learnings by failure (cf. above with Pelamis) where the knowledge gained is transferred by staff moving from one company to another.

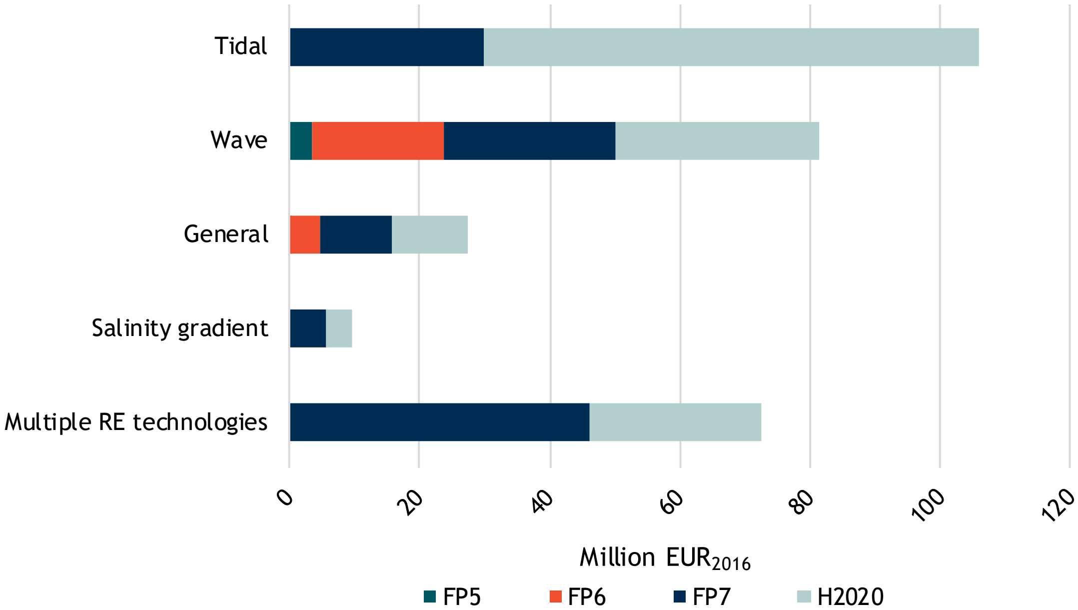
Since the beginning of the FPs, numerous wave devices have appeared and disappeared (e.g. Pelamis). Nevertheless, the learnings from these projects are still present today in the industry:

- staff and knowledge transfer from one company to another (e.g. the formation of specialist engineering consultancy Quoceant, which was formed by several members of the Pelamis team and now supports many ocean energy developers);
- increased resource understanding;
- increased components understanding.

Due to the complexity of the wave resource and its inconstant nature, cooperative research is now focusing on the development of specific components such as the PTO – Power Take Off (e.g. Sea-Titan). Over 20 % of EU funding for wave technology went to component design and component demonstration. Industry can use the specific components and knowledge for their converters and is still focused on demonstration of full-scale wave energy converters, which is still supported by H2020 projects (CEFOW) and INNOVFIN EDP (Waveroller). EU support enables to understand how to reduce the project costs to improve the LCOE of the sector in the long term (e.g. Wetfeet, see Chapter 3) as well as better understand the resource (e.g. OPERA, see Chapter 3).

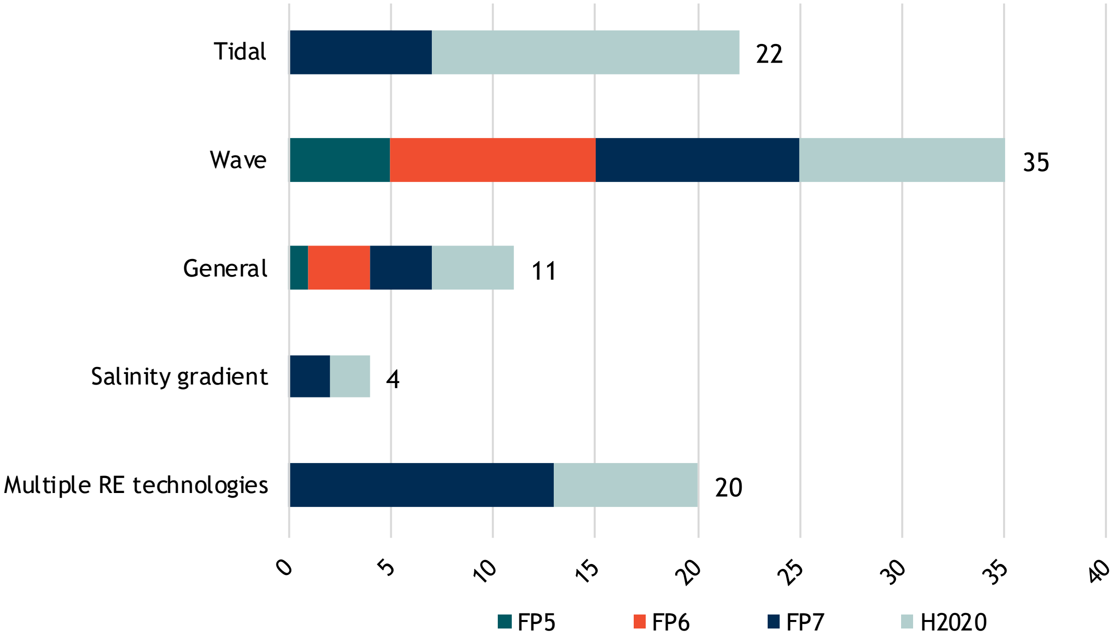
Salinity gradient technologies also received funding under FP7 and H2020 for four projects (see Figure 2.2). Funding for this research topic was allocated to component design. The technologies are still in early R&D stage as they need to overcome problems linked to the membrane. **OTEC** needs to overcome problems relating to increasing the piping size to develop devices with a larger power capacity. OTEC and salinity gradient have not been priority areas in the FPs.

Figure 2.1 EU funding per sub-technology/area (2016 million euros)



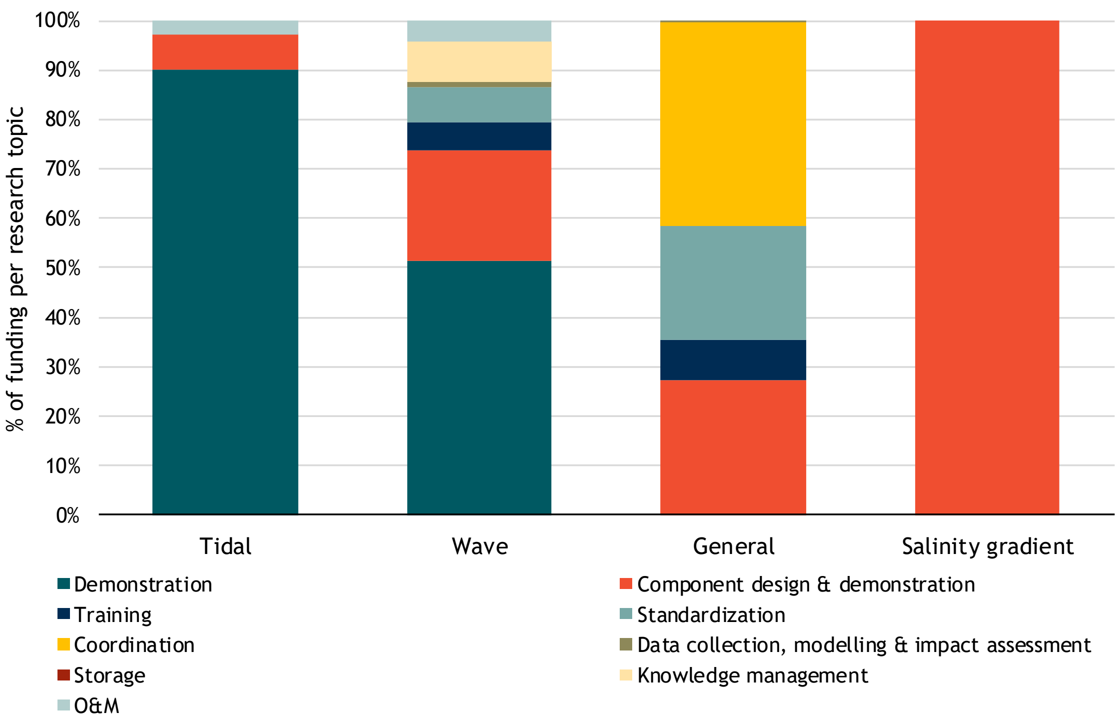
Source: CORDIS (2018)
The area 'multiple RE technologies' includes projects in which ocean is one of multiple RE technologies.

Figure 2.2 Number of projects per sub-technology/area



Source: CORDIS (2018)
The area 'multiple RES technologies' includes projects in which ocean is one of multiple RE technologies.

Figure 2.3 Research topics per sub-technology/area



Source: CORDIS (2018)

2.1.2 Top recipients

Table 2.2 shows the top recipients of R&D funding from FP7 and H2020, and highlights the diversity of organisations that have received R&D funding. This includes device developers, marine contractors, universities and even naval defence organisations. Five of the top recipients are based in the UK, others being in France, Finland, Belgium and Ireland. Table 2.3 shows that EUR 62.6 million FP7 and

H2020 funding was allocated to parties in the United Kingdom. This is four times as much as the next biggest recipient, France (EUR 15.5 million). Organisations in neighbouring countries Belgium and Ireland also received over EUR 10 million each.

Table 2.2 Top 10 recipients of EU funding by organisation (in 2016 euros).

Rank	Organisation	Country	Type of organisation	Funding	Number of ocean projects
1	Nova Innovation Ltd	UK	Device developer	12 254 297	4
2	Wello Oy	FI	Device developer	9 471 460	1
3	GeoSea NV	BE	Device developer	8 167 509	1
4	Openhydro Technology France	FR	Device developer	7 721 334	1
5	Marine Current Turbines Ltd	UK	Device developer	7 295 815	2
6	The University of Edinburgh	UK	University	5 449 869	15
7	Scotrenewables Tidal Power Ltd	UK	Device developer	5 023 375	1
8	Green Marine (UK) Ltd	UK	Marine contractors	4 656 819	1
9	DCNS Energies	FR	Naval defence	3 599 047	1
10	University College Cork	IE	University	3 329 261	9[4]

Source: CORDIS (2018)
The source data covered the recipients of H2020 funding, and partially the recipients of FP7. No data was available for recipients of FP5 and FP6 funding. The number of ocean projects accounts for the number of projects where the organisation participated that were related solely to ocean energy. The projects covering multiple RE technologies were not included in this table, because there was no indication of the amount of the project funding to a specific technology per organisation.

Table 2.3 Top 10 recipients of EU funding by country (in 2016 euros)

Rank	Country	Funding
1	United Kingdom	62 567 815
2	France	15 465 305
3	Belgium	12 436 575
4	Ireland	10 758 855
5	Finland	9 916 946
6	Spain	8 669 050
7	Sweden	8 298 185
8	Netherlands	6 729 029
9	Portugal	5 307 832
10	Italy	4 579 391

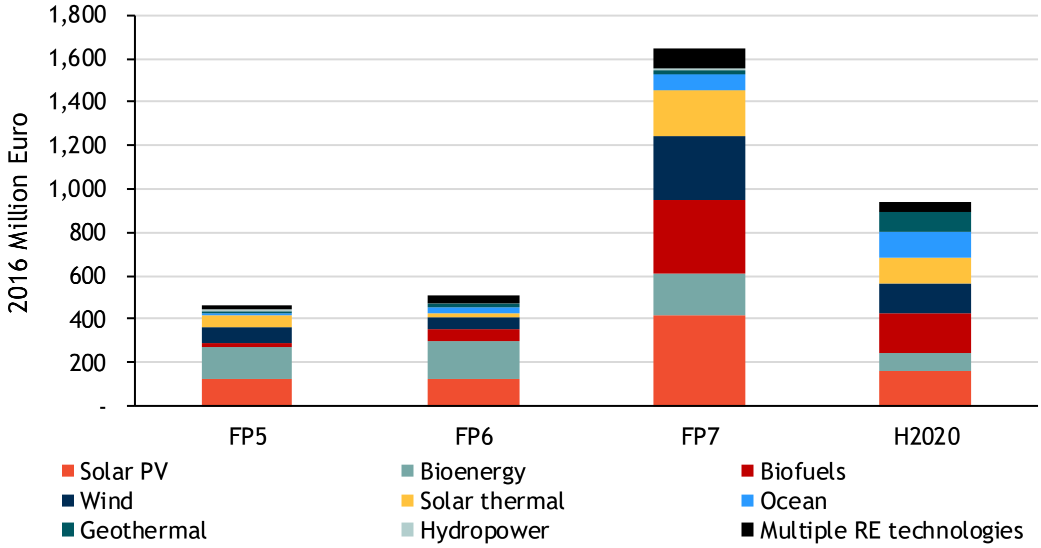
Source: CORDIS (2018)
The source data covered the recipients of H2020 funding, and partially the recipients of FP7. No data was available for recipients of FP5 and FP6 funding. Projects under 'multiple RE technologies', as mentioned in the introduction of section 2.1, are not included in this table.

2.1.3 Share of funding for each sector in proportion to the overall funding of all RE technologies

Ocean energy projects received 6 % of the EUR 3.6 billion awarded to all RE technologies through the FP5, FP6, FP7 and H2020 programmes. In FP5, ocean energy projects had the lowest share of funding available for RE technologies accounting for only 0.8 %. This share went up to 4.8 % for FP6 and has increased to 13.2 % of the funding provided under H2020 (until the end of 2017).

[4] One of these projects did not have an indication of the EC funding awarded to it.

Figure 2.4 Amount of EU R&D funding for each RE technology per FP



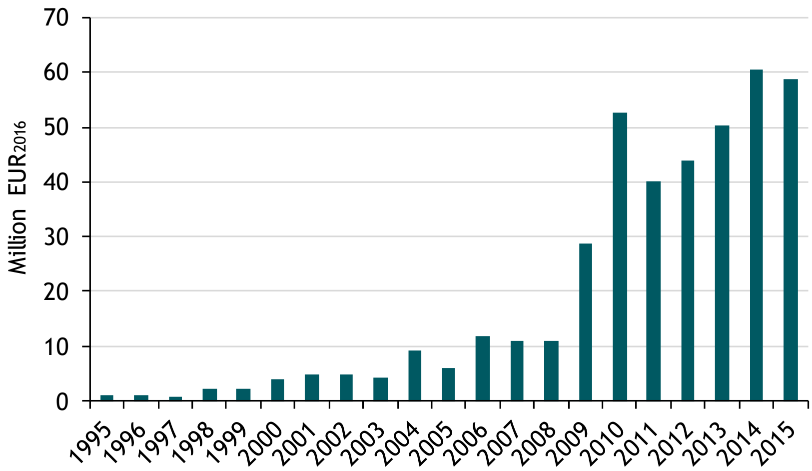
Source: CORDIS (2018)
Note: The area 'multiple RE' includes projects of multiple RE technologies.

2.2 Member State R&D funding

2.2.1 Evolution over time

Annual R&D funding in ocean technologies by MS sharply increased after 2008, from EUR 5.3 million on average between 1995 and 2008, to EUR 47.8 million on average between 2009 and 2015 (see Figure 2.5). Several MS have considerably increased their budgets, such as Ireland. Other MS only started funding ocean R&D at a later stage, such as Spain and Sweden in 2005 and 2006 respectively. Compared to other RE technologies, ocean R&D funding is still a very modest share of MS R&D funding for RE technologies.

Figure 2.5 Annual MS R&D funding in the EU for ocean technologies

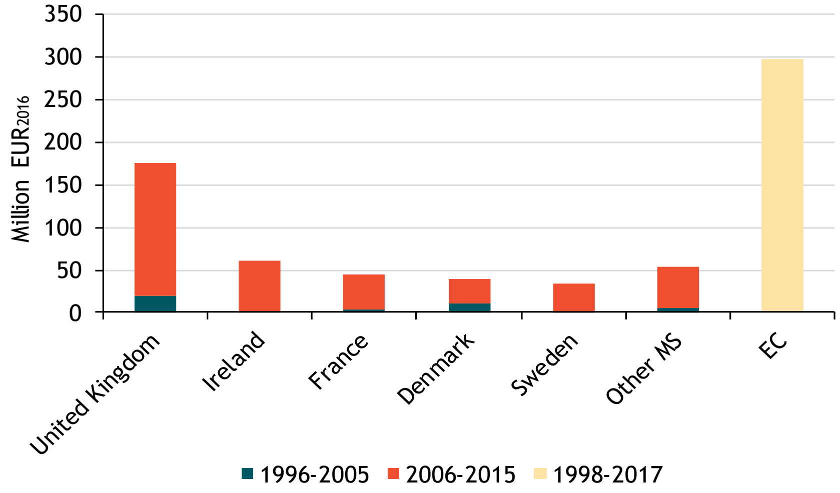


Source: Based on data from OECD/IEA (2018)
Note: Data for 20 EU countries was available in this source: The EU15 plus Czech Republic, Estonia, Hungary, Poland, Slovakia.

2.2.2 Largest Member State funders

Figure 2.6 shows the EU R&D funding compared to the largest five MS funders, which are the United Kingdom, Ireland, France, Denmark and Sweden. Ocean energy funding differs from other RE technologies in two ways. Firstly, Germany is not part of the largest MS funders (see Figure 2.6). This is mainly because there are no 'sector leading' devices being developed in Germany (although there are numerous component developers active that are of relevance to ocean devices, new technology developers). Secondly, EC funding is substantially higher than that of the largest MS funders. Ocean R&D funding is very different in this sense compared to the other RE technologies, where the EC funding is of a similar magnitude as the funding of the largest MS funder, or lower.

Figure 2.6 Amount of national R&D funding and EU funding for ocean energy



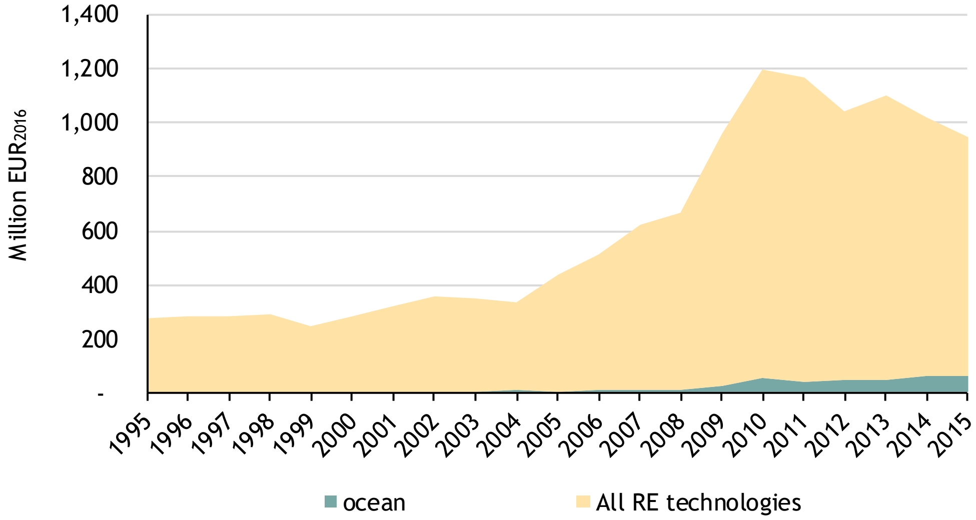
Source: Own elaboration based on data from OECD iLibrary (2018), Eurostat (2018) and CORDIS (2018). Data for Italy was not available for 2010 and 2015, and data for the UK was not available for 2008.
Note: Time window of comparison between Member State and European Commission funding is shifted two years due to data availability of Member State budgets for the scope of analysis (FP5-H2020).

2.2.3 Share of total renewable energy technology funding

In the period of 1995 to 2015, Member States allocated 3.2 % of their national R&D funding for RE technologies to ocean energy. From 1995 to 2008 the share of funding for ocean was relatively low, with shares between 0.4 % and 2.8 % of the MS budgets for all RE technologies. From 2009 onwards, the share of ocean energy increased, with shares between 3 % and 6.2 %.

Overall ocean energy is the second least funded technologies by MS R&D budgets; only hydroelectric technologies receive less funding.

Figure 2.7 Share of national R&D funding for ocean energy in proportion to the overall funding for all RE technologies



Source: Based on data from OECD/IEA (2018).
Note: Data for 20 EU countries was available in this source: The EU15 plus Czech Republic, Estonia, Hungary, Poland, Slovakia. Data for Italy was not available for 2015, for the Netherlands for 2004 and data for Poland was not available before 2009 for any RE technologies.

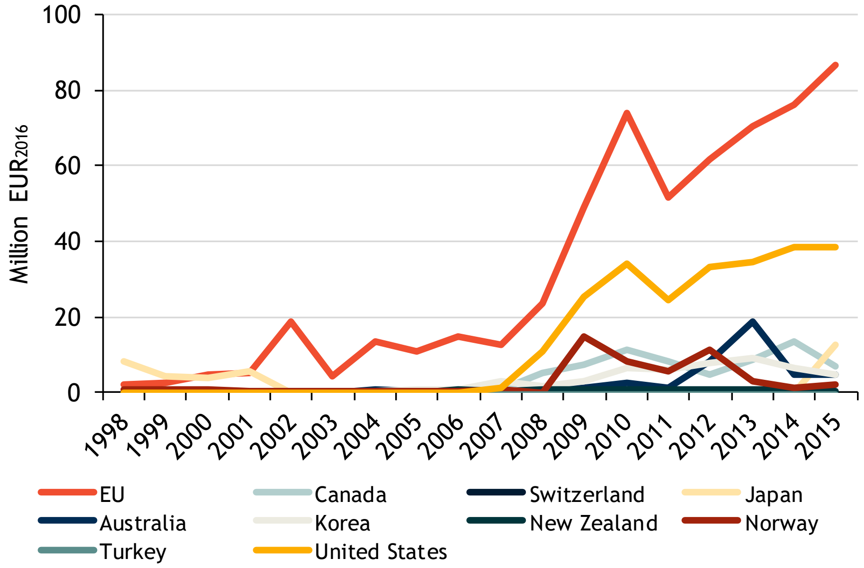
2.3 Private and international R&D funding

2.3.1 International public R&D funding

The EU and MS provide significantly more R&D funding for ocean energy technologies than other countries, spending on average EUR 32 million per year between 1998 and 2015. As shown above, a large part of this funding comes from the EU FPs. The EU was also one of the first to provide R&D funding to ocean technologies. Japan is the only other country with significant funding before 2006. After 2006, the United States of America (USA) started funding research too, amounting to EUR 30 million per year on average between 2008 and 2015. Other countries with significant R&D budgets are Canada, Australia, Norway and Korea. In Korea, a 254 MW tidal plant started operating in 2011, with a further 2 680 MW in the pipeline up to 2017.[5]

[5] JRC (2015) 2014 JRC Ocean Energy Status Report.

Figure 2.8 Annual R&D budgets of IEA countries for ocean technologies



Source: OECD/IEA (2018)
Note: EU covers EU and MS funding. National budgets for 2016 were excluded from the analysis because they are early estimates and lack reliability/coverage. Data covers 20 EU countries: the EU15 and Czech Republic, Estonia, Hungary, Poland, Slovakia and the European funding programmes FP5, FP6, FP7 and H2020. For countries outside the EU, national budgets were available for Australia, Canada, Japan, Korea, New Zealand, Norway, Switzerland, Turkey and the USA. Data for Italy was not available for 2010 and 2015, and data for the UK was not available for 2008. China was excluded from the analysis as reliable data for the time period of interest was not available.

2.3.2 Private R&D funding

There was no comprehensive data available on private R&D funding for ocean technologies over the last 20 years. The sector is still small, however, Ocean Energy Europe (OEE), an industry association representing companies active in the European ocean sector, estimates that in the last 10 years OEE members have invested more than EUR 1 billion in R&D activities[6].

2.4 Conclusions

The EU R&D budget for ocean technologies is leading internationally. Ocean energy technologies receive a relatively high amount of R&D funding from the EU, and MS are increasingly funding the technology as well. The EU and its MS were the first to provide R&D funding to ocean technologies in the world and provide more than any other country. Research projects focused on knowledge sharing, standardization and component design and demonstration of technologies. Especially for tidal technologies, EU funding enabled Europe to be the leader in device development and first mover on single device testing, as well as first array projects. Wave technologies also received funding for demonstration projects, as well as component design, which is now the biggest issue to overcome for this sub-sector. Most funding goes to organisations in the United Kingdom and France, which are also in the top 5 funders at MS level.

[6] Ocean Energy Europe, n.d., Europe needs ocean energy. Available at https://www.oceanenergy-europe.eu/ocean-energy/

3 Research effectiveness

R&D projects can lead to patents, publications, spin-offs and several other, less concrete but potentially important direct outputs such as standardisation, knowledge exchange and last but not least the impact on education such as the increased number of Marine Courses given and/or the increased number of test sites (in situ and in-vivo). Such impacts are the most direct impacts of R&D funding and therefore provide the cleanest view on the effectiveness of research budgets spent. In this section we discuss patents, publications, spin-offs and other direct research outputs, and their relation to R&D funding for the ocean sector.

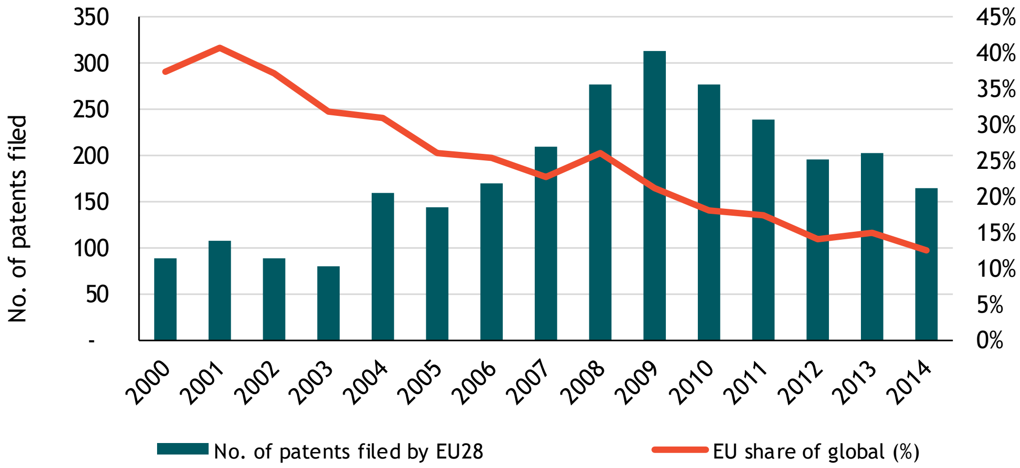
3.1 Patents

Patents are a commonly used indicator to measure the output of R&D funding as data is readily available, in a standardised form, and a direct measurement of the output of R&D funding. However, some limitations have to be taken into account, such as the fact that filing a patent is not an objective of all research projects and that the economic value of patents differs strongly.

3.1.1 Evolution over time

Figure 3.1 shows the profile of patents filed for ocean energy technologies in the EU. Since 2006, the number of patents filed have been above 170 a year. The number of EU patents increased until 2009, when 313 patents were filed, after which it decreased again to pre-2007 levels. The reason for this decrease is a shift away for developing new devices to improving existing ones.

Figure 3.1 Evolution of ocean energy patents filed by EU countries



Patent applications outside of the EU have been rising, which translates into a downward trend in the EU's share of global patents, from approximately 40 % in 2000/2001 to 15 % in 2013. Incentives and (test) project sites in non-European countries have increased over the past years, explaining this shift.

In the EU, most patents were filed in the United Kingdom (24 % of EU total), followed by the Germany (18 %), Spain (13 %) and France (10 %). The United Kingdom and France also received the most R&D funding from the EU under FP7 and H2020. Germany and Spain on the other hand did not have large

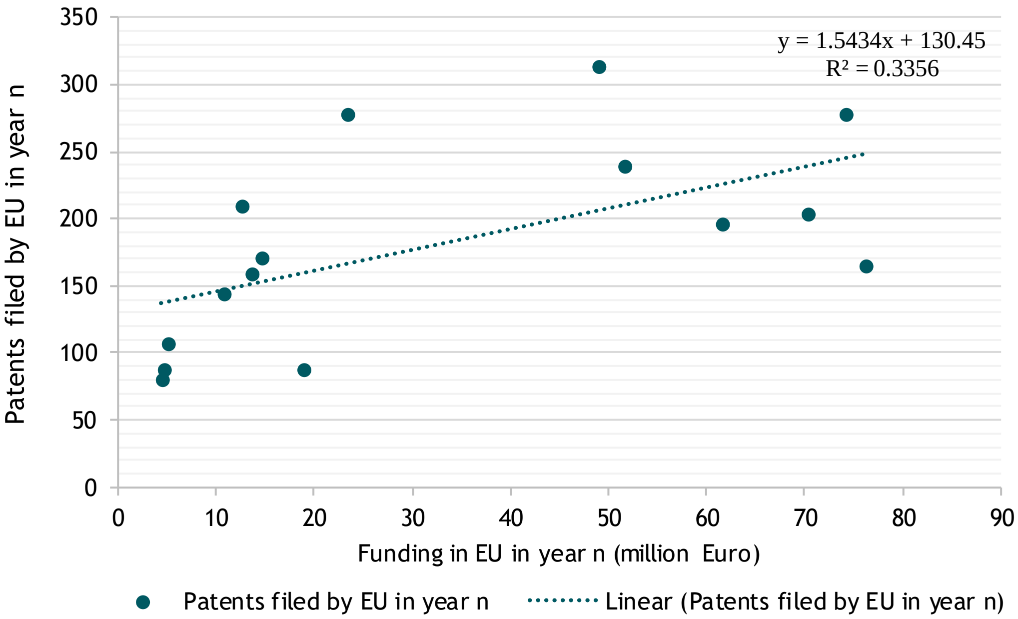
R&D budgets, nor did they receive a lot of EU R&D funding. However, they do house component developers that are relevant to ocean energy devices. The other large R&D funders - Denmark, Ireland and Sweden - only filed 10 % of the total EU patents.

3.1.2 *Effectiveness of R&D funding in producing new patents*

In theory, higher R&D budgets in a region are expected to lead to an increase in the number of patents filed from that region. The extent to which this relation exists in the hydroelectric sector provides insight into the objectives of the research (is it targeted at technology development, so more likely to result to a patent application?) and the effectiveness of the research (was it successful in developing the technology so resulting in a patent application?).

Figure 3.2 shows that there is no clear correlation between the total amount of patents filed and the amount of EU R&D funding (MS and EU combined). This again shows that the sector is shifting its focus to improvements on existing devices instead of creating new ones. This is in line with the findings for other RE sectors and underlines that patent applications are generally not a primary objective of a research project.

Figure 3.2 Effectiveness of R&D funding in producing new patents



Notes: We tested a delay of 0, 1, 2, 3, 4 and 5 years for the patents filed from year 2000 to 2014. 2015 data of patents was excluded because the source (IRENA) mentioned it is common to have delays of 3 years from a patent application and the year is reflected in the database. The correlation went up when 2015 data was excluded. A delay of 0 years between funding year and patents filed showed the highest correlation (R^2 = 0.3356).

3.1.3 *Contribution of EU funding*

Although it may not be the main focus of EU-funded research, FP funding has contributed to the creation of patents in several research projects. From the 11 projects that responded to our questionnaire, 2 projects reported a patent application as a result of EU funding. FP7 SURGE contributed to the application of approximately 60 patents (see box below).

Project spotlight: SURGE

The FP7-funded project SURGE (Simple Underwater Generation of Renewable Energy, 2009-2013) aimed to design, build and deploy at a fully exposed test site an array of WaveRoller wave energy converters, and connect these to the national grid. The project enabled the validation of design methodologies and further improvements of the technology. For example, a panel was instrumented with strain gauges, deployed in 2014 and the data recorded was used to validate the design methodology, which concluded in 2015. This led to third party certification of the following project SURGE2, which was the first wave energy converter to receive technology certification and design approval by a certification body. The SURGE2 project is also the First of a Kind (FOAK) product and forms part of the current solution that is being supplied to customers. Approximately 60 patents have been filed since the start of the project and all are in some way a result of what was learnt during SURGE. Next to patents, the third-party validation and certification associated with SURGE has made a direct contribution to the business goals of AW-Energy, which led the project.

More information on the project is available as a case study in the annex of this report.

3.2 Publications

Publications of research papers are a useful indicator to measure the output of R&D funding. Publications have a close relation with public R&D funding, allowing us to differentiate the effect of public R&D funding from private R&D funding. Publications are categorised by country on the basis of the address of the author. If it has authors from different regions, the publication is counted for both regions.

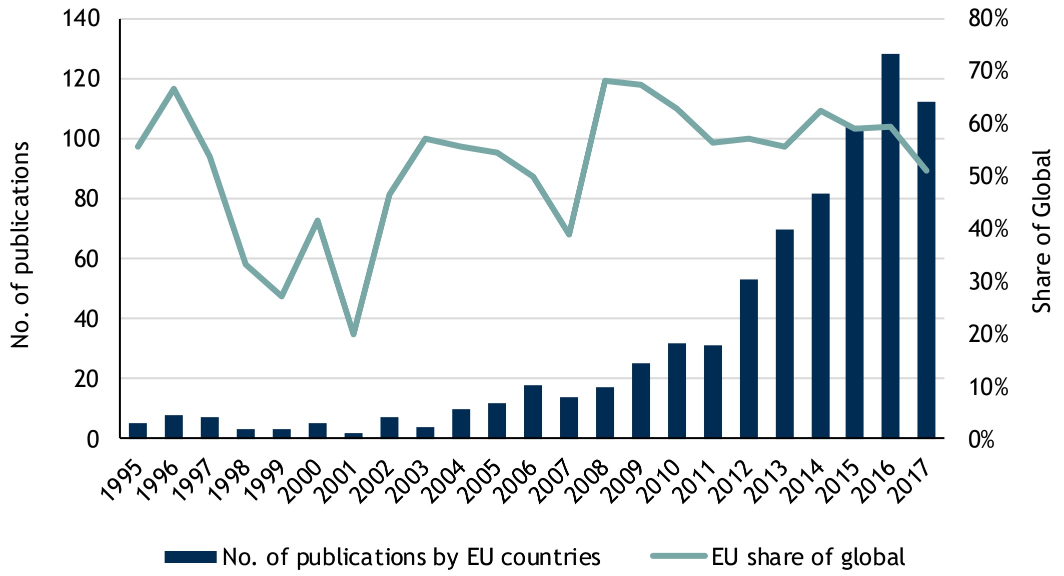
3.2.1 Evolution over time

Figure 3.3 shows the evolution of ocean publications by EU-based authors over the years. The number of publications on ocean energy had an upward trend over the years 1995 to 2016.

The EU has a leading position in ocean publications, with EU-based authors involved in 752 publications, more than half of the global publications between 1995 and 2017. For countries outside the EU, the USA is the most active country in ocean energy publications, with 254 publications having an author based in the USA (see Figure 3.4). This is followed by China (137) and Canada (64).

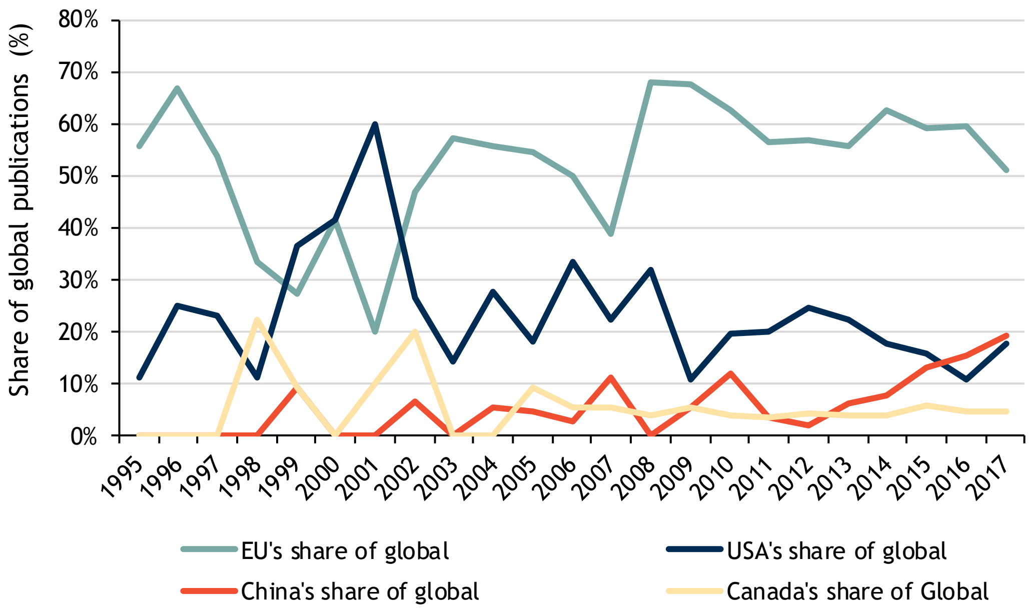
Within the EU, most publications had authors in the UK (341), Spain (118), Portugal and Ireland (73 each), France and Sweden (60 each), followed by Italy (51), Denmark (43) and The Netherlands (34).

Figure 3.3 Evolution of ocean publications by EU countries



Source: Web of Science (2018), using keywords: 'wave energy', 'tidal energy', 'ocean thermal energy', 'salinity gradient energy' or 'marine energy' in the title, topics and abstract of articles between 1995 and 2017. Wave energy results were delimited to publications that had 'Energy Fuels' in the 'Research Area' field to remove false positives. Duplicates between the different keyword searches were removed. The share of global refers only to those publications with an address listed. 1 % of the global publications had no address listed in that period of time.
Notes: One article can have multiple authors (therefore, also multiple countries). The count is the number of articles in which at least one author listed an EU MS as their address.

Figure 3.4 Comparison of the share of ocean global publications between key countries



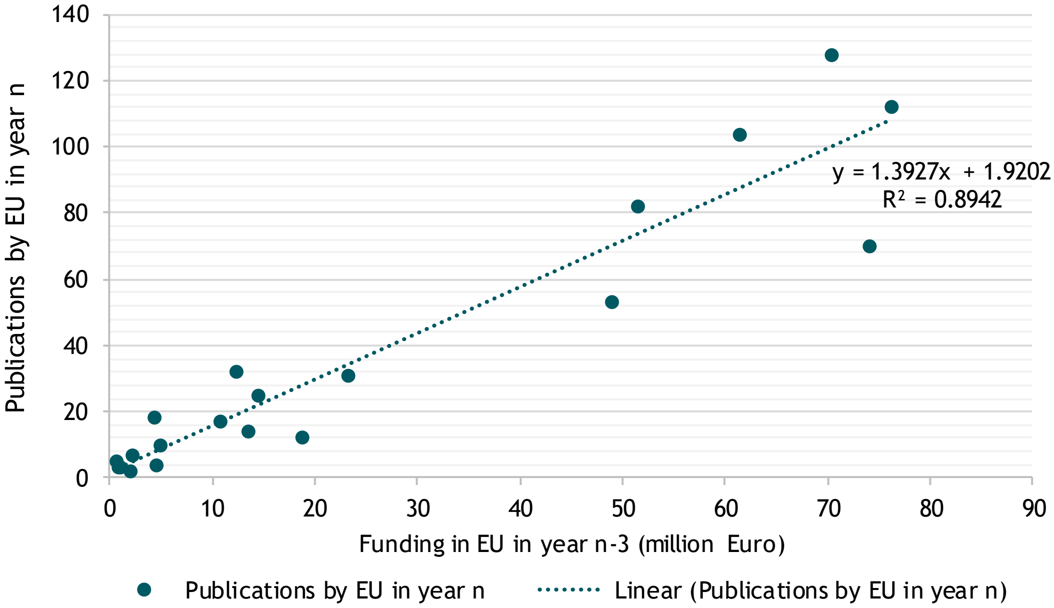
Source: Web of Science (2018)
Notes: The shares of the different countries/regions are not cumulative since one article can have multiple authors (therefore, also multiple countries).

3.2.2 *Effectiveness of R&D funding in producing publications*

In theory, higher R&D budgets in a region are expected to lead to an increase in the number of publications from that region. The extent to which this relation exists in the ocean energy sector provides insight into the objectives of the research (does it aim for a publication?) and the effectiveness of the research (is it successful in realising a publication?).

Figure 3.5 compares the total number of EU publications to the amount of EU R&D funding (MS + EU combined), accounting for a time lag between the moment of funding and the publication. The number of publications correlates more closely to R&D funding than the number of patents does, indicating that publicly funded R&D projects in the ocean energy sector have a higher focus on publishing and/or are more effective at publishing. This is in line with the findings for other RE sectors and underlines that publishing is often one of the primary objectives of a research project. The highest correlation was found with 3 years of delay between funding and publication, but also for other time lags, the EU funding and publications show a high correlation.

Figure 3.5 Effectiveness of R&D funding in producing publications



Notes: We tested the publication effectiveness of R&D funding for the period 1995-2015. Funding in EU includes EU funding and MS funding. We tested different delays (0, 1, 2, 3, 4 and 5 years) to evaluate which one had the highest correlation. After 2 years of delay, for each year of delay, the sample size was reduced by one number (e.g. with 0, 1 and 2 years of delay the sample size was 21 years, with 3 delay the sample size was 20 years, etc.) With 1 year of delay (n-1), the R^2 is the lowest of all the ones tested (0.8093). The highest R^2 was found using 3 years of delay (0.8942).

3.2.3 Contribution of EU funding

Between 2008 and 2017, 151 publications explicitly reported benefitting from EU funding sources, which equates to 20 % of the total number of EU publications in those years. Not all publications report their sources of funding, so it is likely that the actual figure is higher. The particular EU funding sources used are not always specified in publications and therefore these figures may include publications funded by other instruments than the Framework Programmes for research and technological development, such as funding from the European Investment Bank (EIB). However, for ocean technologies it is expected that nearly all funding came from the FPs, as the technologies are still at research and demonstration phase. At least 52 % of the EU funding sources in that period came from the FP6, FP7 and H2020 funding programmes.

The top EU organisations in terms of publications are listed in Table 3.1. The whole top 10 consists of universities, which is not surprising as they are most likely to publish scientific papers. Some of them received considerable funding through the EU FPs. The University of Edinburgh, the University College Cork and the University of Exeter are in the top 20 recipients of EU R&D funding for ocean, and produce a substantial part of the EU publications. A lot of the EU R&D funding went to device developers and marine contractors (see Table 2.2), which are less likely to publish scientific papers, therefore the overlap between the top funding recipients and top publishers is limited to universities.

All the universities in Table 3.1 are located in MS that received considerable EU R&D funding and/or had a substantial R&D budgets within the country (e.g. Denmark).

Table 3.1 Top organisations in the EU contributing to ocean publications (1995-2017)

Rank	Institutions	Country	No. of Publications	EU funding rank
1	University of Edinburgh	UK	54	6
2	University of Plymouth	UK	49	*30+*
3	Universidade de Lisboa	Portugal	44	*30+*
4	University of Santiago de Compostela	Spain	44	*30+*
5	Uppsala University	Sweden	41	*30+*
6	University of Exeter	UK	32	20
7	Aalborg University	Denmark	27	*30+*
8	University College Cork	Ireland	27	10
9	University of Southampton	UK	20	*30+*
10	Maynooth University	Ireland	18	*30+*

Source: Web of Science (2018)

The questionnaire for this study also shows the contribution of EU funding to publications. Nearly all project managers that responded to the questionnaire reported a publication as one of the results of EU-funding. Publications are the most frequently reported impact of EU funding for ocean technologies (see also Section 3.4 below).

3.3 Start-ups and spin-offs

The creation of start-ups and spin-offs is another potential impact of research projects, which can function as an important link between the research and the development of a European industry. Start-ups and spin-offs are not reported consistently, however. Therefore, questionnaire results are used to provide insight into these impacts.

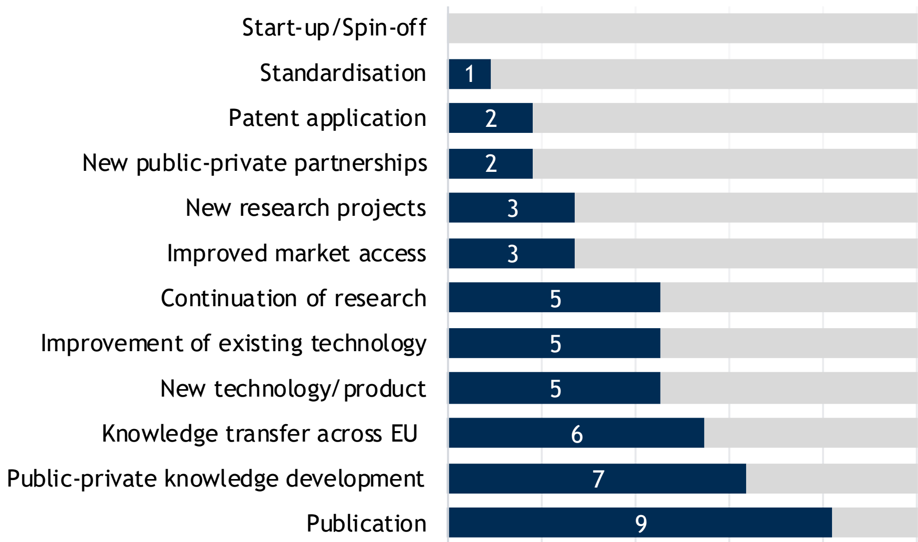
None of the 11 projects responding to the questionnaire reported the creation of a start-up/spin-off as result of their EU-funded project. The projects were more focused on publications and knowledge development (see Section 3.4 below)., In general, these results are consistent with the fact that ocean technologies are in the early stages of development, and it is likely too early to have spin-offs for many of them. Academic publications are expected to be a more prevalent impact compared to outputs such as improved market access or the creation of start-ups, which require a mature technology that is close to reaching commercialization.

There are however spin-offs from universities that received EU funding for ocean R&D. One of these Seabased Industry AB, a manufacturer and deployer of wave energy converters (WECs). Seabased is a spin-off from Uppsala University, which has participated in several EU-funded projects (e.g. FP6 CA-OE, FP7 CEFOW, and H2020 EQUIMAR). Uppsala University and Seabased are now collaborating in several research projects. Another example is Innosea, a spin-off company from the Ecole Centrale de Nantes, which received EU funding for various ocean energy projects. Since its foundation, Innosea has also received EU funding in two H2020 projects (WETFEET and DEMOTIDE, see project spotlights in chapter 3 and 4). Tocardo International BV is a spin-off from the engineering company Teamwork Technology BV, which cooperated with the Energy Research Foundation ECN and multiple Dutch engineering companies to develop its technologies. Teamwork Technology received EU funding for several projects before Tocardo was created in 2008 (with support from Dutch funding). Tocardo has since then received EU funding in FP7 TIDAL-EC and H2020 InToTidal (see project spotlight in chapter 4).

3.4 Other research outputs

While patents, publications and start-ups/spin-offs are often the most tangible and easily quantifiable outputs of EU-funded research of RE technologies, there are many other outputs that contribute to the development of a leading sector. To get a better understanding of these other impacts, a questionnaire was sent out to project coordinators of EU-funded R&D projects, and several research projects were analysed in greater detail. The results of the questionnaire are presented in Figure 3.6 below.

Figure 3.6 Impacts of EU funding based on questionnaire results (out of 11 responses in total)



Source: Own elaboration based on questionnaire conducted as part of this study.

The results of the questionnaire indicate that outputs of EU funding include publications, knowledge development between public and private entities and knowledge transfer across Europe, as well as new technology or product development, improvements of existing technology and continuation of research that would otherwise be discontinued. A clear example of knowledge transfer is the CORES project, which developed knowledge on components and concepts that is now applied to other floating device types (see the project spotlight in section 4.1). Other impacts which were less frequently mentioned are improved market access, new research projects, new public-private partnerships, patent applications and standardisation. There is a now a better understanding of the ocean energy sector. A common understanding has been developed on concepts such as site assessments.

In parallel to this, EU-funding had a strong and positive impact on education. This can be seen by the increasing number of universities all around Europe not only offering courses in ocean energy but also taking an active part in the further developments of the industry. Less than 10 years ago, the number could be counted on a single hand. Now, at least 17 universities are strongly involved (see Table 3.2). Not only the number of universities has increased, but also the number of seminars, study books and other study materials with dedicated texts on ocean energy technologies shows increased attention and knowledge sharing within the academic world.

Table 3.2 Non-exhaustive list of universities involved in ocean energy by including them in their curricula or by participating in EU or industry-funded projects

Name university and country
Universitaet Linz - **AT**
Universiteit Gent - **BE**
Aalborg Universitet - **DK**
Ecole Centrale De Nantes - **FR**
National Technical University of Athens - **GR**
University College Cork - **IE**
Alma Mater Studiorum-universita Di Bologna - **IT**
Scuola Superiore Di Studi Universitari E Di Perfezionamento Sant'anna - **IT**
Technische Universiteit Delft - **NL**
Norges Teknisk-naturvitenskapelige Universitet NTNU - **NO**
Chalmers University of Technology - **SE**
Uppsala Universitet - **SE**
University of Edinburgh - **UK**
University of Plymouth - **UK**
University Of Exeter - **UK**
Queen's University Belfast - **UK**
University Of Wales Swansea - **UK**
University Of Strathclyde - **UK**

In general, EU support enabled the creation of platforms aiming to facilitate the development of a European wide coordinated, unified and streamlined ocean sector. For wave energy, the project SOWFIA (Streamlining of Ocean Wave Farm Impacts Assessment) drew together partners in Europe who have a focus in planned wave farm developments. For the ocean sector in general, ETIP OCEAN (European Technical and Innovation Platform Ocean) facilitates exchanges within the industry as well as helps push the sector towards a common goal and better communicate and agree upon the targets. This platform, focusing on Technical, Financial and Environmental aspects, is used by developers and key industry players. To ensure the integration and enhancement of leading European research infrastructures specialising in research, development and testing of Offshore Renewable Energy (ORE) systems, MaRINET and Marinerg-I aimed to develop a business plan to put this international network of infrastructures on the European Strategy Forum for Research Infrastructures (ESFRI) roadmap. They also aimed to improve access of developers to research infrastructure. There is now open access to test centres, which greatly supports R&D activities. The FP6-funded EU Ocean Energy Europe (EU-OEA) has effectively promoted the ocean energy sector and contributed to knowledge sharing and networking across the ocean energy industry as well (see the case study in Annex A). The European Enterprise Network has also been helpful in connecting with partners across Europe. All these activities have improved collaboration across the EU, and with this a better understanding of the benefits of collaboration for public as well as private parties. EU funding and network building activities have also helped the continuity of knowledge development, also in the case of failed research projects, which provided valuable lessons learnt for the rest of the sector.

Project spotlight: SOWFIA

The SOWFIA (2010-2013) project drew together partners in Europe who have a focus in planned wave farm developments. The aim was to facilitate the development of European-wide coordinated, unified and streamlined environmental and socio-economic Impact Assessment (IA) practice for offshore wave energy conversion developments. Wave farm demonstration projects have been studied in each of the collaborating EU countries. Rather than focus on one specific device, this project benefited from the range of wave energy converters (WECs) being tested at each of the wave farm demonstration sites and the staggered time frames. By utilising the findings from technology specific monitoring at multiple sites, SOWFIA aimed to accelerate knowledge transfer and jump start European-wide expertise on environmental and socio-economic IA of large scale wave energy projects. The project showed that sea trials at established test centres should be subject to less rigorous consenting requirements, which should then be compensated for by a more exhaustive monitoring of the test sites. Additionally, existing legislation is fit for purpose, but more appropriate for larger wave energy developments. It showed that environmental impacts vary according to size and location of the development and should be taken into account. The virtual centre of excellence, developed during this project is expected to provide an ongoing resource for expertise in IA development of European wave farm projects leading to faster permitting processes and subsequent reduction in the cost of electricity generated from wave energy.

Source: EC, 2018, Intelligent Energy Europe

Project spotlight: WETFEET

The purpose of the H2020 WETFEET project was to identify and characterise the wave energy sector challenges, propose solutions (‘breakthroughs’) and initiate its development from TRL 2 to TRL 3-4. While the breakthrough features were aimed to positively impact the wave energy sector as a whole, the work focused on two specific wave energy converters (WECs): the Oscillating Water Column (OWC) and the Symphony (a variable volume submerged point-absorber). The results show that there is a possible reduction in maximum loads, from 30 % to 80 % (however, the evaluation on required investment should be done). A removable cocoon hosting critical components was tank tested on the Symphony, which shows it is feasible and applicable on other wave devices. The working principle of a structural membrane (with potential use for negative spring in heaving WECs) was proven (via simulations) and tested with a 1.5 m membrane. Additionally, the manufacturing procedure of Power Take Off (PTO) based on commercial materials was validated with ~40 % pneumatic to electric efficiency (tank test), and the sharing moorings in an array has been identified and quantified (increased loads seen in interconnected flexible lines, so more investigation needed). These results are expected to be contribute to other WEC designs too.

Source: EC, 2018, Community Research and Development Information Service; project website (http://www.wetfeet.eu/)

Project spotlight: OPERA
OPERA (H2020) collects and shares 2 years of open-sea operating data of a floating oscillating water column wave energy converter. This supports wave energy R&D, by giving a better understanding of the resource. In addition, the project is the first open-sea deployment for four cost-reducing innovations, advancing from TRL3-4 to TRL5. Together, these four innovations have a long-term cost reduction potential of over 50 %. Documenting and sharing this open-sea experience also induces a step-change in the knowledge of risk and uncertainties, costs and societal and environmental impacts of wave energy. The consortium brings together world leaders in wave energy research from four European countries and the IPR owner and most advanced teams to exploit each of these innovations. Last but not least, the project brings national in-cash co-financing of over EUR 2 million to directly fund the open-sea testing.
Source: EC, 2018, Community Research and Development Information Service; project website

3.5 Conclusions

The EU and MS R&D funding have been effective in establishing and maintaining a leading academic position globally on ocean technologies. The EU has a leading position in publications on ocean energy, authoring up to three times more publications than the USA and China. Interest in China is growing, but the number of publications is still far below that of the EU.

Our analysis and questionnaire results show that EU funding has directly contributed to these publications. From all EU MS, the United Kingdom filed the most patents and authored the most publications, which is not surprising as UK organisations received four times more EU R&D funding than any other MS. On top of that, the UK also spent three times more than any other MS on ocean R&D from its national budget, culminating to EUR 177 million between 1995 and 2015. It thus holds a leading position within the EU. The correlation between funding and publications is also visible in other MS. The MS in the top 10 recipients of EU R&D funding have authored the majority of EU publications on ocean technologies. MS that had a significant national R&D budget, such as Denmark, also authored a considerable number of papers.

Not many patents were filed for ocean technologies. From the eleven managers of EU-funded research projects, only one indicated that a patent resulted from the project. The EU's share of global patents has been decreasing, as incentives and (test) project sites outside of the EU have increased over the past years. In the EU, there is currently a greater need for the optimisation of ongoing developments and devices rather than the development of new ones.

This is also visible from the other impacts that the EU R&D funding had, such as knowledge development, knowledge transfer across the EU, and improvements of existing technologies. In general, EU funding supported the development of a European wide coordinated, unified and streamlined ocean sector, and had a positive impact on knowledge and education on ocean energy technologies throughout Europe, with many universities participating in EU or industry funded ocean projects and including ocean energy in their curricula. The EU also provided funding to several universities and companies from which spin-offs were created that are now active in the ocean sector. These spin-offs now also receive EU funding, which ensures continuity in the sector.

4 Technology development

One of the core objectives of R&D funding on RE technologies is to contribute to the development of the technology to make it cost competitive and allow for increased uptake of the technology. The impacts on technology development can be assessed technologically, or from an economic point of view, looking at the costs, performance and competitiveness of the technology. This section focuses on key indicators that assess technology development from an economic point of view: capex, opex and Levelised Cost of Energy (LCOE).

4.1 Capex

Capex (capital expenditure) refers to the initial investment costs of the ocean projects. Cost-reducing innovations can contribute to a downward trend in capex, which in turn can make the sector more cost competitive and allow for increased uptake of the technology. One of the main limitations of this indicator is that capex is highly location- and technology-specific and will thus vary between projects.

As no ocean plants are deployed at commercial scale yet (except for the La Rance tidal barrage that was built in 1966), capex estimations for ocean energy show very large variations, from EUR 2 000/kW to EUR 12 000/kW.[7] Estimations of capex for OTEC are typically higher at between EUR 3 000/kW and EUR 34 000/kW. The capex for ocean energy include civil and structural costs, mechanical equipment costs, balance of plant costs, electrical and I&C supply and installation, and development costs. For tidal energy, wave energy and OTEC, the largest cost component in the capex is mechanical equipment, followed by civil and structural costs.

The capex costs of ocean energy are on a decreasing trend (except for OTEC) as the industry now better understands how to build their foundations so they can resist harsh conditions, how and when to install them, how to build machines that produce more while decreasing the amount of materials used (after a phase when over-sizing was common as part of testing, the ocean energy industry is moving into an efficiency phase). This learning process is taking time, and the commercial competitiveness of the sector are often linked to a single technology or service provider. Thus, it will be a few years before ocean technology reaches the capex of wind (after the first-generation arrays, second-generation arrays will be needed before capex can be reduced). EU funding has directly contributed to several cost-reducing improvements, such as in the H2020 InToTidal and FP7 CORES project (see project spotlights below).

Project spotlight: InToTidal
The InToTidal project (H2020) project builds on the technology for tidal turbines developed by Tocardo International over the past 10 years. The objective of the project is to execute the last step of the development and demonstration of an integrated and generic solution for offshore tidal energy production, making it ready for successful commercial business application. The system was tested and demonstrated in this project, while the resulting system will be used for long term testing after the project.
Source: EC, 2018, Community Research and Development Information Service

[7] Estimations given in the NREL database, the REN21 reports (2012-2015), JRC (2015), ES/IEA (2015), IPCC (2011), SI Ocean (2014), Energy Technologies Institute (ETI, n.d.), and other academic reports (e.g. Segura et al., 2017).

Project spotlight: CORES

The CORES project (FP7) concentrated on the development of new concepts and components for power-take-off, control, moorings, risers, data acquisition and instrumentation based on floating Oscillating Water Column (OWC) systems. The components and concepts developed also has relevance to other floating device types. At the root of the CORES objectives was a wave-to-wire modelling toolbox that enabled developers to evaluate the effect of changes made in device components on performance and cost-effectiveness. The toolbox comprises a range of relevant numerical models, validated at bench-scale and then tested at sea. The main achievements of the CORES project include the development of a validated turbine design methodology and an improved air turbine design for OWCs. The air turbine is a key element in the power conversion chain as it is the primary converter of pneumatic power to mechanical power. The project researchers also worked on a robust electrical system, concentrating in particular on the power take-off system and they successfully developed new improved mooring design methods to improve device performance and reduce project costs.

Source: EC, 2018, Community Research and Development Information Service

4.2 Opex

Opex (operational expenditure) includes fixed and variable costs for operation and maintenance (O&M) of the plants. Similar to capex, cost-reducing innovations can contribute to a downward trend in opex, which in turn can make the sector more cost competitive. Opex is less location-specific than capex but not completely disconnected from it, and it can show large variations between sub-technologies. Only global figures were available for the opex.

As with capex, there is limited data available on the opex of ocean energy plants, as they are not yet operational on a commercial scale. Published estimates for average opex range from 1.6 EURct/kWh up to 40 EURct/kWh.[8] No estimates were found for salinity gradient technologies, which are the farthest from commercial deployment. Overall, due to the infancy of the sector, the opex is expected to be considerably higher than for more mature RE technologies. No cost trends can yet be determined.

4.3 LCOE

The Levelised Cost of Energy (LCOE) is an indicator to compare the project costs of different energy generation technologies.[9] Similar to capex and opex, cost-reducing innovations can contribute to a downward trend in LCOE, which in turn can make the technology more cost competitive. While LCOE is a relatively comprehensive measure of the technology’s costs, it does not include all the costs for delivering energy, such as ancillary services and transmission and distribution costs.

The LCOE of ocean technologies is very high and uncertain, particularly for OTEC, which has the lowest TRL, the LCOE estimations range from 5 to 75 EURct/kWh. Decreasing the LCOE will only be possible if more and larger projects are built and put in the water. For wave technologies, the very high LCOE highlights the technological barriers that are still present. Service vessels are not suited for a single device demonstration, which is one of the reasons for the high costs, others being the lack of adequate, affordable materials. EU funding is supporting several projects that develop technology

[8] Estimations given in the NREL database, ES/IEA (2015), IPCC (2011), SI Ocean (2014), Energy Technologies Institute (ETI, n.d.), and other academic reports such as Muralidharan, S. (2012).
[9] There are different ways of calculating the LCOE; the method applied here is explained in the methodology document.

evaluation protocols (e.g. FP7 EQUIMAR), design tools (e.g. DTOCEAN) and testing of specific components that help overcome these barriers.

Tidal technologies are moving towards a final design, which is the stage at which LCOE reduction becomes more important. EU funding has helped the sector move towards this final design and supports several demonstration projects. Supported by FP7 CLEARWATER and H2020 DEMOTIDE, a 4.5 MW tidal energy park has been installed and is currently being upscaled (see project spotlights below). For tidal technologies, the challenges now lie in the supply chain development and grid connection.[10]

Project spotlight: Direct Drive TT

The H2020-funded project Direct Drive Tidal Turbine (Direct Drive TT) delivered a feasibility study for Nova Innovation's innovative technology. This study proved that by eliminating the gearbox from the turbine drive train, direct drive technology can improve the output of the turbine, cutting operating costs and lifetime cost of tidal energy by over 20 %. The project provided Nova with a business case for the development of a direct drive turbine. This goal is being delivered in the Phase 2 SME Instrument Direct Drive Tidal Turbine (D2T2) project. The D2T2 turbine sits at the heart of Nova Innovation's business plan; all future Nova turbines will incorporate technology developed in this project. The sea testing of the D2T2 turbine should be completed in 2019, and the first commercial device deployment is planned for 2021. The market is still developing, but estimated sales are of 95 MW per year by 2030, based on the results of the feasibility study conducted during the Direct Drive TT project.

The project also influenced the tidal energy market in a broader sense. The emerging tidal energy market used to focus on building larger devices. The Direct Drive TT project was at the vanguard of a different business strategy, focused initially on commercialising small-scale devices before increasing device scale. This strategy is now gaining wider acceptance from other EU tidal energy technology developers, including companies such as Schottel, SME and Sabella.

More information on the project is available as a case study in the annex of this report.

Project spotlight: CLEARWATER

The FP7 CLEARWATER project supported the design and deployment of an open ocean 4.5 MW tidal energy farm in the Inner Sound in the Pentland Firth, off the Northern coast of Scotland, which is known as Meygen Phase 1A. The project demonstrated the technical and economic feasibility of a multi-turbine tidal energy array, an essential step to catalyse the development of commercial projects in the EU ocean energy industry. The Clearwater project aimed to provide a transition from high cost single turbine demonstration deployments of marine turbines to economically viable multi-hundred turbine arrays in oceans and managed water assets. The park has been generating electricity since November 2016.

The project will provide a number of step changes that aim to catalyse the European marine industry by:

- generating a targeted 10 000 MWh of clean energy to the European grid;

[10] Ecorys and Fraunhofer (2017), Study on Lessons for Ocean Energy Development.

- de-risking the environmental consenting process through novel monitoring methodologies to provide a holistic approach to monitoring;
- improving the efficiency of future ocean energy farms;
- reducing per MW costs by up to 20 % versus single unit via the application of advanced manufacturing processes.

Source: EC, 2018, Community Research and Development Information Service; SIMEC Atlantis Energy website (https://simecatlantis.com); Orkney Renewables website (http://www.orkneymarinerenewables.com); news articles on www.offshorewind.biz

Project spotlight: DEMOTIDE

The DEMOTIDE project (H2020) will design, build and operate a 4 x 1.5 MW (6 MW) turbine array at the MeyGen Phase 1B site, Pentland Firth, Scotland. The potential for build-out on the MeyGen site to 400 MW installed capacity, based on the available local high flow tidal resource, make this a site ripe for commercial exploitation. The project builds directly on the Meygen Phase 1A project, which involved the deployment of four 1.5 MW turbines to demonstrate that tidal array projects are commercially viable and technically feasible (see the project spotlight CLEARWATER). Phase 1B aims to significantly reduce the LCOE from tidal generation, after which Phase 1C aims to build 49 additional turbines of 73.5 MW in total.

Source: EC, 2018, Community Research and Development Information Service; SIMEC Atlantis Energy website (https://simecatlantis.com); Orkney Renewables website (http://www.orkneymarinerenewables.com); news articles on www.offshorewind.biz

4.4 Conclusions

As ocean technologies are still in research and demonstration phase, cost estimates of capex, opex and LCOE of plants are still very uncertain. Although the ocean energy plants still have a high capex, opex and LCOE, costs are on a decreasing trend and the industry progresses up the learning curve (except for OTEC, which still has a very low TRL). Thanks to R&D, the industry now has a better understanding of construction requirements and optimisation. As projects such as Direct Drive TT, CLEARWATER and DEMOTIDE show, EU R&D funding has contributed directly to these developments and has helped tidal technologies to successfully demonstrate the technology. It also supports wave technologies overcome technological barriers through various projects. Cost reductions are expected as R&D efforts continue.

5 Social, economic and environmental impacts

Public R&D funding for RE technologies is justified by several social, economic and environmental impacts. In this section we evaluate a range of indicators that provide insight into these impacts: installed capacity, annual generation, industry turnover, imports/exports, jobs and share of energy consumption.

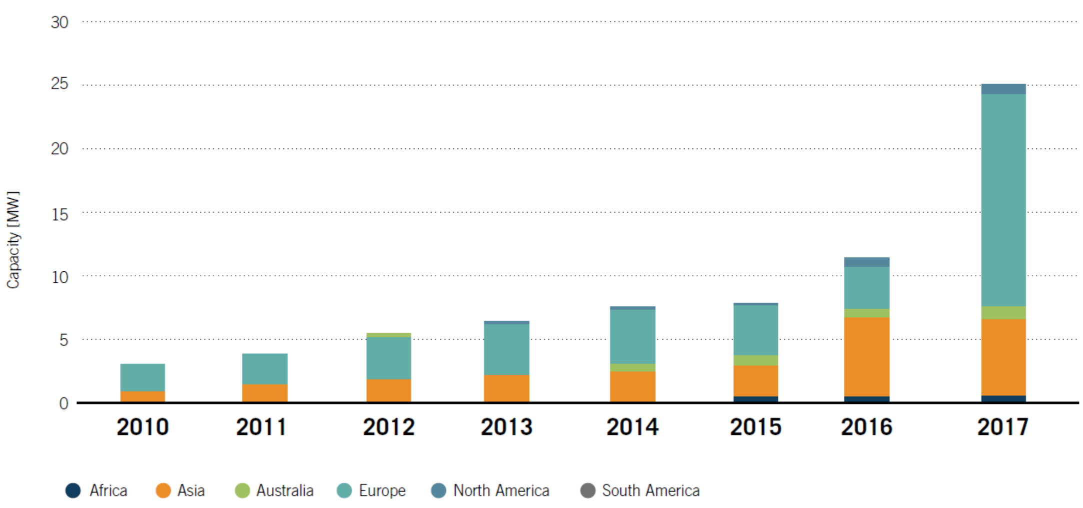
A direct link between these indicators and R&D funding is hard to establish, as the impact of R&D funding is confluent with numerous other factors that drive or prevent deployment. Still, the indicators presented in this section are relevant indicators to assess the evolution of the ocean energy sector over time.

5.1 Installed capacity

As installed capacities for RE technologies provide (near) carbon free energy that prevents the need for fossil fuel-based energy, they contribute to reducing greenhouse gas emissions and can be considered a measure of the environmental impacts. Installed capacity refers to the maximum installed generation capacity. This is expressed in MWe for electricity.

Europe is currently a global leader in ocean power, more than doubling its installed capacity in 2017.[11] The major tidal project behind this was the MeyGen/Inner Sound Phase 1A in the UK; while the major wave energy projects were the Sotenäs project in Sweden and Wello's Penguin prototype at the European Marine Energy Centre (EMEC).

Figure 5.1 Cumulated ocean energy capacity by location in 2010-2017 (tidal barrage not included)



Source: OES (2017)[12]

[11] OES (2017), Annual report: an overview of ocean energy activities in 2017
[12] OES (2017), Annual report: an overview of ocean energy activities in 2017

Overall, however, ocean energy deployments are taking place at a slower pace than expected. According to the targets set in 2009 in the different EU National Renewable Energy Action Plans, a combined tidal and wave energy capacity of 2250 MWe was expected by 2020.[13] It seems that actual capacity will stay below 15 % of this target. At the end of 2016, 14 MWe of ocean energy was installed[14] and at present no ocean energy plants have reached commercial scale yet.[15] High up-front costs and capital needs for first arrays, technological challenges relating to the harsh ocean environment, and regulatory challenges such as licencing are the main challenges in the sector and have delayed development.

Tidal current technologies are at demonstration phase and are deploying first arrays. According to Ocean Energy Europe (2017)[16], by the end of 2016, there were over 21 tidal turbines of over 100kW in demonstration (i.e. scaled devices or test devices for a short to medium period of time) in European waters totalling 13 MWe and construction was ongoing in several more sites. The first array of three 100 kWe turbines was installed by Nova Innovation in the Shetland islands (expected 6 turbines by 2019)[17], followed by four 1.5 MWe turbines in the Meygen project in the Pentland Firth, Scotland (see project spotlights in chapter 4). It is expected that each turbine will generate 4.4 GWh per year. The Nova Innovation project has received a H2020 SME grant[18]; while the Meygen project has received H2020 funding for its second phase, and has 398 MWe planned.[19] Tocardo has also installed a 1.25 MWe array in the Eastern Scheldt and a 300 kWe array at the Afsluitdijk. Further, Tocardo has received H2020 funding to develop an integrated solution for tidal energy. Tocardo has also supplied the turbines for the BlueTEC Texel Tidal platform (which received support from LIFE+).[20] OpenHydro also had several ongoing projects, but has been liquidated due to accumulated debt, and related projects have therefore been cancelled.

In late 2018, marine energy developer Minesto completed the offshore commissioning and test programme of its EU-funded 500 kWe Deep Green tidal device offshore Holyhead, North Wales, which aims to demonstrate the company’s first utility-scale system of its pioneering subsea kite technology. With support from the French government, HydroQuest and its equity partner CMN are planning to install a 1 MWe demonstration project at the Paimpol-Brehat in 2019.[21]

Wave energy projects are less advanced, as well as OTEC and salinity gradient technologies, for which pilot projects are being developed. According to Ocean Energy Europe (2017)[22], over the past years and up to the end of 2016, 13 wave energy devices of 100 kWe or bigger had been deployed at

[13] JRC (2015) 2014 JRC Ocean Energy Status Report
[14] JRC (2017) JRC Ocean Energy Status Report: 2016 Edition
[15] Tidal barrages are not taken into account. There is one tidal barrage plant in Europe: a 240 MW La Rance tidal barrage, located in north-west of France, which has been operational since 1966. It generates about 500 GWh per year. Tidal barrages are an older technology and do not receive R&D funding by the EU. It is unlikely that more tidal barrages will be created in Europe in the near future, even though the technology is ready and bankable. This is due to the negative environmental impacts of the technology. In the UK, a proposed tidal barrage project (the Severn barrage) has been rejected several times, due to the potential environmental effects that such a structure could have on the nearby ecosystem. In addition, the economic benefits of the project were not clear enough. Most recently, the Tidal Lagoon Swansea Bay, a 320 MW proposed project to build the world’s first tidal lagoon power plant in the UK, was rejected by the Government. The main reason given was the additional costs for the electricity consumers, compared to offshore wind and nuclear power projects between 2031 and 2050.
[16] https://www.oceanenergy-europe.eu/wp-content/uploads/2017/05/170228-Ocean-energy-spotlight-final.pdf
[17] See: https://www.novainnovation.com/bluemull-sound; http://grebeproject.eu/wp-content/uploads/2017/09/Tidal-Energy-Nova-innovation-Scotland.pdf; https://tethys.pnnl.gov/annex-iv-sites/nova-innovation-shetland-tiday-array-bluemull-sound
[18] In 2016, to develop a commercial demonstrator of Nova’s innovative direct drive tidal turbine technology (Phase 2 of Shetland Array) to develop a commercial demonstrator of Nova’s innovative direct drive tidal turbine technology
[19] https://www.andritz.com/hydro-en/hydronews/hy-hydro-news-30/hy-news-30-14-meygen-scotland-hydro; https://marineenergy.biz/2018/10/15/overhauled-meygen-turbine-up-for-redeployment/
[20] https://www.bluewater.com/wp-content/uploads/2014/06/Bluetec-LIFE-Laymans-report.pdf
[21] https://marineenergy.biz/2018/06/12/hydroquest-ocean-1mw-tidal-turbine-to-hit-the-water-in-spring-2019/
[22] https://www.oceanenergy-europe.eu/wp-content/uploads/2017/05/170228-Ocean-energy-spotlight-final.pdf

sea, totalling almost 5 MWe; and there are further projects under construction. For example ESB's Westwave in Ireland aims to develop 5 MWe of wave energy, supported by NER300 funding[23]; while Wello (the CEFOW project) aims to complete a 3 MWe array consisting of three devices (of which one has been deployed[24]) by 2020 with support of H2020 funding.[25] The Sotenäs project (Sweden) is also installed in the water with a capacity between 1 and 3 MWe, though the second phase has been cancelled. This project was connected to the grid, but not generating at the moment.[26] The company, Seabased, recently signed a number of contracts for wave energy developments in Ghana, Sri Lanka, the Canary Islands and in the Caribbean.[27] In general, there are still many issues that need to be addressed before these wave technologies can be deployed at commercial scale.

If wave technologies reach commercial scale, the impact could be much larger than that of tidal technologies, as the resource potential is much greater. The technical potential for tidal current capacity in Europe is estimated at 14 GW[28], or 48 TWh per year.[29] For wave, it is estimated that the potential wave energy capacity for the North-Eastern Atlantic including the North Sea is about 290 GW and deep water capacity of the European coast of the Mediterranean Sea 30 GW.[30] Technical potential for wave generation is estimated at 2,800 TWh per year in Western and Northern Europe; about 58 times larger than tidal.[31]

5.2 Annual generation

While installed capacity is a commonly used indicator to measure the progress in deploying RE technologies, it can be somewhat misleading due to differences in capacity factors. Annual generation includes the effects of these differences and is therefore a valuable indicator to complement the statistics on installed capacities.

Generation by ocean energy plants, which are still at pilot and demonstration scale, is close to zero. The JRC reported that three tidal energy converts (MeyGen, Andritz Hydro and Alstom) together generated over 10 GWh between 2013 and 2014.[32] Data on electricity generation from tidal and wave plants still varies, as the projects are still in progress. Last year, Meygen 1A project reported a generation peak of 700 MWh in August, when only two of the four turbines were operational.[33] This year, in only 5 months of being fully operational, it delivered more than 8 GWh to the grid.[34] Also recently, Scotrenewables reported their project FloTEC generated 3 GWh in its first year of testing.[35]

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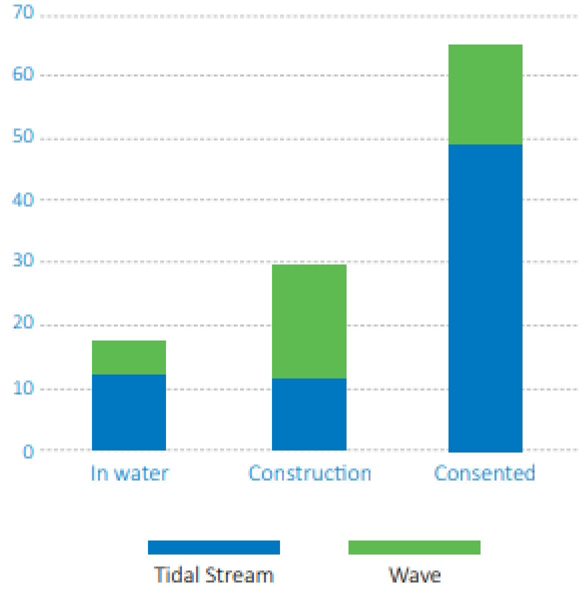
[23] https://www.esb.ie/tns/press-centre/2014/2014/07/08/4094; https://setis.ec.europa.eu/energy-research/project/converting-irelands-energy-potential-west-wave; https://www.irishtimes.com/news/environment/catching-the-wave-harnessing-ireland-s-water-power-1.3559960
[24] Wello Penguin device in Orkney, Scotland (deployed in 2012 thanks to EU funding, redeployed in 2017 after adjustments to the devices mooring system)
[25] https://www.oceanenergy-europe.eu/wp-content/uploads/2017/05/170228-Ocean-energy-spotlight-final.pdf; https://ec.europa.eu/inea/en/horizon-2020/projects/h2020-energy/ocean/cefow; http://www.emec.org.uk/about-us/wave-clients/wello-oy/cefow-clean-energy-from-ocean-waves/
[26] https://tethys.pnnl.gov/annex-iv-sites/soten%C3%A4s-project; https://www.wavehub.co.uk/latest-news/the-sotenaes-wave-energy-plant-grid-connected
[27] https://marineenergy.biz/2017/10/30/seabased-cancels-sotenas-wave-park-expansion-continues-rd/; https://marineenergy.biz/2018/05/22/seabased-rounds-up-e715k-crowdfunding-cash/
[28] IEA (2011) World Energy Outlook 2010
[29] IPCC (2011) IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation
[30] IEA-RETD (2011) Accelerating Deployment of Offshore Renewable Energy Technologies, cited in: Ecorys, Deltares, Oceanic (2012) Blue Growth: Scenarios and Drivers for Sustainable Growth from the Oceans, Seas and Coasts
[31] IPCC (2011) IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation
[32] JRC (2017) JRC Ocean Energy Status Report: 2016 Edition
[33] See: https://www.power-technology.com/features/talking-tidal-meygen-kicks-gear/
[34] From April 2018 to the end of August 2018. See: https://www.powermag.com/meygen-array-sets-global-records-for-harnessing-tidal-power/
[35] Scotrenewables, 2018, Press release: Scotrenewables tidal clocks record level of power generation. Published on August 22, 2018. See: http://www.scotrenewables.com/flotec/press-release-scotrenewables-tidal-clocks-record-level-of-power-generation/

As more first arrays and demonstration plans are being developed, more generation may follow in the coming years. According to Ocean Energy Europe, about 12 MWe in tidal stream and 17 MWe in wave technology was under construction at the end of 2016, with about 65 MWe more consented. The majority of these activities take place in Europe.

Figure 5.2 Wave and tidal energy projects in water, under construction and consented at end 2016 (MWe). Source: Ocean Energy Europe (2017), Ocean energy project spotlight Investing in tidal and wave energy[36]



5.3 Share of energy consumption

Share of energy consumption refers to the participation of ocean energy in the gross final electricity consumed. This indicator allows us to analyse the participation of the ocean sector in the overall target of increasing the share of energy from RES in the EU's gross final energy consumption.

The share of gross final electricity consumption from ocean energy is still negligible in the EU. Therefore, it is not surprising that electricity generation from ocean energy has the lowest share out of all RE technologies. More installations will need to be deployed for this share to rise.

5.4 Industry turnover and jobs

Industry turnover is the total amount invoiced from the market sales of goods and/or services supplied to third parties by all sellers in the ocean sector. Following the definition in EurObserv'ER, it focuses on the main economic activities of the supply chain including manufacturing, installation of equipment and operation and maintenance (O&M). A growing turnover indicates a growing market. Employment is an important indicator to understand the socio-economic impact of RE technology deployment.

EurObserv'ER does not have data on industry turnover in the ocean energy sector. The sector is still at R&D level, thus turnover figures are kept very confidential. EurObserv'ER does not have data on jobs either: the sector is still in its infancy, with only one commercial tidal plant operational. Other

[36] https://www.oceanenergy-europe.eu/wp-content/uploads/2017/05/170228-Ocean-energy-spotlight-final.pdf

sources have varying estimations. IRENA estimates global jobs in ocean technology to be around 1,000 in 2018[37]. This is lower than in 2017, for which IRENA reported 4,870 global ocean jobs, of which 723 ocean jobs in the UK and 324 in Spain (other countries were not available).[38] A study on the blue economy by DG MARE estimates that the EU ocean energy sector generates 1,350 direct jobs across Europe, with total employment in the sector at about 2,000 jobs.[39]

5.5 Conclusions

Ocean technologies are not deployed at commercial scale yet, and therefore only supply a very small amount of electricity to the grid. Industry turnover is kept confidential, and estimations on the number of jobs vary greatly. Ocean technologies will need to be developed further and deployed at commercial scale before they will have substantial social, economic and environmental impacts. With the support of R&D funding, further technological developments and understanding can bring the ocean industry to this level of maturity in the future.

[37] http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/May/IRENA_RE_Jobs_Annual_Review_2018.pdf
[38] https://www.irena.org/documentdownloads/publications/irena_re_jobs_annual_review_2017.pdf
[39] DG MARE (2018) – The 2018 annual economic report on EU blue economy

6 Conclusions

Between FP5 and H2020, the EU has taken a leading position in the research and development of ocean technologies, especially in tidal currents and wave power. The European Commission provided more funding than the four largest MS funders combined. Ocean is the only RE technology in which this is the case. The EU and its MS were also the first to provide R&D funding to ocean technologies and provide more than any other country in the world.

The funding has been effective in establishing and maintaining a leading academic position globally, with the EU authoring up to three times more publications than the USA and China. Interest in China is growing, but the number of publications is still far below that of the EU. The EU's share of global patents has been decreasing, as incentives and (test) project sites outside of the EU have increased over the past years. The focus in the EU is on optimising ongoing developments and devices rather than developing new ones. This is also visible from the other impacts that EU R&D funding has had, such as knowledge development and knowledge transfer across the EU, more focus on the technologies in universities, the creation of spin-offs, and improvements of existing technologies.

EU support enabled tidal and wave technologies to increase their TRL level from TRL 2-3 (proof of concept) to TRL 5-6 (demonstration in relevant environment). It supported research projects that have benefitted both tidal and wave technologies, by developing a series of technology evaluation protocols and design tools. It also allowed learnings by failure for both tidal and wave, which has helped understand the technologies better. For wave technologies specifically, EU support allowed a better understanding of the environment and enabled the testing of components and amongst others the Power Take Off (PTO), to gain in-depth knowledge and overcome the technological barriers that are still present. For tidal technologies, EU funding supported the testing and improving of components and turbines, and enabled the demonstration of integrated solutions for offshore tidal plants. Developments related to components need to be directed towards specific device development, so that demonstration projects will arise.

The EU is currently funding several demonstration projects. The tidal sector has progressed over the past years and now has the first tidal arrays in the water that generate electricity to the grid. This is an important step towards commercialisation. Technological drawbacks have slowed down developments for wave technologies in the past years, but there are wave devices being planned for the coming years that have a capacity between 0.5 and 5 MWe. In general, however, there are still many issues that need to be addressed before wave technologies can be deployed at commercial scale. High up-front costs and capital needs for first arrays, technological challenges relating to the harsh ocean environment, and regulatory challenges such as licencing are the main challenges in the sector.

Due to the infancy of the sector, the costs (capex, opex and LCOE) are very high and the ranges in values is still very broad. Nevertheless, the industry understands that if it wants to have a place in the energy mix, these values need to be similar to that of offshore wind. To get there, the sector will need large scale projects to gain a better understanding of the resources, the environment, and the behaviour of the devices. With the continued support of R&D funding, further technological developments and understanding can bring the ocean industry to this level of maturity.

Annex 5A - Case studies

Case study: EU-OEA

Author:	Fiona Buckley	Approver:	Rob Flynn
Project title:	EU-OEA (Ocean Energy Europe)		
Lead partner:	Peter Delf, 63, Rue d'Arlon, 1040 Bruxelles		
Project location*:	Brussels, Belgium		
Technology area/s:	Ocean energy		
Start and end date**:	November 2007 to October 2009		
Project cost:		EC funding:	EUR 445 120
Other funding sources:	Private funding from individuals		
Quantifiable outputs and impacts:	EU-OEA aimed to set up an association for the ocean energy sector. By this means they facilitated discussions between the European Commission and the whole of the ocean energy sector (Wave, Tidal, OTEC – Ocean Thermal Energy Conversion and Salinity Gradient). This enabled the European Commission to have a better understanding of the sector, have a single point of contact for the industry as well as get feedback from the industry on what the main concerns were.		
Further information:	Project website: http://oceanenergy-europe.eu/		

Project description

The aim of the EU-OEA project was to contribute and actively support implementation of activities of the Framework Programme FP6, analysis and dissemination of results, and definition of future activities, with a view to enable the ocean energy industry and the EU achieve its R&D strategic objectives.

The project was led by two independent individuals who were experts (one in renewables and the other in finances) and benefited the ocean energy sector by establishing a coherent representative body across the EU, and at EU level. Since then the EU-OEA - now renamed Ocean Energy Europe - has effectively promoted the ocean energy sector at EU and Member State levels, but also in international markets and the investor community. This has helped to generate a critical mass behind the ocean energy sector. The project has thus had a clear, long-term and tangible impact. Today, Ocean Energy Europe is the largest network of ocean energy professionals in the world with over 120 members.

Outputs and impacts

The outputs of the project were:

- an improved presence for the ocean energy industry in the EU's decision-making process;
- more efficient allocation of public funding, due to the presence of an industry consensus on the best path forward for the ocean energy industry;
- better knowledge sharing and networking across the ocean energy industry, thanks to the presence of a platform[40] which facilitates these processes.

The outputs were achieved by facilitating dialogue and discussions among the key stakeholders in the ocean energy sector, which includes the industry and research communities. This was done via conferences and workshops. Ocean Energy Europe still holds a yearly conference[41]. While the need for such dialogue and activities is clearly recognised and accepted by all stakeholders, public funding provided a catalyst to kick-start these processes.

The EU-OEA project has been of critical importance to the development of the ocean energy sector. Such bodies are needed by industry to build consensus on the optimal way forward. This process of reaching consensus has resulted in a more efficient allocation of public support for the ocean energy sector, so that support has a maximum impact. It has also provided the sector with a united voice on regulatory issues such as Maritime Spatial Planning, or the EU Emission Trading System (ETS).

EU-OEA/Ocean Energy Europe has promoted the benefits of ocean energy among decisions makers, in the EU and further afield. Furthermore, Ocean Energy Europe promotes the sector to the investment community. The results of this are the number of subsidies that the ocean sector has received following EU-OEA and the subsequent OEE.

Ocean Energy Europe (EU-OEA) also facilitated much needed networking and knowledge-sharing among the ocean energy industry, thereby generating economic activity and innovation in the sector. This was done by facilitating exchanges and discussions between the experts and actors in the sector via forums, conferences and meetings.

Today, Ocean Energy Europe is a cornerstone institution in the ocean energy sector, and in many ways, defines the sector itself and its direction. Its impact on the ocean energy community can thus not be understated: the EU-OEA/Energy Europe project significantly changed how the ocean energy sector operates and communicates to external stakeholders.

Outlook and commercial application of the outputs

The EU-OEA project continues to have an impact today through the work of Ocean Energy Europe. Ocean Energy Europe is largely funded by the ocean energy industry itself and has become a self-sustaining project.

[40] Project website: http://oceanenergy-europe.eu/
[41] https://www.oceanenergy-europe.eu/annual-event/oee-2018/

The role of EU funding

The project was funded under FP6. The EU contribution, which was also the total project cost, was EUR 445 120. The project funding helped to leverage further investment from the ocean energy industry, through uptake of membership in EU-OEA. The project allowed EU-OEA to provide a better service to the ocean energy industry, thus providing a more favourable value proposition for the industry. The project helped generate intangible benefits such as goodwill and an increased reputational perception.

Full project participant list

Organisation	Country	Type
Peter Delf	United Kingdom	Individual
Alla Weinstein	United States of America	Individual

Case study: Direct Drive TT

Author:	Fiona Buckley	**Approver:**	Pieter Goubert
Project title:	Direct Drive Tidal Turbine (Direct Drive TT)		
Lead partner:	Nova Innovation Ltd (Nova), 45 Timber Bush, Edinburgh, UK. EH6 6QH		
Project location:	Edinburgh, UK		
Technology area/s:	Ocean energy		
Start and end date:	October 2014 to March 2015		
Project cost:	EUR 71 429	**EC funding:**	EUR 50 000
Other funding sources:	In-kind contribution from Nova Innovation		
Quantifiable outputs and impacts:	1 spin-off project to develop a commercial demonstrator of the Direct Drive Tidal Turbine investigated in this feasibility study (the D2T2 project). Short-term impacts: - 7 direct, full-time-equivalent jobs at Nova associated with the D2T2 project; approximately 4 direct FTE jobs with suppliers to the D2T2 project; approximately 20 indirect jobs in the project supply chain; - two patent applications; - cutting the lifetime cost of energy of Nova tidal turbines by over 20 %. Long-term impact: - projected sales of over EUR 300 million per year by 2030 (450 tidal turbines) based on the business plan developed in the Direct Drive TT project.		
Further information:	Project website www.novainnovation.com/d2t2 (NB this site relates to the spin-off SMEI Phase 2 D2T2 project: the Direct Drive TT project does not have a website) Project Manager: Gavin McPherson, Head of Policy and Research at Nova Innovation Ltd. T +44 (0)131 241 2000 E gavin.mcpherson@novainnovation.com**Error! Hyperlink reference not valid.**		

Project description

Tidal energy offers clean, predictable, invisible power generation through seabed-mounted tidal turbines. Tidal energy is:

- **clean:** it produces zero carbon emissions in operation;
- **predictable**: tidal currents are highly predictable - minutes, weeks or years in advance;
- **invisible**: once deployed, turbines are out of sight and have minimal environmental impact.

With the first arrays recently deployed, the tidal energy sector is now 'coming of age' and poised for rapid growth over coming years.
Existing technologies for exploiting tidal energy resources are relatively unproven and expensive. Significant cost reduction and real-world operational experience are required to improve the reliability of turbines and bring costs down to the point where tidal power can compete with conventional forms of generation.

The *Direct Drive TT* project delivered a feasibility study for Nova's innovative direct drive tidal turbine. This study proved that by eliminating the gearbox from the turbine drive train, direct drive technology boosts the reliability, availability, efficiency and output of the turbine, cutting operating costs, and slashing the lifetime cost of tidal energy by over 20 %.

The project was driven by Nova as the sole participant and direct project beneficiary. It built on preliminary research by Nova that indicated a direct drive turbine would lower the lifetime cost of tidal energy, accelerating Nova's access to the global tidal energy market estimated by Nova to be worth EUR 82 billion.

The Direct Drive TT project provided Nova with a business case for the development of a direct drive turbine. Following successful testing of a small-scale prototype, the next crucial step was to demonstrate a commercial direct drive product. This goal is being delivered in the Phase 2 SME Instrument Direct Drive Tidal Turbine (D2T2) project). The D2T2 turbine sits at the heart of Nova Innovation's business plan; all future Nova turbines will incorporate technology developed in this project. The-sea testing of the D2T2 turbine should be completed in 2019, and the first commercial device deployment is planned for 2021.

Outputs and impacts

The output of this project was a feasibility study for Nova's direct drive tidal turbine. The results of this study confirmed the commercial and technical viability of the direct drive product.

Key project outputs:

- Confirmed that direct drive technology slashes the lifetime cost of energy by 20 % (work done since has increased this estimate to 30 %).
- Demonstrated a potential tidal energy market of 50 GW for the device, and a similar market for river deployments.
- Identified key market barriers, including: access to finance; availability of suitable sites; supply chain bottlenecks; development of industry standards; and supportive policy frameworks.
- New products: Nova's Direct Drive turbine
- Two patent applications have been submitted and further applications are in progress.

- Spin-offs: the D2T2 project Jobs: 7 direct, full-time-equivalent jobs at Nova associated with the D2T2 project; approximately 4 direct FTE jobs with suppliers to the D2T2 project; approximately 20 indirect jobs in the project supply chain.
- Installed capacity: the market is still developing, but estimated sales are of 95 MW per year by 2030. This estimation is based on devices based on the Direct Drive TT feasibility study.

Broader impacts:

- Phase 1 SME Instrument project encouraged Nova to engage with the H2020 programme. As a result, Nova is now involved in four ongoing H2020 projects, collaborating with leading EU academics and blue-chip industrial companies.
- The emerging tidal energy market had traditionally focused on building larger devices. The Direct Drive TT project was at the vanguard of a different business strategy, focused initially on commercialising small-scale devices before increasing device scale. This strategy is now gaining wider acceptance from other EU tidal energy technology developers, including companies such as Schottel, Minesto, SME and Sabella.
- The supply chain for the D2T2 project is serviced by European companies. The project is building the foundations for a future EU tidal industry that is able to service the European and global electricity markets.

By accelerating the development of the Direct Drive technology, EU funding was instrumental in achieving these outputs.

Outlook and commercial application of the outputs

The direct Drive TT study was instrumental to Nova's decision to continue developing the direct drive tidal turbine and led to the spin-off project: D2T2. This project is being funded by a EUR 2.25 million grant from the European Commission under phase 2 of H2020's SME Instrument programme.

The D2T2 project is designed to produce a commercial demonstrator of Nova's innovative direct drive tidal turbine technology. This will represent a milestone in the long-term commercialisation of tidal energy as a source of predicable renewable power. The first D2T2 turbines will be installed in 2021. Nova has two patents pending as part of the D2T2 project, with further patent applications underway.

The commercial potential of the D2T2 turbine is rooted in the business plan developed during the Direct Drive TT project. Nova estimates it will produce 95 MW of D2T2 turbines per year by 2030. This supports Nova's ambition to be one of the world's leading tidal energy developers.

The role of EU funding

The project received EUR 50 000 in funding from the European Union under the SME Instrument Phase 1 programme. EU funding amounted to 69 % of the total project costs; the remainder of the costs were met by Nova Innovation, and no additional private funding was required.

The conditions associated with this funding included delivering a final project report and maintaining record of expenditure (though no mandatory audit was required). Benefits of the SME Instrument programme include:

- business coaching opportunities from industry professionals;
- increased exposure to policy makers, potential partners and investors;

- a 'mark of quality' for potential investors and business partner;
- access to a wide range of EU business acceleration services;
- access to further SME Instrument funding under Phase 2.

This project gave Nova familiarity with EU the H2020 programme, which the team had previously and incorrectly) feared might be complex, burdensome and academically focused. However, the overhead involved with applying for and managing this grant was low, and this encouraged them to apply – in addition to excellent support and encouragement from the Enterprise Europe Network.

Overall, Phase 1 of the SME Instrument is an excellent way to engage companies with the EU R&D programme. Nova is now leading three H2020 projects with a total value of over EUR 27 million (D2T2, TiPA and EnFAIT). In addition, Nova is a partner on other EU projects – none of this would have happened without the Direct Drive TT project.

Full project participant list

Organisation	Country	Type
Nova Innovation Ltd (sole participant)	UK	Private company

Case study: SURGE

Author:	Fiona Buckley	**Approver:**	Christopher Ridgewell
Project title:	SURGE (Simple Underwater Generation of Renewable Energy)		
Lead partner:	Aw-Energy Oy - Vantaanpuistontie 31, 01730 Vantaa		
Project location:	Vantaa, Finland		
Technology area/s:	Ocean energy		
Start and end date:	May 2009 to April 2013		
Project cost:	EUR 5 373 000	**EC funding:**	EUR 2 997 000
Other funding sources:	Private investment AW-Energy		
Quantifiable outputs and impacts:	The aim of the project was to design, build and deploy at a fully exposed test site an array of WaveRoller wave energy converters and connect these to the national grid.		
Further information:	Project website https://cordis.europa.eu/project/rcn/92897_en.html Product Quality and Certification Manager Dr. Tuula Mäki at AW-ENERGY T +358 50 5398959 E tuula.maki@aw-energy.com		

Project description

The scope of the project was to design, build and deploy at a fully exposed test site an array of WaveRoller wave energy converters and connect these to the national grid. AW-Energy was the project coordinator and led the design construction and deployment activities.

Outlook and commercial application of the outputs

After the project completed the devices were modified based on learnings achieved during the project to further improve the technology and validate the design methodologies. For example, the panel was instrumented with strain gauges, redeployed in 2014 and the data recorded was used to validate the design methodology, which concluded in 2015. This ultimately led to third party certification for our next project SURGE2, the first wave energy converter to receive technology certification and design approval by a certification body. The SURGE2 project is also AW-Energy's First of a Kind (FOAK) product and forms part of the current solution that they are supplying to customers. Regarding patents, approximately 60 patents have been filed since the start of that project and all are in some way a result of what the company learned during SURGE.

Thus, the SURGE project has had a direct impact in demonstrating the technology to customers and forming a solid foundation for our design methodology. Although patents are useful, AW-Energy believes the third-party validation and certification that they received after and due to SURGE have a more direct contribution to their business goals.

The role of EU funding

Naturally the role of the EU funding was vital as the project would have been unlikely to happen without it. The project coordinator sees the role of the EU funding as a message and a statement as well: advancing and supporting wave energy was seen as an important step towards mostly renewable energy production and the technology itself as feasible and applicable.

Full project participant list

Organisation	Country	Type
AW Energy Oy	Finland	Private company
Municipiode Peniche	Portugal	Private company
InstitutoHidrográfico	Portugal	Academic
WaveEC/Offshore Renewables Centro de Energia Offshore Associacao	Portugal	Research institute
Estaleiros Navais de Peniche, S.A	Portugal	Private company
Eneolica Energias e Ambiente SA	Portugal	Private company
Bosch Rexroth AG	Germany	Private company

Annex 5B - Literature

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Annex 5C - List of EU-funded projects

Research projects focused on ocean technology only:

Acronym	Rcn	Project title	EC funding (euros)	Programme	Topic
BUTTERFLY	210663	Development and market uptake of innovative system to obtain electrical energy from ocean wave resources	49 157	H2020-EU.2.3.1.;H2020-EU.3.2.5.;H2020-EU.3.2.3.	SMEInst-08-2016-2017
OWEACS	72308	Ocean wave energy absorbing coastal structures	145 976	FP5-EESD	1.1.4.-3.
SEEWEC	75096	Sustainable Economically Efficient Wave Energy Converter	2 782 744	FP6-SUSTDEV	SUSTDEV-1.2.6
WAVE DRAGON MW	79799	Development and validation of technical and economic feasibility of a multi MW Wave Dragon offshore wave energy converter	2 878 325	FP6-SUSTDEV	SUSTDEV-1.2.6
WAVEGEN	75016	WAVE PUMP SUBMERGIBLE POWER GENERATOR	815 455	FP6-SME	SME-1
WAVESSG	75084	Full-scale demonstration of robust and high-efficiency wave energy converter	1 210 018	FP6-SUSTDEV	SUSTDEV-1.2.6
OCTTIC	207016	Open-Centre Tidal Turbine Industrial Capability	2 990 158	H2020-EU.3.;H2020-EU.2.	FTIPilot-01-2016
ALDA	86585	Demonstration plant of a tunnelled wave energy converter	1 748 846	FP6-SUSTDEV	SUSTDEV-1.1.1
AQUABUOY	86578	Aquabuoy demonstration offshore wave energy plant	1 761 703	FP6-SUSTDEV	SUSTDEV-1.1.1
AWS-MKII	86583	Deployment, monitoring and evaluation of a prototype advanced wave energy device (AWS)	2 563 910	FP6-SUSTDEV	SUSTDEV-1.1.1
BREAKWAVE	86580	Breakwave - OWC in breakwater douro	3 138 200	FP6-SUSTDEV	SUSTDEV-1.1.1
CA-OE	73951	Co-ordinated Action on Ocean Energy	1 969 395	FP6-SUSTDEV	SUSTDEV-1.2;SUSTDEV-1.2.6
CAPMIX	96071	Capacitive mixing as a novel principle for generation of clean renewable energy from salinity differences	2 603 409	FP7-ENERGY	ENERGY.2010.10.2-1
CEFOW	195136	Clean energy from ocean waves	17 040 517	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-03-2014
CLEARWATER	185364	CommerciaL Energy ARray for Widespread Acceleration of Tidal European Resources	7 754 882	FP7-ENERGY	ENERGY.2012.2.6.1
CORES	88274	Components for Ocean Renewable Energy Systems	3 850 158	FP7-ENERGY	ENERGY-2007-2.6-01
D2T2	207451	Direct Drive Tidal Turbine (D2T2) Accelerator project	2 250 266	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
DEMOTIDE	207512	DEMOnstration for Tidal Industry DErisking	19 958 716	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-03-2015
Direct Drive TT	194732	Feasibility study for an innovative direct drive tidal turbine	50 120	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
DTOCEAN	110303	Optimal Design Tools for Ocean Energy Arrays	4 210 995	FP7-ENERGY	ENERGY.2013.2.6.1
eForcis	205142	eForcis and BeForcis, Wave Energy Generators for marine buoys and devices.	50 000	H2020-EU.2.3.1.;H2020-EU.3.3.	SMEInst-09-2016-2017

Acronym	Rcn	Project title	EC funding (euros)	Programme	Topic
EnFAIT	209958	Enabling Future Arrays in Tidal	14 663 024	H2020-EU.3.3.2.	LCE-15-2016
EQUIMAR	88421	Equitable Testing and Evaluation of Marine Energy Extraction Devices in terms of Performance, Cost and Environmental Impact	4 453 350	FP7-ENERGY	ENERGY-2007-2.6-03
ETIP OCEAN	205421	European Technology and Innovation Platform for Ocean Energy	621 250	H2020-EU.3.3.3.;H2020-EU.3.3.2.	LCE-36-2016-2017
EU-OEA	86360	European ocean energy association	514 983	FP6-SUSTDEV	SUSTDEV-1;SUSTDEV-1.1.8
FFITT	211183	Fish Flow Innovations Tidal Turbine	49 157	H2020-EU.2.3.1.;H2020-EU.3.2.5.;H2020-EU.3.2.3.	SMEInst-08-2016-2017
FloTEC	199964	Floating Tidal Energy Commercialisation project (FloTEC)	9 782 380	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-03-2015
GEOWAVE	104953	Geotechnical design solutions for the offshore renewable wave energy industry	1 155 141	FP7-SME	SME-2011-1
INNOWAVE	197992	Maximising the technical and economic performance of real wave energy devices	804 637	H2020-EU.1.3.1.	MSCA-ITN-2015-EID
InToTidal	206075	Demonstration of Integrated Solution for offshore Tocardo Tidal power plants.	1 966 265	H2020-EU.3.;H2020-EU.2.	FTIPilot-01-2016
LABBUOY	60072	Economically efficient floating device for wave power conversion into electricity. part i: mathematical & physical model testing (LABBUOY)	695 209	FP5-EESD	1.1.4.-6.
MAGNETIDE	106347	Improved magnets for energy generation through advanced tidal technology	1 157 801	FP7-SME	SME-2011-1
MARVEL	209289	Novel MAterial and Process Design for ReVerse Electrodialysis-Water ELectrolysisEnergy System	140 313	H2020-EU.1.3.2.	MSCA-IF-2016
MoWE	210328	Mooring of floating wave energy converters: numerical simulation and uncertainty quantification	196 818	H2020-EU.1.3.2.	MSCA-IF-2016
NEREIDA MOWC	86572	Nereida MOWC: OWC integration in the new mutriku breakwater	962 069	FP6-SUSTDEV	SUSTDEV-1.1.1
OCEAN_2G	207910	Second Generation technologies in ocean Energy	1 877 609	H2020-EU.3.;H2020-EU.2.	FTIPilot-01-2016
OCEANERA-NET	111295	The coordination of national research activities of Member States and Associated States in the field of Ocean Energy (ERA-NET)	2 222 329	FP7-ENERGY	ENERGY.2013.10.1.3
OCEANERA-NET COFUND	207018	Ocean Energy ERA-NET Cofund	5 879 270	H2020-EU.3.3.3.;H2020-EU.3.3.2.	LCE-34-2016
OCTARRAY	210302	Scaling up to the Normandie Hydro Open-Centre Tidal Turbine Pilot Array	14 746 984	H2020-EU.3.3.2.	LCE-15-2016
OHT	210694	A hydraulic collection tower, with a novel energy storage device for wave energy arrays	49 157	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
OPERA	200240	Open Sea Operating Experience to Reduce Wave Energy Cost	5 741 264	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-02-2015
OpTiCA	208955	Optimisation of Tidal energy Converter Arrays	146 128	H2020-EU.1.3.2.	MSCA-IF-2016
POLYWEC	105863	New mechanisms and concepts for exploiting electroactive Polymers for Wave Energy Conversion	2 106 648	FP7-ENERGY	ENERGY.2012.10.2.1
PowerKite	199439	PowerKite - Power Take-Off System for a Subsea Tidal Kite	5 074 364	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-02-2015
PULSE STREAM 1200	94495	Full scale demonstration prototype tidal stream generator	8 851 238	FP7-ENERGY	ENERGY.2008.2.6.1
REAPOWER	96203	Reverse Electrodialysis Alternative Power Production	2 919 804	FP7-ENERGY	ENERGY.2010.10.2-1

Acronym	Rcn	Project title	EC funding (euros)	Programme	Topic
RED-Heat-to-Power	193740	Conversion of Low Grade Heat to Power through closed loop Reverse Electro-Dialysis	4 002 383	H2020-EU.3.3.5.	LCE-01-2014
SEA2GRID	98267	Grid connection of Wave Energy Converters: investigation on storage requirements and solutions	174 905	FP7-PEOPLE	FP7-PEOPLE-2010-IEF
SNAPPER	91915	The development of a novel rare-earth magnet based wave power conversion system - Snapper	1 092 593	FP7-SME	SME-1
STANDPOINT	94488	Standardisation of Point Absorber Wave Energy Convertors by Demonstration	5 632 669	FP7-ENERGY	ENERGY.2008.2.6.1
SUBPORT	211181	Subsea socket for offshore Platforms based on Tide turbines	49 157	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
SURGE	92897	Simple Underwater Generation of Renewable Energy	3 312 195	FP7-ENERGY	ENERGY.2008.2.6.1
TAOIDE	205865	Technology Advancement of Ocean energy devices through Innovative Development of Electrical systems to increase performance and reliability	3 237 774	H2020-EU.3.3.2.	LCE-07-2016-2017
TIDAL-EC	191798	Tidal Energy Converter Cost Reduction via Power Take Off Optimisation	1 043 498	FP7-SME	SME-2013-1
TidalHealth	196295	Health Condition Monitoring of Small Scale Tidal Generators Using Miniature Torque Sensors	50 125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
TIDALSENSE	107809	Development of a condition monitoring system for tidal stream generator structures	1 266 138	FP7-SME	SME-1
TidalSense Demo	102179	Demonstration of a Condition Monitoring System for Tidal Stream Generators	1 659 307	FP7-SME	SME-2011-3
TIDES	185360	Tidal Demonstration for Energy Scheme	8 065 489	FP7-ENERGY	ENERGY.2012.2.6.1
TIPA	205920	Tidal Turbine Power Take-Off Accelerator	4 401 565	H2020-EU.3.3.2.	LCE-07-2016-2017
WATEC	210382	Development of a novel wave tidal energy converter (WATEC) to lower renewable electricity generation costs.	49 157	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
WaveBoost	205867	Advanced Braking Module with Cyclic Energy Recovery System (CERS) for enhanced reliability and performance of Wave Energy Converters	3 988 744	H2020-EU.3.3.2.	LCE-07-2016-2017
WAVEDRAGON 1:4.5	70544	Sea testing and optimisation of power production on a scale 1: 4.5 test rig of the offshore wave energy converter wave dragon (WAVEDRAGON 1:4.5)	1 971 308	FP5-EESD	1.1.4.-5.
WAVEIMPACT	109401	Wave Farm Impacts and Design	100 240	FP7-PEOPLE	FP7-PEOPLE-2013-CIG
Wavepiston	196254	Low price wave energy conversion through force cancellation.	50 125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
WAVEPORT	94487	Demonstration & Deployment of a Commercial Scale Wave Energy Converter with an innovative Real Time Wave by Wave Tuning System	4 971 199	FP7-ENERGY	ENERGY.2008.2.6.1
WAVESTAR	86577	High-efficient, low-weight, pile-supported 500-kW wave energy converter	2 199 523	FP6-SUSTDEV	SUSTDEV-1.1.1
WAVETRAIN	73452	Research Training Network Towards Competitive Ocean Wave Energy	2 254 852	FP6-MOBILITY	MOBILITY-1.1
WAVETRAIN 2	88284	Initial Training Network for Wave Energy Research Professionals	3 995 306	FP7-PEOPLE	PEOPLE-2007-1-1-ITN
WETFEET	193803	Wave Energy Transition to Future by Evolution of Engineering and Technology	3 465 525	H2020-EU.3.3.5.	LCE-01-2014
No acronym	64052	Turbine efficiency project for swilling waterflows	29 387	FP5-EESD	1.1.4.-5.
No acronym	51821	Establishment of a European thematic network on wave energy (wave energy network)	794 568	FP5-EESD	1.1.4.-5.
No acronym	56427	Measurement of wave energy dissipation in perforated breakwaters	93 883	FP5-HUMAN POTENTIAL	

Research projects focused on ocean technology in combination with wind or hydro:

Acronym	Rcn	Project title	EC funding	Programme	Topic
ACORN	111007	Advanced Coatings for Offshore Renewable ENergy	1 044 124	FP7-SME	SME-2013-1
H2OCEAN	102016	Development of a wind-wave power open-sea platform equipped for hydrogen generation with support for multiple users of energy	4 630 318	FP7-TRANSPORT	OCEAN.2011-1
HEXATERRA	109873	The development of a modular 'stepping locomotion' system for installation on subsea trenching machines used for subsea energy cable burial	1 208 400	FP7-SME	SME-2013-1
ICONN	198515	European Industrial DoCtorate on Offshore WiNd and Wave ENergy	847 953	H2020-EU.1.3.1.	MSCA-ITN-2015-EID
MARINA PLATFORM	93425	Marine Renewable Integrated Application Platform	9 428 112	FP7-ENERGY	ENERGY.2009.2.9.1
MARINCOMP	110244	Novel Composite Materials and Processes for Offshore Renewable Energy	2 381 759	FP7-PEOPLE	FP7-PEOPLE-2013-IAPP
MARINERGI	207639	Marine Renewable Energy Research Infrastructure	1 966 067	H2020-EU.1.4.1.1.	INFRADEV-02-2016
MARINET	98372	Marine Renewables Infrastructure Network for Emerging Energy Technologies	9 450 610	FP7-INFRASTRUCTURES	INFRA-2010-1.1.23
MERMAID	101743	'Innovative Multi-purpose off-shore platforms: planning, Design and operation'	5 609 878	FP7-TRANSPORT	OCEAN.2011-1
OceaNET	109180	OceaNET	3 446 918	FP7-PEOPLE	FP7-PEOPLE-2013-ITN
ORECCA	94058	Off-shore Renewable Energy Conversion platforms – Coordination Action	1 731 134	FP7-ENERGY	ENERGY.2009.2.9.2
PLENOSE	109725	LARGE MULTIPURPOSE PLATFORMS FOR EXPLOITING RENEWABLE ENERGY IN OPEN SEAS	282 075	FP7-PEOPLE	FP7-PEOPLE-2013-IRSES
POSEIDON	197564	Market maturation of Floating Power Plant's Floating Wind- Wave- Energy Device	1 147 010	H2020-EU.2.3.1.; H2020-EU.3.3.	SIE-01-2014
RiCORE	194433	Risk Based Consenting of Offshore Renewable Energy Projects	1 397 016	H2020-EU.3.3.7.; H2020-EU.3.3.2.4.; H2020-EU.3.3.2.2.; H2020-EU.3.3.2.1.	LCE-04-2014
SAFS	209673	Development of screw anchors for floating Marine Renewable Energy system arrays incorporating anchor sharing	192 158	H2020-EU.1.3.2.	MSCA-IF-2016
SEAMETEC	194749	Smart Efficient Affordable Marine Energy Technology Exploitation using Composites	50 120	H2020-EU.2.3.1.; H2020-EU.3.3.	SIE-01-2014-1
UPWAVE	200258	Demonstration of a 1-MW wave energy converter integrated in an offshore wind turbine farm	20 722 490	H2020-EU.3.3.2.4.; H2020-EU.3.3.2.2.; H2020-EU.3.; H2020-EU.3.3.; H2020-EU.3.3.2.1.; H2020-EU.3.3.2.	LCE-03-2015
WETMATE	106010	WETMATE – a 33 kV Subsea Wet-Mateable Connector for Offshore Renewable Energy	1 235 224	FP7-SME	SME-2012-1
AQUAGEN	97520	Development of cost-effective, water-based power take-off system for marine energy applications	1 823 916	FP7-SME	SME-1
MERIKA	111362	Marine Energy Research Innovation and Knowledge Accelerator	3 959 479	FP7-REGPOT	REGPOT-2012-2013-1

Annex 6

Technology Sector Report Bioenergy

(Deliverable D2.6)

Authors:
Onne Hoogland (Trinomics)
Elske Veenstra (Trinomics)
Perla C. Torres Vega (Trinomics)
Heidi Saastamoinen (VTT)
Janne Kärki (VTT)

Trinomics

1 Introduction

This report is one in a series of eight technology reports for the study *Impacts of EU actions supporting the development of renewable energy (RE) technologies*, prepared for the European Commission. The report has two objectives: 1) describing how EU research and development (R&D) funding for bioenergy technologies has impacted the bioenergy sector in the EU, and 2) describing more broadly the development of the bioenergy sector to which the EU R&D funding has contributed. It is based on a compilation of data from several databases, a questionnaire sent to coordinators of EU-funded R&D projects, case studies, interviews and literature research. The methodology applied for this study is documented in a separate deliverable.[1] Where relevant, limitations and assumptions are mentioned throughout this report.

Bioenergy is energy derived from organic matter, particularly biomass and/or renewable waste, that can be used for heating, cooling, transport and electricity-generation. The conversion of biomass and renewable waste to the final energy products can follow many routes. Starting from biomass harvesting, transportation and pre-treatment of biomass fuel, including conversion into intermediate bioenergy carriers, followed by bioenergy production processes such as combustion, gasification, and liquefaction.

Bioenergy technologies can be further subclassified into thermochemical and biochemical processes. Common thermochemical conversion technologies include biomass-fired heat boilers and combined heat and power plants (CHP). In biochemical conversion, fuel is produced by means of biological transformations such as digestion or fermentation.

In addition to these technologies, the scope of this sector report also covers projects related to improvements in the industrial biorefinery processes and to biogas technologies. Liquid biofuels are treated in separate sector report (biofuels) and are therefore not treated in this report. Waste-to-energy projects are, for the most part, also excluded from this report unless they explicitly refer to the conversion of solely organic/renewable waste.

Bioenergy includes several conversion pathways (e.g. combustion, gasification and pyrolysis) and each has various sub-technologies. In addition, fuel procurement is a central part of bioenergy and more efficient and productive supply chains for biomass have been developed and implemented.

The technologies used for combustion of biomass are mature. While there has been no single breakthrough in biomass combustion in this century, biomass boilers have become more efficient, more flexible and their environmental performance has improved. For fluidised bed boilers, the main technological advances have been related to increasing boiler capacities and development of solutions that enable the use of more challenging fuels - such as agro biomass - without compromising the efficiency or the lifetime of the boiler components. For biomass used in pulverised coal-fired boilers, various co-firing concepts using biomass have been implemented and commercialised during the last twenty years. Due to the ever more stringent emissions regulations, more efficient systems have been introduced to prevent air pollution. Flue gas condensers (or scrubbers), which improve the boiler

[1] Trinomics (2018) - Study on impacts of EU actions supporting the development of renewable energy technologies – Literature review and methodology (Deliverables D1.1 and D1.2)

efficiency and simultaneously reduce emissions, have become more popular in biomass boilers in recent years.

Different power and heat production systems based on gasification technologies have been developed during the last decades. Combustion of gasified low-quality biomass and wastes in large utility boilers has recently become a commercially available alternative and a few units have been built. Several pulp mills have also adopted bark gasifiers to displace natural gas and/or oil use in lime kilns. A novel high-efficiency gasification-based waste-to-energy solution, in which the gas is cleaned up before combustion, has also been demonstrated on commercial scale recently. Various small gasifiers coupled to internal combustion engines are commercially available for small-scale production of power and heat from high-quality wood chips. However, their feedstock specifications are still very restrictive and their overall efficiency is low.

Various biomass pre-treatment methods have also been in the research focus for the last decade. The aim of the pre-treatment is typically either to enable the use of biomass in new applications or improve their compatibility for the current use. For example, torrefied and steam exploded pellets have been developed to increase the suitability of biomass for pulverised fuel combustion and to improve their storing and transport characteristics compared to traditional wood pellets. Biomass can also be converted into a liquid form via pyrolysis. Production and combustion of biomass fast pyrolysis oil has been recently demonstrated at industrial scale after intensive R&D efforts. Although pyrolysis oil is completely different from petroleum oil, it has been shown to be a suitable replacement for heavy fuel oil in boilers provided that the differences in properties are taken into account. Although these technologies can be considered commercial, we have not yet seen them penetrate the market widely.

R&D has also focused on integrating bioenergy with other concepts and technologies, like renewable hybrids with bioenergy and intermittent renewable energy (e.g. solar power). In addition, R&D on the integration of biomass-fired boilers with carbon capture and storage will be essential in the future to limit global warming to less than 2 °C. Finally, R&D on finding the best value for biomass is increasingly supported, with biomass for energy generation featuring as one of multiple potential uses of biomass.

2 Historical R&D funding

2.1 EU R&D funding

2.1.1 Evolution over time

The European Commission has supported bioenergy technologies with close to EUR 600 million during FP5-7 and H2020 allocated to over 280 projects. Another EUR 87 million was provided to projects that focused on combinations of bioenergy and other RE technologies (see Table 2.1). This makes bioenergy the second largest recipient of EU R&D funding, after solar PV.

Table 2.1 EU funding per framework programme (1998 to mid-March 2018, 2016 million euros)

	Bioenergy		Bioenergy and other renewable energy sources	
Framework programme	EU funding	Number of projects	EU funding	Number of projects
FP5	149	92	13	6
FP6	170	45	37	6
FP7	192	78	27	7
Horizon 2020 (H2020) *(data available up to mid-March 2018)*	86	67	10	4
Total EU funding	**597**	**282**	**87**	**23**

Source: CORDIS (2018)
Note: Funding includes all funds made available through the Framework Programmes. It is not limited to the energy challenges but also includes funding through other programmes/instruments such as the SME instrument.
H2020 includes all projects awarded and registered in CORDIS up to mid-March 2018. As H2020 runs from 2014 to 2020, not all funding had been awarded at this point.

2.1.2 Evolution of research topics

Many bioenergy sub-technologies have been supported by EU R&D funding. The majority of funding and projects were for research on combustion (see Figure 2.1 and Figure 2.2). Particularly under FP5 and FP6, combustion was the main topic of EU-funded research in bioenergy. Combustion then became a mature technology so research was primarily driven by the industry and only a limited number of calls were made for new projects on combustion in the most recent EU FPs.

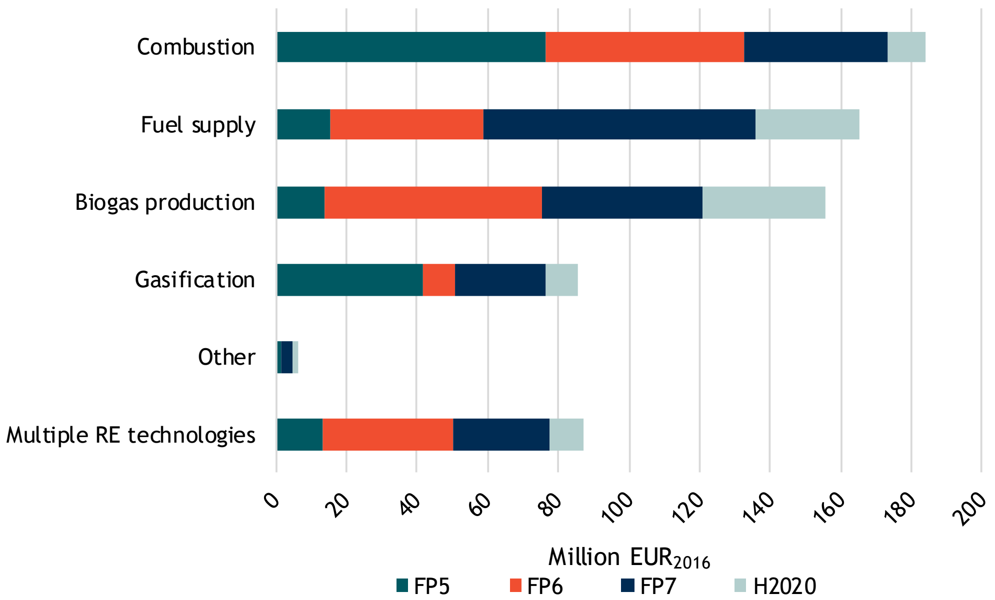
Fuel supply has been the main recipient of EU funding since FP7. This has been due to the increased appreciation that fuel supply accounts for half of the costs in bioenergy production and that sustainable biomass supply is limited. An example of a fuel supply project (S2Biom) is provided in the 'project spotlight' box at the end of this section.

Biogas production also received a large share of the EU funding, particularly under FP6. At this time, there was a boom in biogas projects, because a good feed-in tariff in Germany supported new biogas installations. Nowadays, biogas is considered a mature technology and research is now focused on the role of biogas in the energy system, including for example, in supporting intermittent energy sources.

Gasification technologies have also been a major receiver of EU funding, especially during FP5. Gasification followed a similar development as combustion, with large funding initially thanks to its closeness to the market and reduced funding in later FPs once the technology was commercially available. It should be noted that part of the recent funding for gasification is excluded from this analysis as it is treated in a separate report on biofuels. So, the actual decrease in funding is not as steep as presented here.

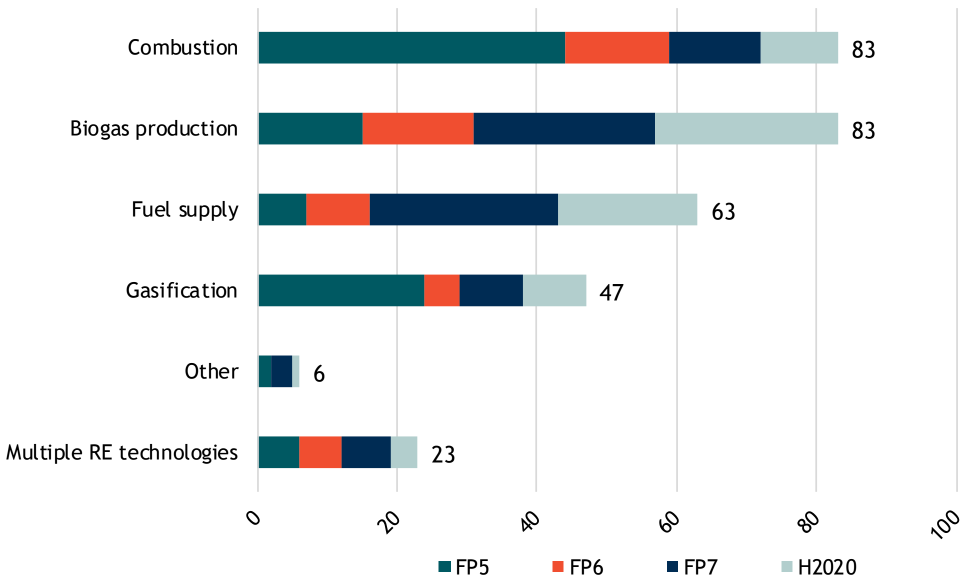
The category of projects 'multiple RE technologies' includes other noteworthy topics such as system integration. Within these projects other avenues for the use of bioenergy in combination with other RE technologies are being explored, for instance as a flexible component in a variable renewable energy dominated energy system, as a storage for intermittent energy production and for combined production of heat, power and transportation fuels. The recently started FLEXCHX project is an example of such a project (see project spotlight box at the end of this section).

Figure 2.1 EU funding per sub-technology/area (million euro$_{2016}$)



Source: CORDIS (2018)
The area 'multiple RE technologies' includes projects in which bioenergy is one of multiple RE technologies.

Figure 2.2 Number of projects per sub-technology/area



Source: CORDIS (2018)
The area 'multiple RE technologies' includes projects in which bioenergy is one of multiple RE technologies.

Project spotlight: S2Biom

S2Biom is a project funded under FP7 and ran from 2013 to 2016. The main output of the project was an extensive and validated data set of biomass characteristics and conversion technologies in the European region. 37 countries were analysed during the project and across fifty (50) lignocellulosic feedstock types from forestry, agriculture and wastes were covered. An important output of the project is that all the data sets are available publicly via a digitalised user friendly S2Biom Toolset intended to aid research, industry and policy makers in their work. With the Toolset, the project produced a new methodology to find where certain biomass can be found, what is the sustainable potential of the biomass for 2030, how much biomass is available in each region and how much it costs.

Source: Interview of the S2Biom project coordinator Dr. Calliope Panoutsou; http://www.s2biom.eu/images/Publications/D10.16_S2Biom_Guidelines_Final.pdf

Project spotlight: FLEXCHX

Recent H2020 projects such as FLEXCHX from 2018 to 2021 aim to more system integrated development. The EU funding will contribute to development of bioenergy hybrids which can be used as a cost-effective solution to tackle challenges of new European energy mix such as seasonal production variation, decarbonisation of transport sector and need for effective utilisation of well-established heating networks and existing combined heat and power plants. The processes developed in FLEXCHX integrate solar driven water electrolysis to biomass gasification and synthesis to produce power, heat and transport fuels from renewable energy sources.

Sources: http://www.flexchx.eu/

2.1.3 Top recipients

The top 10 recipients of EU funding in bioenergy technologies include five research institutes, three universities and two private companies (see Table 2.2). These organisations have received 14 % of the EU funding in most recent years (2008 to early 2018), illustrating that bioenergy is a field of research where funding is highly dispersed, compared to other RE sectors where the top 10 accounts for much higher shares of the total funding.[2] This is also visible when considering that only two recipients In the bioenergy sector managed to attract more than EUR 5 million of EU funding in recent years. This is very low compared to sectors such as solar PV, biofuels, and wind where 19, 10 and 9 organisations, respectively, attracted funding in excess of EUR 5 million, and also lower than in smaller sectors such as ocean, geothermal and solar thermal.

As a result, the composition of the top 10 organisations for bioenergy does not provide as much insight as in other sectors. Based on the top 10, it seems that the majority of the funding flows to universities and research institutes and that the participation of the private sector is limited. But when looking further down the list of recipients, more private sector participants can be found: Mantex (#16), Homebiogas (#17) and Biomass Technology Group (#19). Overall, EU R&D in the bioenergy sector has a medium level of private sector involvement compared to the other RE sectors studied for this project.

[2] In RE sectors such as ocean (44%), geothermal (53%) and hydro (71%), the top 10 organisations attract a relatively large share of the total funding. For bioenergy (14%), solar PV (25%), wind (26%), biofuels (31%) and solar thermal (32%), the top 10 organisations attract much lower shares of the total funding available.

Table 2.2 Top 10 recipients of EU funding by organisation (2008 to mid-March 2018, in 2016 euros)

Rank	Organisation	Type of organisation	Funding
1	VTT Technical Research Centre of Finland	Research institute	5 364 880
2	Wageningen University	Research institute	5 237 362
3	Universita degli Studi di Foggia	University	3 735 153
4	National University of Ireland, Galway	University	3 149 778
5	Stichting Energieonderzoek Centrum Nederland (ECN)	Research institute	2 750 374
6	DBFZ Deutsches Biomasseforschungszentrum Gemeinnuetzige GmbH	Research institute	2 706 523
7	Sveriges Lantbruksuniversitet	University	2 507 876
8	Bios Bioenergiesysteme GmbH	Engineering firm	2 273 804
9	Lindhurst Engineering Limited	Engineering firm	2 143 289
10	Institut Technologique FCBA	Research institute	1 999 179

Source: CORDIS (2018)
The source data covered H2020 funding and FP7 funding from 2008, which includes 38 % of total funding for bioenergy identified in section 2.1.1. No data was available for recipients of FP5, FP6 and part of the FP7 funding. Projects under 'multiple RE technologies' are not included in this table.

The main recipients of EU funding in terms of countries are Germany, Italy and the Netherlands (see Table 2.3). These countries received 33 % of the total EU funding available for bioenergy, with German organisations in particular, receiving a substantial share of the funding.

Table 2.3 Top 10 recipients of EU funding by country (2008 to mid-March 2018, in 2016 euros)

Rank	Country	Funding
1	Germany	33 339 197
2	Italy	23 583 225
3	Netherlands	18 033 146
4	Finland	17 992 253
5	United Kingdom	16 972 952
6	Spain	16 907 833
7	Austria	13 935 146
8	Sweden	13 105 870
9	France	12 628 903
10	Belgium	10 436 407

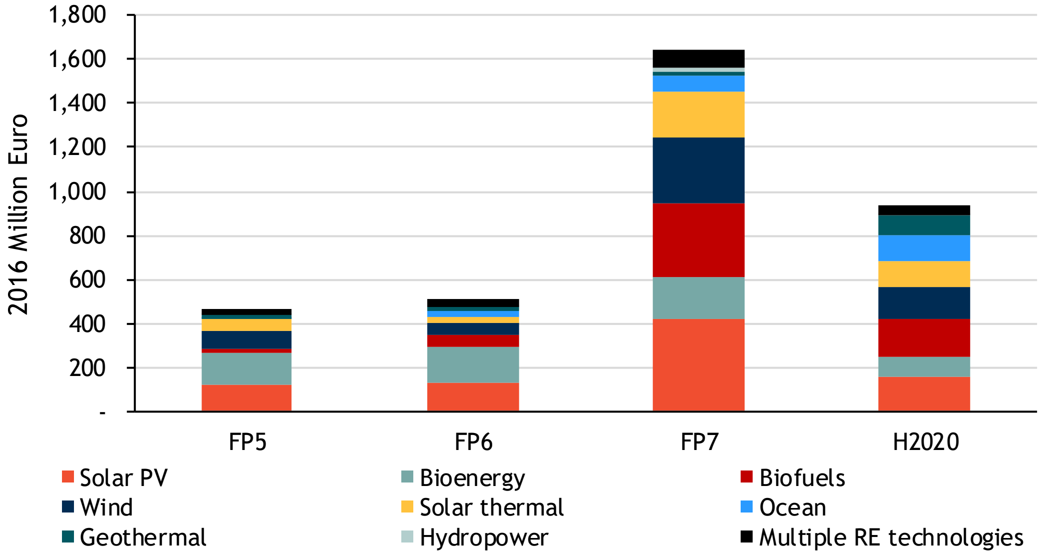
Source: CORDIS (2018)
The source data covered H2020 funding and FP7 funding from 2008, which includes 38 % of total funding for bioenergy identified in section 2.1.1. No data was available for recipients of FP5, FP6 and part of the FP7 funding. Projects under 'multiple RE technologies' are not included in this table.

2.1.4 Share of total RE technology funding

Bioenergy projects received 17 % of the EUR 3,6 billion awarded to all RE technologies through the FP5, FP6, FP7 and H2020 programmes. In FP5, it received 32 % of total funding and in FP6 33 %. Bioenergy's share reduced in the subsequent programmes, in FP7 projects it accounted for 12 % of the funding and in H2020 it reduced further to 9 %. Taking all these funding programmes into account, bioenergy was the second largest recipient of EU funding, ranking behind solar PV and slightly ahead of biofuels and wind energy.

The high share of bioenergy projects funded in the earlier FPs can be explained by the maturity of the technology. At that time, bioenergy was much more mature than technologies such as wind and solar PV and was deployed at a much larger scale. As a consequence, the technology received a relatively high level of support through FP5 and FP6. From FP7 onwards, the discussions about the sustainable limits of bioenergy production and its scalability intensified[3]. Furthermore, its short-term impact on emission reductions was questioned[4] and political uncertainty related to future sustainability criteria existed, while other RE technologies advanced rapidly. This resulted in a reduced focus on bioenergy in the EU FPs compared to other RE technologies. Nevertheless, it should be kept in mind that the funding for bioenergy in FP7 is still higher than in FP5 or FP6 and that the H2020 funding so far (approximately halfway) is already more than half the funding of FP5 and FP6. Hence, the R&D funding for bioenergy did not reduce in absolute terms.

Figure 2.3 Share of funding for each technology sector in proportion to overall funding (H2020 only up to mid-March 2018)



Source: CORDIS (2018)
The area 'multiple RE technologies' includes projects that combine multiple RE technologies.

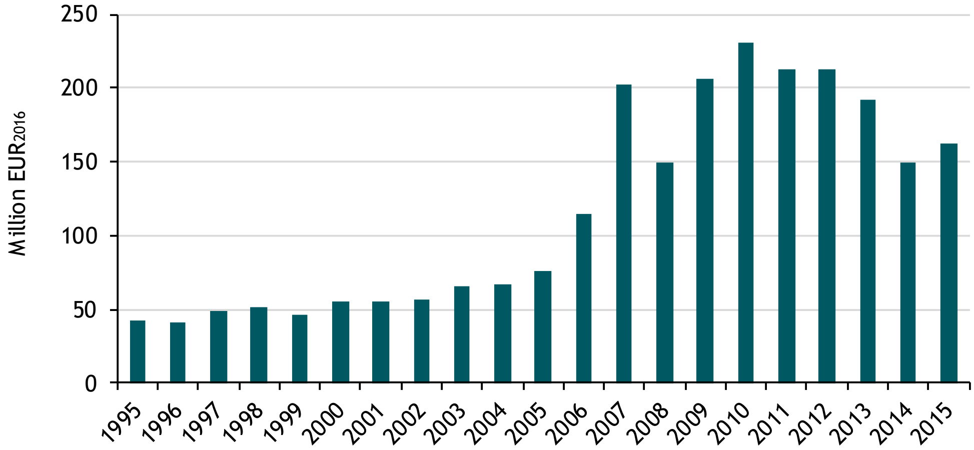
2.2 Member State R&D funding

2.2.1 *Evolution over time*

Annual R&D funding by Member States (MS) increased after 2005, from EUR 55 million on average between 1995 and 2005 to EUR 183 million on average between 2006 and 2015 (see Figure 2.4).This is 5 times as high as the average annual EU funding between 2006 and 2015 (EUR 37 million). MS R&D funding peaked in 2010, after which there has been a decreasing trend.

[3] See for instance the Sustainability Criteria in Renewable Energy Directive 2009/28/EC and the Report from the commission to the Council and the European Parliament on sustainability requirements for use of solid and gaseous biomass sources in electricity, heating and cooling. 2010.
[4] See for instance http://www.ieabioenergy.com/iea-publications/faq/woodybiomass/biogenic-co2/

Figure 2.4 Annual MS R&D funding in the EU for bioenergy



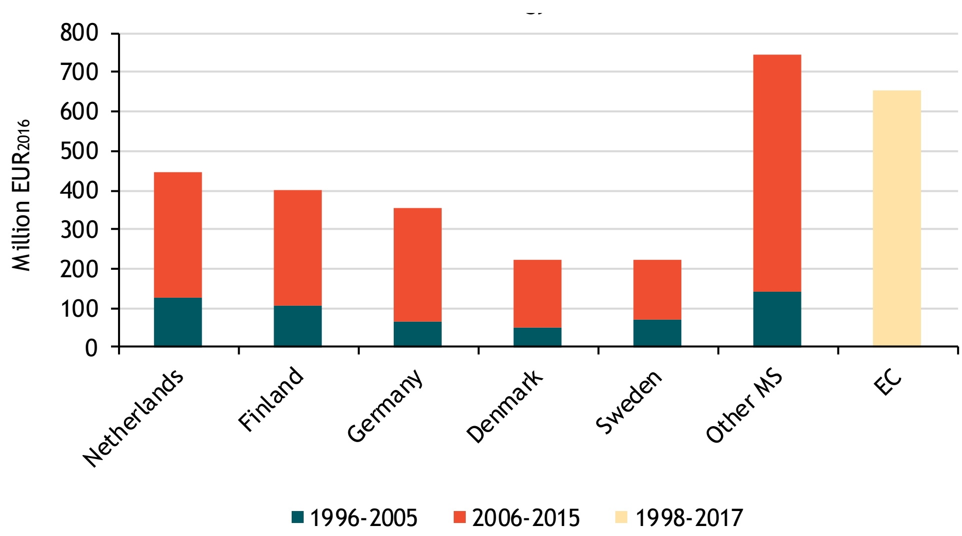
Source: Based on data from OECD/IEA (2018).
Note: Data for 20 EU countries was available in this source: The EU15 plus Czech Republic, Estonia, Hungary, Poland, Slovakia from the New Member States (NMS-13). Data from the source's larger category 'biofuels', was grouped according the definition of bioenergy in this study: bioenergy data includes sub-categories 'solid biofuels', 'biogases' and 'applications for heat and electricity'. Budgets from the unallocated categories 'Other biofuels' and 'Unallocated biofuels' that were higher than 1 million EUR were split between biofuels and bioenergy technologies using a 5-year ratio of the historic budgets of the respective MS. When no historic ratio was found for a MS, the average EU ratio was used to allocate the budgets. Data from the sub-categories 'solid biofuels', 'biogases' and 'applications for heat and electricity' was missing for all MS for the period 1995-2003, with the exception of Czech Republic and Finland (data was missing from 1995 to 2002), as well as France (data was missing from 1995 to 2001). Data of those sub-categories was also missing for the United Kingdom (on years 2003-2005, 2008, and 2010-2012), Italy (during years 2010- 2015), Poland (all the years in the dataset).During those years the MS' budgets derived solely from unallocated funding.

2.2.2 Largest MS funders

The largest funders of R&D for bioenergy are the Netherlands, Finland, Germany, Denmark and Sweden (see Figure 2.5). Together they have provided 69 % of total MS funding. All MS provided significantly higher funding to bioenergy during the period 2005-2015 than in the period 1995-2004. EC funding has been a considerable source of funding, higher than the funds available from any individual MS.

The large funds available in Finland and Sweden can be explained by the large availability of biomass in these countries. For the Netherlands, bioenergy plays an important role in meeting the country's renewable energy targets, which are for a substantial part fulfilled by co-firing of imported biomass.

Figure 2.5 Bioenergy R&D budgets of the main Member States (1996-2015) and the EC (1998-2017)



Source: Own elaboration based on data from OECD iLibrary and CORDIS (2018)

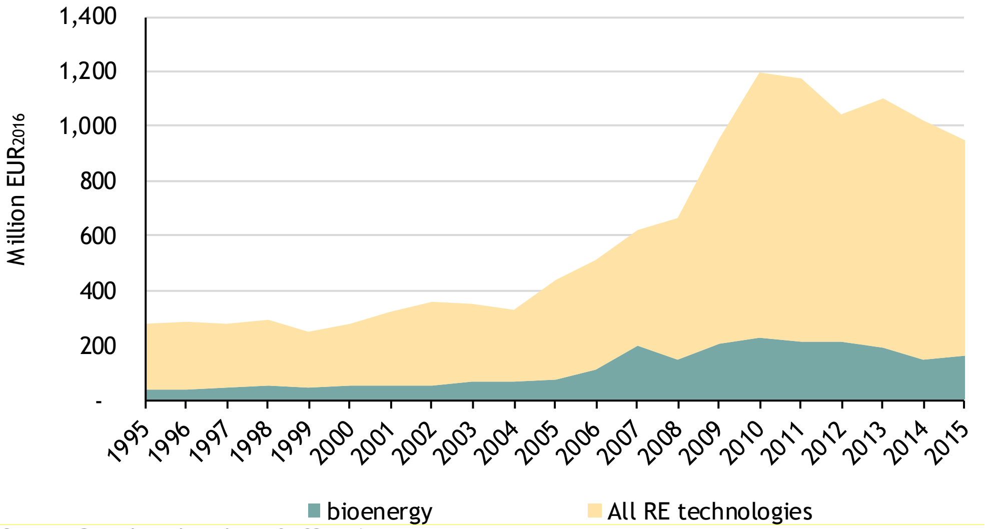
Note: National budgets for 2016 were excluded from the analysis because they are early estimates and lack reliability/coverage. EC funding includes projects in which bioenergy is one of multiple RE technologies. MS R&D funding data from the sub-categories 'solid biofuels', 'biogases' and 'applications for heat and electricity' was missing for all MS for the period 1995-2003, with the exception of Czech Republic and Finland (data was missing from 1995 to 2002), as well as France (data was missing from 1995 to 2001). Data of those sub-categories was also missing for the United Kingdom (on years 2003-2005, 2008, and 2010-2012), Italy (during years 2010- 2015), Poland (all the years in the dataset). During those years the MS' budgets derived solely from unallocated funding.
Note: Time window of comparison between MS and EC funding is shifted 2 years due to data availability of MS budgets for the scope of analysis (FP5-H2020).

2.2.3 Comparison of total RE technology funding

In the period of 1995 to 2015, Member States allocated 19 % of their national R&D funding for RE technologies to bioenergy. From 2006 to 2009, the share of bioenergy increased, with shares between 22 % and 33 %. From 2010 onwards, the share started to decrease (see Figure 2.6). The decline can be explained partly with maturity of technologies, especially regarding biomass combustion processes[5]. Additionally, there has been growing interest in non-energy uses of biomass feedstock meaning that some R&D funding of biomass related activities has been allocated to funding categories that are outside the scope of this analysis.

In absolute terms, MS R&D budgets for bioenergy have increased considerably, growing from EUR 42 million in earlier years to more than EUR 163 million in recent years. Overall, bioenergy has been one of the key RE technologies supported by Member States, ranking only behind solar PV.

Figure 2.6 National R&D funding for bioenergy and for all RE technologies



Source: Based on data from OECD/IEA (2018).
Note: Data for 20 EU countries was available in this source: The EU15 plus Czech Republic, Estonia, Hungary, Poland, Slovakia from the New Member States (NMS-13). Data for Italy was not available for 2015, for the Netherlands for 2004 and data for Poland was not available before 2009 for any RE technologies.

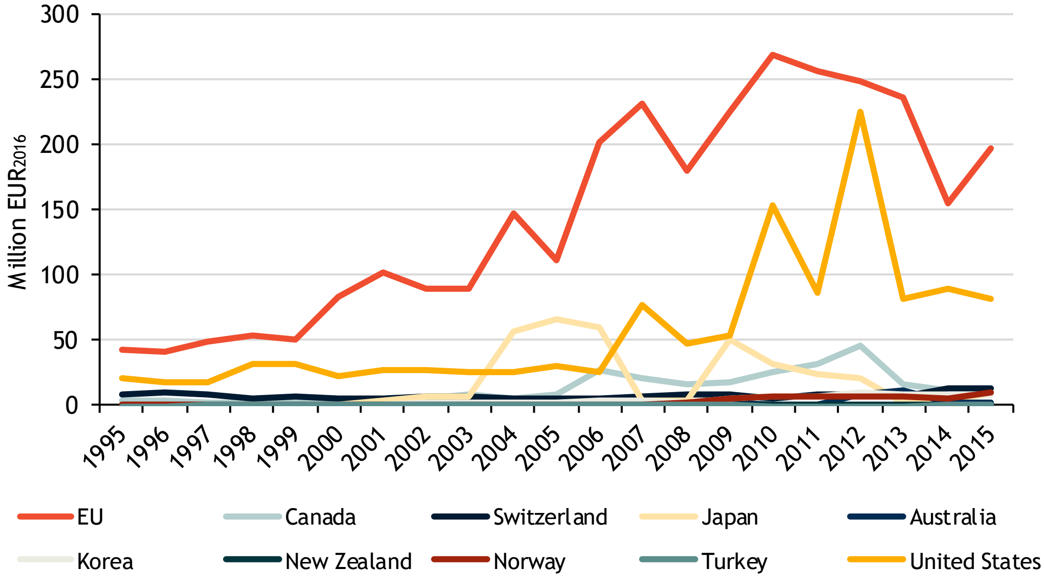
2.3 Private and international R&D funding

2.3.1 International public R&D funding

Funding from the EU and MS combined for bioenergy R&D is larger than in other countries, with 146 EUR million on average between 1995 and 2015. The United States provided EUR 57 million per year on average, followed by Japan (EUR 17 million per year) who reported exceptionally high R&D budgets for bioenergy between 2004 and 2006, which varied between EUR 57 per year and EUR 66 million per year. The other country with significant R&D budgets for bioenergy is Canada, with EUR 13 million per year.

[5] Based on expert interview and https://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-BIOMASS.pdf

Figure 2.7 Comparison of international R&D funding for bioenergy



Source: OECD/IEA (2018).
Note: EU: European Commission and Member State budgets combined.
Data covers 20 EU countries: the EU15 and Czech Republic, Estonia, Hungary, Poland, Slovakia and the European funding programmes FP5, FP6, FP7 and H2020. For countries outside the EU, national budgets were available for Australia, Canada, Japan, Korea, New Zealand, Norway, Switzerland, Turkey and the US. Data for Italy was not available for 2010 and 2015, and data for the UK was not available for 2008.

2.3.2 *Private R&D funding*

There is limited data available on private R&D funding for renewable energy sources (RES) and the scoping of the RE categories is not fully in line with the scope of this study. Nevertheless, the data that is available gives an indication on how private R&D funding compares to public R&D funding and how the private funding in the EU compares to that of the US.

Table 2.4 shows the estimated private R&D funding on energy from biomass and waste in Europe and the USA over the past 3 years. It indicates that the European private sector spends the same or more than the USA on bioenergy. Public EU R&D funding in the EU (see previous section) is currently the same order of magnitude as private R&D funding, both around 200 million per year.

Table 2.4 Corporate R&D budgets for biomass and waste energy in Europe and the USA

Region	Corporate R&D budgets (USD[6] bn)		
	2015	2016	2017
Europe	0.1	0.1	0.2
USA	0.0	0.0	0.2

Source: Frankfurt School-UNEP Centre/BNEF - Global Trends in Renewable Energy Investment. 2016-2018 editions.

2.4 Conclusions

Bioenergy has been one of the main RE technologies funded through the EU Framework Programmes, receiving 17 % of the total funding. Most of the funding was initially targeted at combustion and biogas production but in FP7 and H2020 the focus shifted to research on fuel supply. Furthermore, a substantial amount of funding has supported the development of gasification technologies and recently

[6] Where USD is the United States dollar.

more system integration research was funded. EU funding has supported a highly diverse number of research institutes, universities and private companies.

EU Member States have also allocated substantial budgets to bioenergy, at 19 % of the total budgets made available over the past 20 years. The combined EU and MS budgets are at a world-leading level, providing a solid basis for EU leadership in bioenergy.

While EU R&D funding for bioenergy has increased over the years in absolute terms, bioenergy's share of the total RE R&D budgets has decreased. This is due to increasing debate around the sustainable limits of bioenergy production and promising developments in other RE technologies which resulted in a reduced focus on bioenergy.

3 Research effectiveness

R&D projects can lead to patents, publications, spin-offs and several other, less concrete but potentially important direct outputs such as standardisation and knowledge exchange. Such impacts are the most direct impacts of R&D funding and therefore provide the cleanest view on the effectiveness of research budgets spent. In this section we discuss patents, publications, spin-offs and other direct research outputs, and their relation to R&D funding for the bioenergy sector.

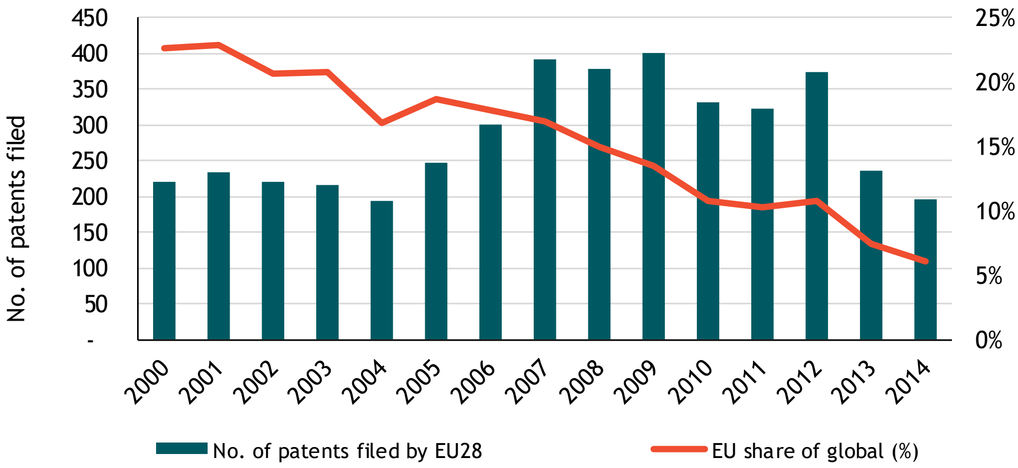
3.1 Patents

Patents are a commonly used indicator to measure the output of R&D funding as they provide a direct measurement of the impact in terms of novel knowledge generated. Furthermore, patent data are readily available, in a standardised form. However, some limitations have to be taken into account, such as the fact that filing a patent is not an objective of all research projects and that the economic value of patents varies significantly.

3.1.1 Evolution over time

Figure 3.1 shows the profile of patents filed for bioenergy technologies in the EU. The number of EU patents increased until 2007, remained relatively stable between 2007 and 2012, and then decreased to pre-2005 levels from 2013 onwards.

Figure 3.1 Evolution of bioenergy patents filed by EU countries



Source: IRENA INSPIRE (2017)

There is a downward trend in EU's share of global patents, similar to most other RE sectors. This is not only due to the decrease of EU-filed patents in absolute terms as the share dropped from 23 % in 2001 to 13 % in 2009 while the number of patents filed increased. This is also due to increased patenting activity from abroad. Growth in patent applications outside of the EU has been most pronounced in China (fewer than 200 before 2003 and more than 1 000 after 2011) and the USA (approximately 100 before 2003 and approximately 500 from 2009).

More than 1 600 patents were filed in Germany, which made it the MS with the most EU patents (38 % of the total number), followed by Spain (8 %), France (7.5 %), the United Kingdom (6 %) and Denmark (5 %). Germany was by far the largest patent contributor in the EU, reflecting the fact that MS had the third largest R&D budget in the period and that it was the main recipient of EU R&D funding during the FP7 and H2020 programmes.

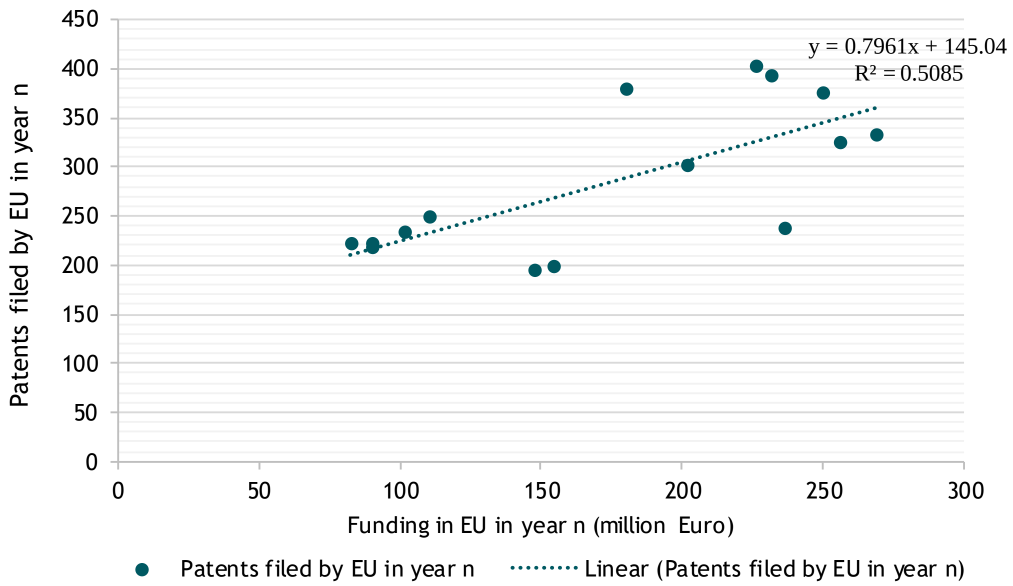
On the other hand, the Netherlands and Finland, assigned more R&D funding to bioenergy than Germany, but didn't file many patents during the period. The Netherlands was ranked as the main MS funder for bioenergy R&D, but it filed less than 3 % of the total number of patents. Finland was ranked as the 2nd largest funder, but filed only 3.4 % of the total number of patents. Similarly, Sweden was ranked the 5th largest funder of bioenergy R&D, but filed around 2 % of the total number. These three MS were also in the list of top recipients of EU R&D funding.

3.1.2 *Effectiveness of R&D funding in producing new patents*

In theory, higher R&D budgets in a region are expected to lead to an increase in the number of patents filed from that region. The extent to which this relation exists in the sector provides insight into the objectives of the research (is it targeted at technology development, so more likely to result to a patent application?) and the effectiveness of the research (was it successful in developing the technology so resulting in a patent application?).

Figure 3.2 compares the total amount of patents filed to the amount of EU R&D funding (MS + EU combined), accounting for a time lag between the moment of funding and the patent application. The highest correlation is however visible if no time lag is taken into account. Even then, there is no clear correlation between the number of patents and the amount of EU funding; the funding levels do not explain the number of patents filed. This is in line with the findings for other RE sectors and underlines that patent applications are generally not the primary objective of research projects.

Figure 3.2 Patent effectiveness



Note: We tested a delay of 0, 1, 2, 3, 4 and 5 years for the patents filed from year 2000-2014. 2015 data of patents was excluded because the source (IRENA) mentioned it is common to have delays of 3 years from a patent application and the year is reflected in the database. The correlation went up when 2015 data was excluded. A delay of 0 years between funding year and patents filed showed the highest correlation (R^2 = 0.5085).

3.1.3 Contribution of EU funding

To capture more directly the impact of EU funding through the Framework Programmes (FP5 to H2020) a questionnaire was sent out to all project coordinators of EU-funded R&D projects. 284 bioenergy projects were identified for this study. It was not possible to contact all project coordinators (due to missing contact links on CORDIS). But 209 project coordinators were contacted with a request to participate in the questionnaire. The overall response rate was 18 % (38 out of 209 projects). Project coordinators of FP7 and H2020 projects constituted the large majority of responses.

Based on the results of the questionnaire (see section 3.4), about 30 % of EU-funded projects (11 out of 38) contributed to a patent application. This is a relatively high share compared to other RE sectors and is particularly high compared to the absolute number of patent applications from the EU (+/- 200/year in recent years). Examples of projects that resulted in patent applications are MOBILE FLIP and UNIfHY (see project spotlight boxes below). Overall, the contribution of EU funding to EU patenting activity is clearly visible.

Project spotlight: MOBILE FLIP (Mobile and Flexible Industrial Processing of Biomass)

MOBILE FLIP is a project funded under H2020 under the topic 'adaptable industrial processes allowing the use of renewables as flexible feedstock for chemical and energy applications' (SPIRE-02-2014). The project is on-going, started in 2015 and is ending in December 2018. The aim of the project is to develop a mobile process for the treatment and valorisation of underexploited biomass from underexploited agricultural and forest-based resources. These raw materials have been underexploited due to a variety of reasons, one of which is that they are found in quite remote locations, so it can be relatively expensive to transfer them to major industrial sites.

The project has developed five case studies of processes related to underexploited biomass and is demonstrating four of them. For two of the processes a patent has been filed. The process with patent related to fractionated recovery of condensables is expected to enter markets by the end of 2018.

By focusing on underexploited biomass the project tries to exploit a sustainable source of bioenergy, enabling further growth in bioenergy's share of energy consumption.

More information on the project is available as a case study in the annex of this report.

Project spotlight: UNIfHY (UNIQUE gasifier for hydrogen Production)

UNIfHY is a FP7 project funded under the topic of 'biomass-to-hydrogen (BTH) thermal conversion process' (JTI-FCG.2011.2.3). It ran from 2012 to 2016. The project's aim was to obtain continuous production of pure hydrogen with biomass steam gasification process coupled with syngas purification. The project was based on the integration of plant components of proven performance and reliability. This is achieved through development and scale-up activities on materials and reactors design. The project submitted the patent 'Internal Circulating Dual Bubbling Fluidized Bed Gasifier' to the Italian Ministry of Economic Development. The patent is for a technology permitting the production of syngas from organic substrates using a small dual fluidised bed reactor for biomass steam gasification.
Source: UNIfHY, Deliverable D1.2: Final Report,
https://cordis.europa.eu/docs/results/299/299732/final1-unifhy-final-report-pub.pdf

3.2 Publications

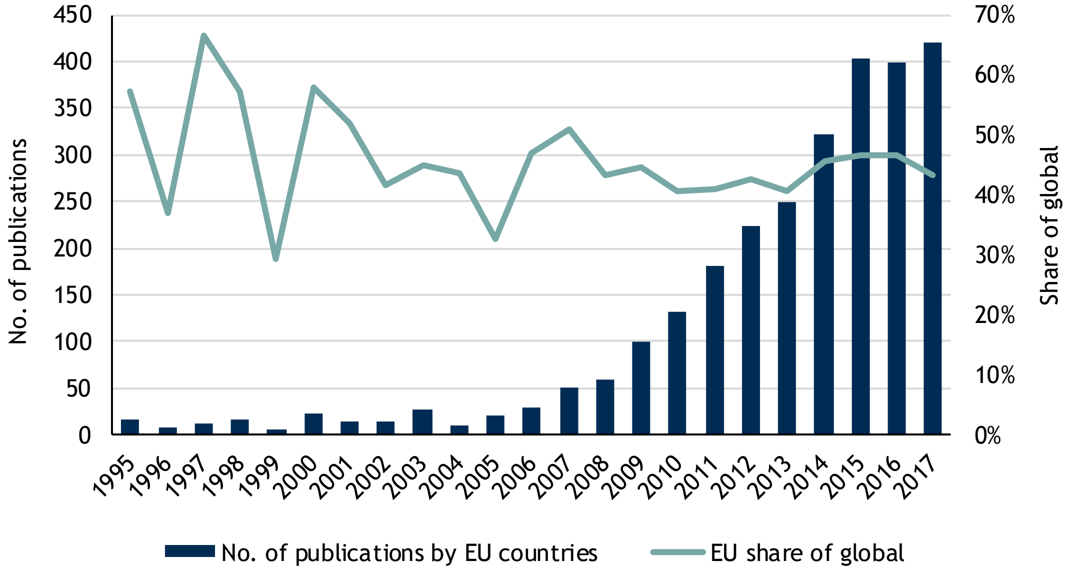
Publications of research papers are a useful indicator to measure the output of R&D funding, as there is enough data available to make a comparison between the EU's performance and the rest of the world. Moreover, publications have a close relation with public R&D funding, allowing us to differentiate the effect of public R&D funding from private R&D funding. Publications are categorised by country on the basis of the address of the author. If it has authors from different regions, the publication is counted for both regions.

3.2.1 Evolution over time

Figure 3.3 shows the profile of bioenergy publications by EU-based authors over the years. The number of publications on bioenergy had an upward trend over the years similar to that of EU R&D funding for bioenergy.

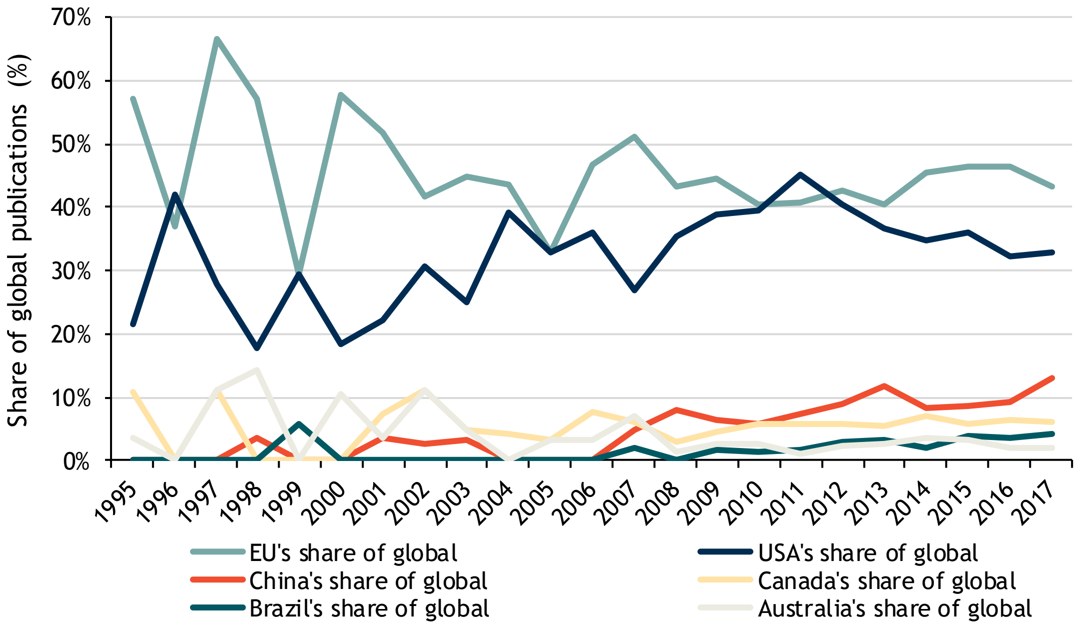
EU-based authors were involved in 44 % of the global publications between 1995 and 2017, making it the global leader. Outside of the EU, the largest number of authors came from the US (36 %), China (9 %), Canada (6 %), and Brazil and Australia (3 % each) (see Figure 3.4).

Figure 3.3 Evolution of bioenergy publications by EU countries



*Source: Web of Science (2018), using keywords: 'bioenergy' NOT'*ethanol*' NOT '*diesel*' in the title, topics and abstract of articles between 1995-2017. The share of global refers only to those publications with an address listed. 0.4 % of the global publications had no address listed in that period of time.*
Note: One article can have multiple authors (therefore, also multiple countries). The count is the number of articles in which at least one author listed an EU MS as their address

Figure 3.4 Comparison of the share of biofuels global publications between key countries



Source: Web of Science (2018)
Note: The shares of the different countries/regions are not cumulative since one article can have multiple authors (therefore, also multiple countries).

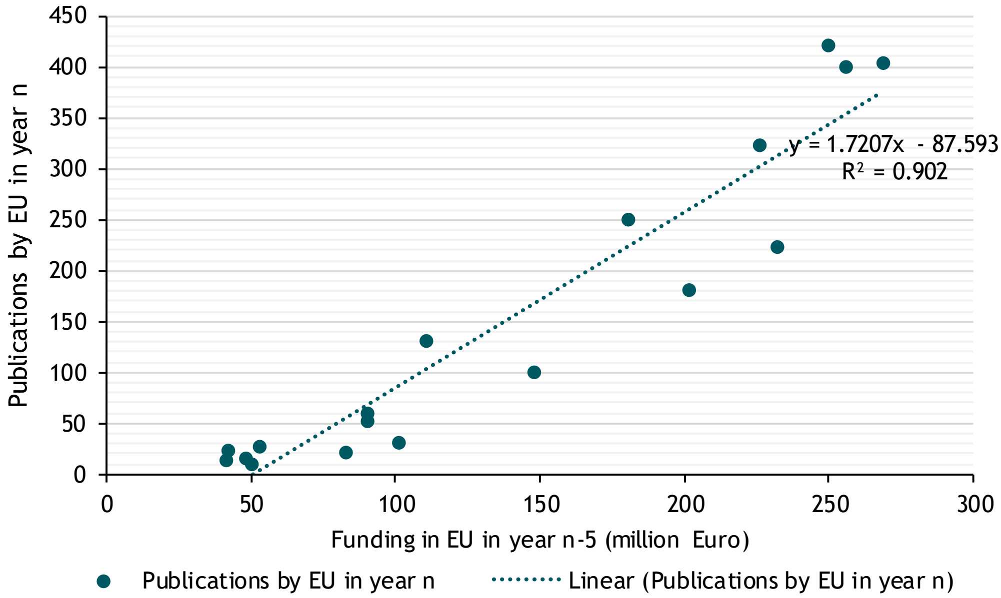
In the EU, Germany is leading with 570 publications between 1995 and 2017, followed by the United Kingdom (509), Sweden (398), Italy (340), and Finland (280). Except for the United Kingdom and Italy, the top five MS include three of the largest funders for R&D.

3.2.2 *Effectiveness of R&D funding in producing publications*

In theory, higher R&D budgets in a region are expected to lead to an increase in the number of publications from that region. The extent to which this relation exists in the bioenergy energy sector provides insight into the objectives of the research (does it aim for a publication?) and the effectiveness of the research (is it successful in realising a publication?).

Figure 3.5 compares the total amount of EU publications to the amount of EU R&D funding (MS + EU combined), accounting for a time lag between the moment of funding and the publication. The number of publications correlates more closely to R&D funding than the number of patents does, indicating that publicly funded R&D projects in the bioenergy sector have a higher focus on publishing and/or are more effective at publishing. This is in line with the findings for other RE sectors and underlines that publishing is often one of the primary objectives of research projects.

Figure 3.5 Publication effectiveness



Note: We tested the publication effectiveness of R&D funding for the period 1995-2015. Funding in EU includes EU and MS funding. We tested different delays (0,1,2,3,4 and 5 years) to evaluate which one had the highest correlation. After two years of delay, for each year of delay, the sample size was reduced by one number (e.g. with 0, 1 and 2 years of delay the sample size was 21 years, with 3 delay the sample size was 20 years and so on). With no delays (n-0) years of delay, the R^2 is the lowest of all the ones tested (0.3482). The highest R^2 was found using 5 years of delay (0.902).

3.2.3 Contribution of EU funding

Between 2008 and 2017[7], 234 publications explicitly reported benefitting from EU funding through FP5, FP6, FP7 and H2020, which is 9 % of the total number of EU publications in those years. Not all publications report their sources of funding, therefore it is likely that the actual figure is higher.

Based on the results of the questionnaire, 21 out of 38 projects reported at least one publication as a result of EU-funded research. This represents 55 percent of the responses.

Furthermore, all the projects presented as case studies in Annex A of this report (DEBCO, INFRES, MOBILE FLIP) delivered many publications as well as the HyTime project presented in the project spotlight box below. Overall, this clearly demonstrated the contribution of EU-funded R&D towards maintaining a leading academic position.

Project spotlight: HyTime

HyTime is a FP7 project that ran from 2012 to 2015. The project illustrates that EU-funded research projects often contribute to EU academic leadership by delivering multiple publications. The main objective of the project was to produce hydrogen by fermentation and the main output was a pilot hydrogen reactor for biomass (sugars) fermentation with a scale of up to 225 litres. The results of the project were disseminated through 6 publications in peer reviewed journals, 3 articles for a wider public, 10 oral presentations, 2 exhibitions, 1 press release and 23 presentations in scientific conferences.

Source: Interview of the HyTime project coordinator Dr. Pieternel Claassen

[7] Before 2008 no information was collected on the funding sources relevant to the publication. From 2008 onwards, the number of publications that provided this information increased, but especially in the early years (2008-2010) few publications reported this information.

The top EU organisations in terms of publications are listed in Table 3.1. It does not show a clear overlap with the top recipients of EU funding, as only two top publishing organisations are among the top 30 recipients of EU funding.[8] This may be due to the fact that EU funding for bioenergy is spread thinly across many organisations, resulting in a less clear division between the top 30 recipients and the other organisations in terms of the amount of EU funding received.

The top publishing organisations does show a clear correlation with MS R&D funding. Countries such as the Netherlands, Finland, Germany and Sweden have the highest MS R&D budgets for bioenergy and dominate the top 10 of organisations with most publications.

Table 3.1 Top organisations in the EU contributing to bioenergy publications

Rank	Institutions	Country	No. publications	EU funding rank
1	Swedish University of Agricultural Sciences	Sweden	208	7
2	Institut National de la Recherche Agronomique (INRA)	France	91	30+
3	Natural Resources Institute Finland Luke	Finland	87	30+
4	University of Eastern Finland	Finland	87	30+
5	Helmholtz Association	Germany	84	30+
6	Wageningen University Research	Netherlands	78	2
7	University of Aberdeen	UK	70	30+
8	Utrecht University	Netherlands	69	30+
9	Potsdam Institut fur Klimafolgenforschung	Germany	61	30+
10	International Institute for Applied Systems Analysis (IIASA)	Austria	60	30+

Source: Web of Science (2018)

3.3 Start-ups and spin-offs

The creation of start-ups and spin-offs is another potential impact of research projects, which can function as an important link between the research and the development of a European industry. Start-ups and spin-offs are not reported consistently. Therefore, questionnaire results are used to provide insight into these impacts.

In the questionnaire only 2 out of 38 project coordinators reported the creation of a start-up or spin-off as a direct output of their EU-funded research in bioenergy. These projects were: BIORECYGAS and HOMEBIOGAS (see project spotlight box below). It should be noted, however, that the HOMEBIOGAS company was already founded before the SME grant that they received.

Apart from the creation of new start-ups, the EU has also funded 51 SMEs in the bioenergy sector through the SME instrument which aims to support ground-breaking innovative ideas developed by small and medium-sized companies and is part of the Framework Programmes. This way, the start-ups that emerge across the EU are supported in the development of their technology.

[8] For this analysis, the top 30 recipients of EU funding were assessed instead of the top 10 that is presented in chapter 2.

Project spotlight: HOMEBIOGAS

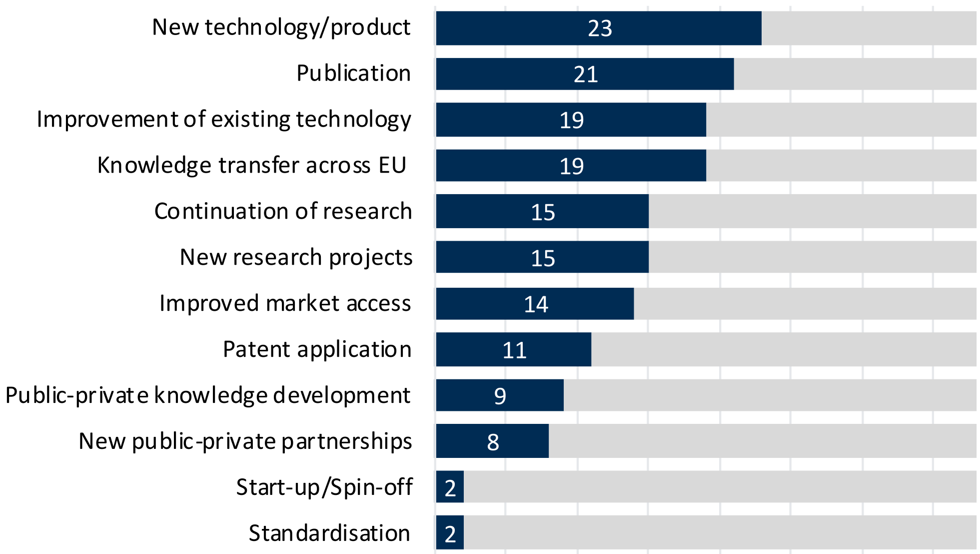
HOMEBIOGAS is a H2020 project funded under the topic of 'boosting the potential of small businesses in the areas if climate action, environment, resource efficiency and raw materials' (SMEInst-11-2016-2017). The project is led by a private for-profit entity that has developed and is marketing systems that convert organic waste into biogas. The biogas can be used as a clean energy source. The company produces systems suited for households (HOMOBIOGAS TG1) and companies in the food industry (HOMOBIOGAS TG6). The project reported the creation of a start-up/spin-off as one of the results of its EU-funded research.

Source: Bioenergy questionnaire outputs

3.4 Other research outputs

While patents, publications and start-ups/spin-offs are often the most tangible and easily quantifiable outputs of EU-funded research of RE technologies, there are many other outputs that contribute to the development of a leading sector. To get a better understanding of these other impacts, a questionnaire was sent out to project coordinators of EU-funded R&D projects. The results of the questionnaire are presented in Figure 3.6.

Figure 3.6 Impacts of EU-funding based on questionnaire results (38 responses in total)



Source: Own elaboration based on questionnaire conducted as part of this study.

The most commonly reported impacts include the development of new technologies/products (23 out of 38) and the improvement of existing ones (19 out of 38). Numerous examples of bioenergy technologies that have been developed and improved through EU-funded R&D projects exist. These include several biomass combustion technologies for power/combined heat and power (CHP) generation (e.g. through DEBCO and BIOMAX), gasification technologies (e.g. through UNIfHY and AERGAS) and pyrolysis technologies. This way, EU R&D funding contributed to developing a wider and better performing portfolio of bioenergy technologies.

About half of all EU-funded projects report publications and knowledge transfer across the EU as an impact. Furthermore, the continuation of research that would be stopped otherwise and the initiation of new research projects are reported by 15 out of 38 projects each. These impacts underline the role that EU funding plays in maintaining a leading academic position.

Improved market access is reported by a relatively high share of respondents compared to other RE sectors, indicating that bioenergy is a relatively mature technology for which entering new markets can be achieved through EU-funded projects. The share of projects reporting public-private knowledge development and new public-private partnerships is comparable to other RE sectors.

Finally, two projects report contributing to standardisation in the sector. One of these, is described in the 'project spotlight' box below. Through such projects, EU R&D funding provides the basis for increased penetration of next generation energy carriers.

Project spotlight: SECTOR

SECTOR is an FP7 funded project that ran from 2011 to 2015. The main objective of the SECTOR project was to optimise and further develop the torrefaction-based technologies, and to solve the technical and ecological problems related to torrefaction. During the project, a standard was proposed (ISO 17225-8: 'Solid biofuels - Fuel specification and classes - Graded thermally treated densified biomass') and Material Safety Data Sheets for torrefied biomass were developed.

Source: Interview of the SECTOR project coordinator Professor Daniela Thrän

3.5 Conclusions

The significant MS and EU budgets for bioenergy have been effective in establishing and maintaining a leading academic position globally. The EU is number 1 in terms of publications and has been able to preserve this leading position for most of the past 20 years. EU funding has contributed to at least 9 % of EU publications directly and has made indirect contributions by fostered collaboration in the EU bioenergy community, continuing research that would be stopped otherwise, and generating many new research projects.

The conversion of R&D budgets to patents has been less successful with a consistently declining share of the global patents and in recent years also a decline in the absolute number of patents from the EU. This downward trend is somewhat concerning and may be an indication of diminishing technology leadership of the EU bioenergy sector.

A large share of the EU-funded projects have contributed to the development of new and existing technologies/products within different bioenergy sub-technologies such as combustion, gasification and pyrolysis. This way, EU funding added new technologies to the bioenergy portfolio and enabled cost reductions, performance improvements and increased uptake of bioenergy technology. Additionally, improved market access has been reported by a relatively high share of the projects, indicating that EU funding also facilitates growth of EU industry turnover and export volumes. Furthermore, EU-funded R&D delivered standards that provide the basis for the penetration of next generation energy carriers.

4 Technology development

One of the core objectives of R&D funding on RE technologies is to contribute to the development of the technology to make it cost competitive and allow for increased uptake of the technology. The impacts on technology development can be assessed technologically, or from an economic point of view, looking at the costs, performance and competitiveness of the technology. This section focuses on key indicators that assess technology development from an economic point of view: capital expenditure (capex), operational expenditure (opex) and Levelised Cost of Energy (LCOE).

4.1 Capex

Capex (capital expenditure) refers to the initial investment costs of the bioenergy projects. Cost-reducing innovations can contribute to a downward trend in capex, which in turn can make the sector more cost competitive and allow for increased uptake of the technology. One of the main limitations of this indicator is that capex is highly location- and technology-specific, and will therefore vary between projects. To be able to provide an overview of the evolution of the capex over time, we consider global historic estimations of capex, including the estimations of regions outside the EU.

There are a large number of bioenergy-based heat and electricity generation technologies, which translates into a wide range of capex costs. The technology is a large determinant of the costs and efficiency of the bioenergy plants, although equipment costs can vary significantly depending on the region, feedstock type and availability, and site feedstock preparation or conversion requirements.

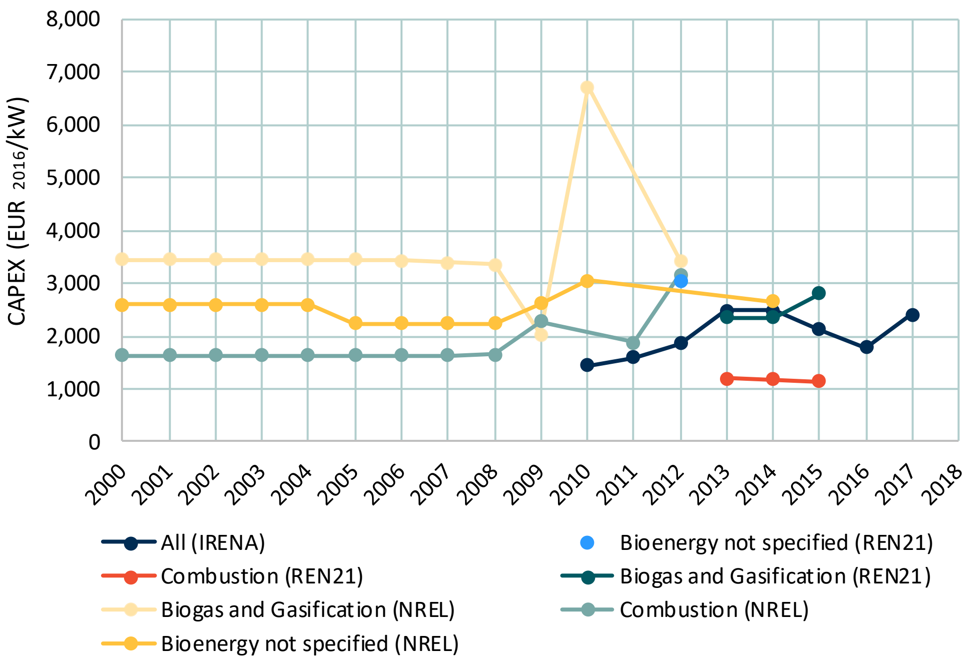
The main factors affecting capex of a bioenergy electricity plants are planning, engineering and construction costs, machinery for fuel handling and preparation, as well as the cost of other equipment such as fuel conversion systems. Small-scale projects tend to have higher capital costs, while large project costs are usually between EUR 400/kW and EUR 2 300/kW. When additional capacity is added to an existing project, the cost of electricity generation decreases and the lower range can be reached.[9]

In Europe, the range of installed costs is wider than the rest of the world, due to the selection of more expensive technology options. For example, some of the most expensive projects in Europe (and the world) use fixed bed gasifiers, with capex ranging between EUR 1 800/kW and EUR 6 400/kW.[10]

Overall, the available capex data for bioenergy capacities does not show a clear trend over time (see Figure 4.1), probably due to the large diversity in technologies and the impact of location-specific factors.

[9] IRENA, 2018, Renewable power generation costs in 2017.
[10] IRENA, 2018, Renewable power generation costs in 2017.

Figure 4.1 Capex of bioenergy electricity generation (global estimates)

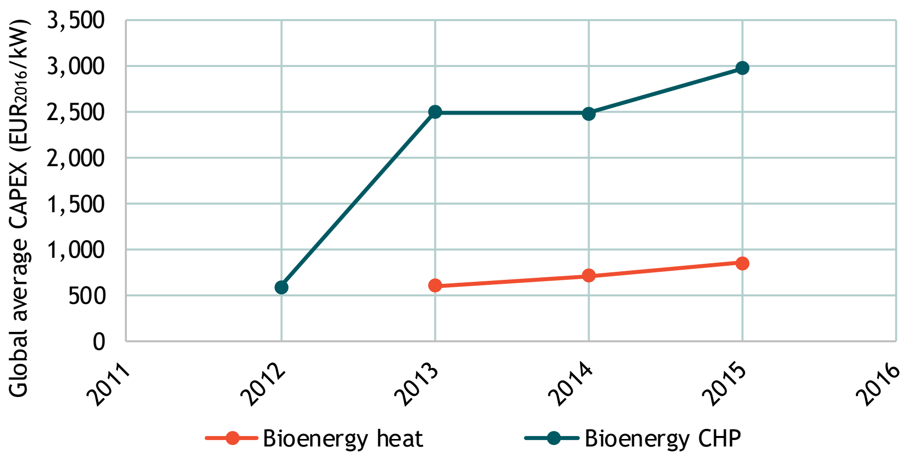


Source: NREL (2015), IRENA (2018), REN21 (2005, 2007, 2010, 2011-2015).
Note: All figures are global, unless specified otherwise.

Data of capex for heat generation from bioenergy is scarcer because the majority of installations are combined heat and power (CHP) units where the cost allocation between heat and power is not straightforward. Based on the available literature, capex for bioenergy CHP installations is between EUR 450/kW and EUR 5 500/kW, while bioenergy heat installations have capex between EUR 300/kW and EUR 1 350/kW. Figure 4.2 shows the median of the ranges found in literature for both sub-technologies.

The capex data shows that CHP has higher costs than electricity or heat only plants, but they also have a higher efficiency (between 80 % and 85 %), and heat produced can be distributed for industrial processes or space and water heating, which can reduce the overall capex in comparison to separate production systems.

Figure 4.2 Capex for heat generation from bioenergy (global estimates)



Source: REN21 (2012-2015).
Note: All figures are global, unless specified otherwise

The lack of a clear downward trend in the capex for bioenergy technologies does not mean that the technology has not improved. In fact, several developments are underway to improve the performance of the technology and reduce its emissions. The UltraLowDust, AER-GAS and AER-GAS2 projects are described below as examples of how EU-funded R&D projects contribute to such technology improvements in the sector.

Project spotlight: UltraLowDust

UltraLowDust is a project funded under FP7 and ran from 2011 to 2014. The project demonstrated and analysed three technologies that can be used for residential biomass combustion at low dust emissions. A new ultra-low emission boiler technology was developed with Windhager for pellet and woodchip combustion (in the project with name UleWIN - ultra low emission boiler by Windhager) and it has been commercially available for two years under the name PuroWIN. At the moment PuroWIN is the gasification technology that can provide lowest emissions regarding CO, OGC and dust in the world - almost zero. The project was able to reduce CO emissions more than 200 mg/MJ from the Base Case, NOx for 27 %, OGC for 85 % and TSP for 94 % and increase the energy efficiency. This was (after project end) proven by certified bench tests based on EN 303-5 type testing conditions.

Source: Interview of the key player of UltraLowDust project Dr. Thomas Brunner

Project spotlight: AER-GAS and AER-GAS2

AER-GAS is a project funded under FP5 and ran from 2002 to 2004. The project developed a new technology for efficient and low-cost steam gasification for clean conversion of solid biomass. The technology is called Absorption Enhanced Reforming (AER) and it can be used in various industrial processes. The project was followed by AER-GAS2 which was funded under FP6 and ran from 2006 to 2009. In the follow-up project AER the process was transferred to commercial scale in an 8 MWth power plant and the proof of power generation from H2-rich AER product gas was obtained.

Source: AER-GAS: https://cordis.europa.eu/result/rcn/82581_en.html; AER-GAS 2: *https://cordis.europa.eu/result/rcn/49622_en.html*

4.2 Opex

Opex (operational expenditure) includes fixed and variable costs for operation and maintenance (O&M) of the plants. Similar to capex, cost-reducing innovations can contribute to a downward trend in opex, which in turn can make the sector more cost competitive. Like capex, opex is also location-specific and can show large variations between sub-technologies. Only global figures are available for the opex as there was a limited number of projects to be compared from the EU .

Opex for bioenergy is usually sub-divided into fixed operation and maintenance (O&M) costs, variable O&M costs and feedstock costs.

Fixed operation and maintenance (O&M) costs for bioenergy electricity plants range from 2 % to 6 % of the total installed costs per year (see Table 4.1). These costs include labour, insurance, scheduled maintenance, routine replacement of components or equipment for boilers, gasifiers and feedstock handling equipment. Fixed O&M costs per kW are lower for larger plants due to economies of scale, particularly for labour.

Variable O&M are around 0.4 EURct/kWh (see Table 4.1). The main components of variable O&M are fuel costs unrelated to biomass, for example ash disposal, unplanned maintenance and equipment replacement, as well as incremental serving costs.

Table 4.1 Fixed and variable O&M costs for bioenergy electricity production (global estimates)

Bioenergy electricity technologies	Fixed O&M (% of Capex/year)	Variable O&M ($EURct_{2016}$/kWh)
Stoker/BFB/CFB boilers	3.2	0.37 – 0.45
Gasifier	3 - 6	0.37
Anaerobic digester	2.1-3.2	0.41
	2.3-7	
Landfill gas	11-20	N/A

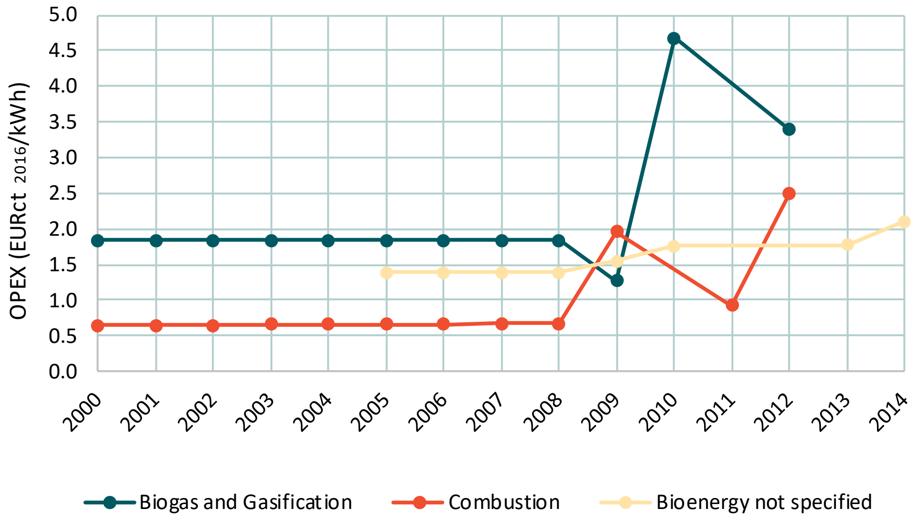
Source: IRENA, 2018.
Note: The data ranges are based on global averages.

Unlike wind, solar and hydro energy, the costs of bioenergy electricity generation also depends on the feedstock supply, which can have highly variable costs. Feedstock can account for 20 % to 50 % of the final costs of electricity from bioenergy[11]. The lowest cost feedstocks are usually agricultural residues (straw and sugarcane bagasse), since they are a by-product of harvesting or processing. The costs of these residues are correlated to the price of their primary commodity, which increased in costs from 2000 to 2011[12]. However, the cost of agricultural commodities has decreased by 28 % in 2016 compared to the peak price in 2011. Other relatively low cost feedstocks are wastes from industrial processes. Agricultural and forestry residues that can be collected and transported over short distances or are available at processing plants as by-products can also have moderate costs, while dedicated energy crops tend to have high prices (particularly if the distances are long). Overall, transport costs can play a significant role in feedstock costs when there are large distances to travel, with low density of feedstock. Therefore, transforming wet biomass into higher-density forms can reduce transportation costs per unit of energy, but transformation costs need to be considered.

Figure 4.3 shows the evolution of the overall O&M costs for bioenergy. Depending on the technology and scale, the O&M ranges from 0.2 EURct/kWh to 5 EURct/kWh in recent years. Overall, no clear trend can be discerned for the opex of bioenergy electricity production.

[11] IRENA, 2018, Renewable power generation costs in 2017.
[12] IRENA, 2018, Renewable power generation costs in 2017.

Figure 4.3 Evolution of bioenergy O&M costs for electricity generation (global, average of estimates)



Source: NREL database (2015).
Note: All figures are global, unless specified otherwise.

For bioenergy heat production, insufficient reliable estimates of the opex could be found in literature.

4.3 LCOE

The Levelised Cost of Energy (LCOE) is an indicator to compare the project costs of different energy generation technologies.[13] LCOE is most commonly used in the context of electricity generation, with the 'E' denoting electricity. LCOE can however also be applied to heat generating technologies, sometimes then denoted as Levelised Cost Of Heat. In this document we use LCOE as Levelised Cost Of Energy, specifying per case if this concerns electricity or heat.

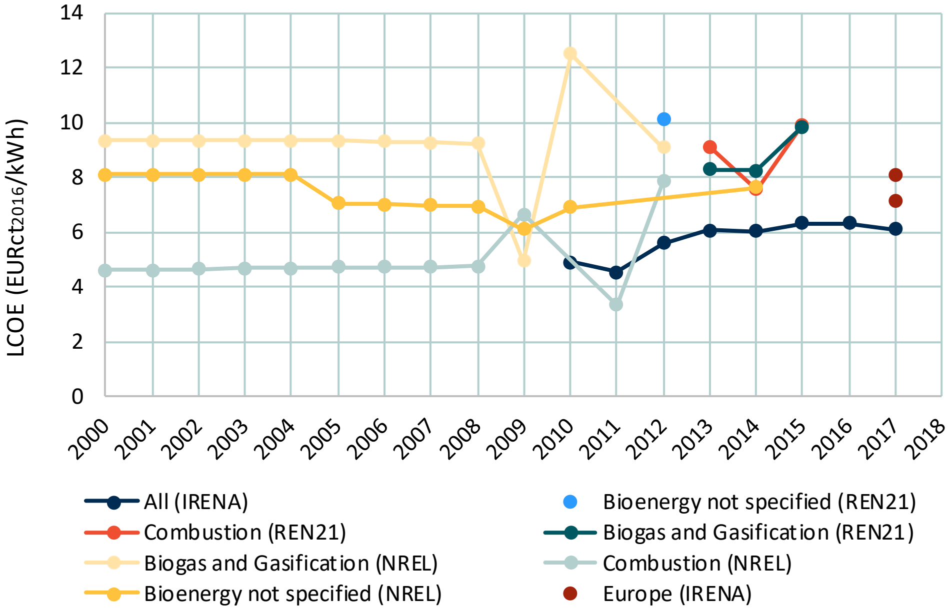
Similar to capex and opex, cost-reducing innovations can contribute to a downward trend in LCOE, which in turn can make the technology more cost competitive. While LCOE is a relatively comprehensive measure of the technology's production costs, it does not include all the costs for delivering energy, such as ancillary services and transmission and distribution costs.

Figure 4.4 shows the evolution of the LCOE for bioenergy electricity production. In 2017 electricity from bioenergy was in the range of fossil-fuel generated electricity (between 4.5 EURct/kWh and 15 EURct/kWh)[14]. The global weighted average LCOE of electricity from bioenergy was only 2 EURct/kWh higher than the lowest fossil fuel-fired cost option.

There are fewer new bioenergy projects for electricity (often electricity and heat combined) than other RES (hydroelectric, solar PV and onshore wind)[15]. This results in a higher impact of variations in the characteristics of the new projects each year. The upward trend between 2010 and 2014 is the result of a shift to more sophisticated bioenergy plants.

[13] There are different ways of calculating the LCOE; the method applied here is explained in the methodology document.
[14] IRENA, 2017
[15] Ibid.

Figure 4.4 LCOE of electricity from bioenergy



Source: NREL (2015), IRENA (2018), REN21 (2005, 2007, 2010, 2011-2015).
Note: All figures are global, unless specified otherwise

The plant capacity factor plays an important role in bioenergy LCOE. Europe has high capacity factors (around 80 %), as a result from investments in higher-cost technologies that can offer process flexibility. These technologies can process several feedstocks, sourcing a steady supply of wood pellets and wood waste. Bioenergy plants that rely on landfill gas and other biogases, wood and wood straws, fuel wood and industrial and renewable municipal waste usually have capacity factors above 80 %, while projects relying on agricultural inputs (e.g. bagasse), tend to have lower capacity factors because they depend on seasonal harvesting.

In 2017, the LCOE in Europe was slightly higher than the global, ranging from 7.2 to 8.1 EURct/kWh (see Figure 4.4). This reflects the selection of more advanced technologies, more stringent emissions controls, and higher feedstock costs.

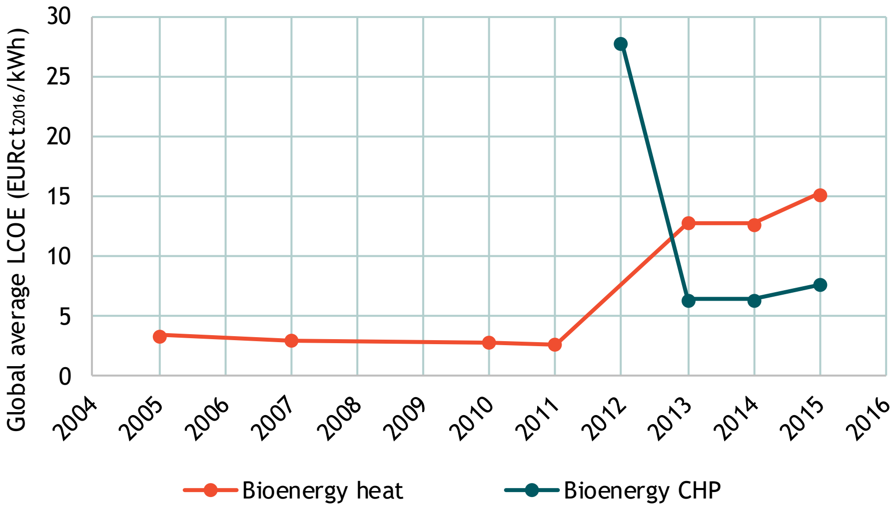
Most of the higher cost projects in Europe use municipal solid waste as feedstock. The primary objective of these projects is waste disposal, not electricity generation. These projects tend to have higher capital costs, since more expensive technologies are needed to reduce the pollutant emissions to acceptable levels. Excluding these plants (which usually have a small installed capacity), the LCOE in Europe is reduced by 0.9 EURct/kWh.

Even though European bioenergy plants relying on municipal waste have a very high LCOE for electricity (higher than 13.6 EURct/kWh), they also sometimes supply distributed heat to local industry or district heating, improving the business case.

The development of LCOE for heat generation from bioenergy technologies is shown in Figure 4.5. The figures presented are the median values for the respective years. It should be stressed that the LCOE of individual plants are in a wide range, with estimates for CHP as high as 64 EURct/kWh and as low as 3.3 EURct/kWh and estimates for heat only plants ranging from 0.75 EURct/kWh to 26 EURct/kWh.

Combined with the limited number of plants, no reliable conclusions can be drawn on the development of the LCOE for heat production.

Figure 4.5 LCOE for heat generation from bioenergy (global estimates)



Source: REN21 (2005, 2007, 2010, 2011-2015).
Note: All figures are global, unless specified otherwise

In spite of the lack of a clear trend in the costs of bioenergy, there are several examples of EU-funded projects that contributed to cost reductions in the sector. Examples include the INFRES project which lowered the LCOE by reducing raw material losses and sharing best practices and the BIOMAX project which increased the competitiveness of biomass-based fuels through logistical, fuel handling and feeding process solutions (see project spotlight boxes below).

Project spotlight: INFRES

INFRES is a project funded under FP7 that ran from 2012 to 2015. The project developed and demonstrated technological and logistical solutions that reduced the fossil energy input in the biomass supply by 20 % and reduce the raw material losses by 15 %. Due to the use of innovative new technologies and the efficient exchange of best practices between the countries in the consortium and other countries with similar natural conditions, the LCOE of bioenergy can be reduced and the volume of forest biomass supply for energy and biorefining can be substantially higher in the future.

More information on the project is available as a case study in the annex of this report.

Project spotlight: BIOMAX

BIOMAX is a project funded in FP5 that ran from 2002 to 2004. The project showed the viability of large-scale circulating fluidised bed (CFB) combustion technology to maximise the use of biomass-based fuels in combined heat and power generation. It increased the competitiveness of biomass-based fuels by developing logistics, fuel handling and feeding process and solutions to lower the risks for high temperature corrosion in the boiler.

Source: https://cordis.europa.eu/project/rcn/86825_en.html

4.4 Conclusions

Due to the large variety in technologies and the large impact of factors not related to the technology itself, such as feedstock prices, the effect of technology development on the cost-competitiveness of bioenergy is hard to isolate. For electricity production the LCOE estimates are most reliable. These are in a range that is competitive with other electricity sources but have not decreased over time. For heat production the data is particularly scarce and the estimates fluctuate widely, which does not allow any substantiated conclusions to be made about the development of the costs of the technology.

Looking at bottom-up inputs from project developers and sector experts, it becomes much clearer how EU-funded projects contributed to the development of bioenergy technologies. EU-funded R&D enabled efficiency improvements, cost reductions and emission reductions for existing technologies and several novel technologies have been demonstrated. Overall, contributing to a better and broader portfolio of bioenergy technologies available for the EU industry, hereby facilitating sustained industrial leadership.

5 Social, economic and environmental impacts

Public R&D funding for RE technologies is justified by several social, economic and environmental impacts. In this section we evaluate a range of indicators that provide insight into these impacts: installed capacity, annual generation, industry turnover, imports/exports, jobs and share of energy consumption.

A direct link between these indicators and R&D funding is hard to establish, as the impact of R&D funding is confluent with numerous other factors that drive or prevent deployment. Still, the indicators presented in this section are relevant indicators to assess the evolution of the bioenergy sector over time.

5.1 Installed capacity

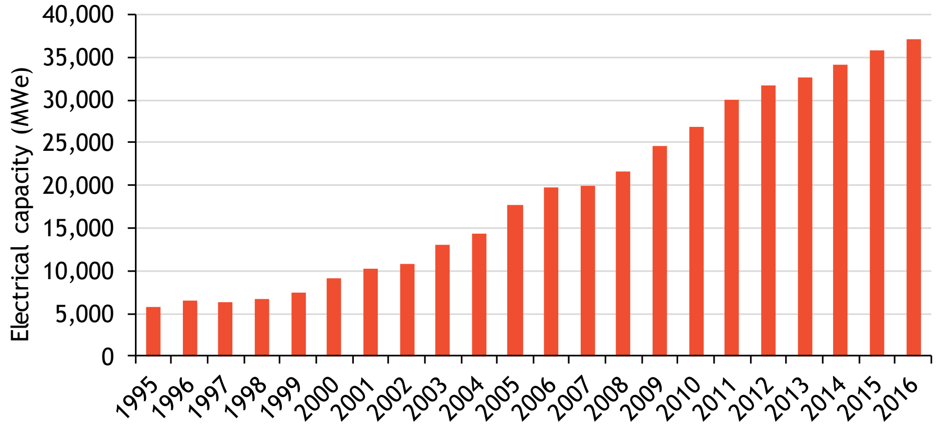
Installed capacity of RE technologies provide (near) carbon free energy, which prevents the need for fossil fuel-based energy. It can therefore be considered as an indicator of environmental impacts. Installed capacity refers to the maximum installed generation capacity for electricity (in MWe) and for heat production (in MWth).

Installed capacity for electricity based on bioenergy has grown six-fold, from 5 800 MWe in 1995 to 37 000 MWe in 2016 (Figure 5.1). Finland and Sweden historically had the most installed capacity, with over 1 100 MWe each in 1995. While Sweden has nearly quadrupled its capacity between 1995 and 2016, Finland has not added a lot of capacity since 1995. Germany and the United Kingdom grew faster than Sweden and are now the two MS with the most installed capacity (9 400 MWe and 5 700 MWe, respectively). Sweden is third, followed by Italy and France. Together with Finland, these six MS have 71 % of total installed capacity for bioenergy in the EU. Also, in smaller economies, the installed capacity grew substantially, such as in Austria, Denmark, the Netherlands, Spain and Belgium.

Two-thirds of installed capacity in 1995 used solid biofuels to generate electricity (see Figure 5.2). Biogases were a minor resource. This has gradually changed over the years. Installed capacity for biogases grew the most and now makes up nearly a third of the total capacity. The share of municipal wastes stayed more or less the same, at a quarter of the total capacity. Capacity using solid biofuels grew less fast, from 3 862 MWe in 1995 to 17 352 MWe in 2016 and now makes up less than half of total capacity.

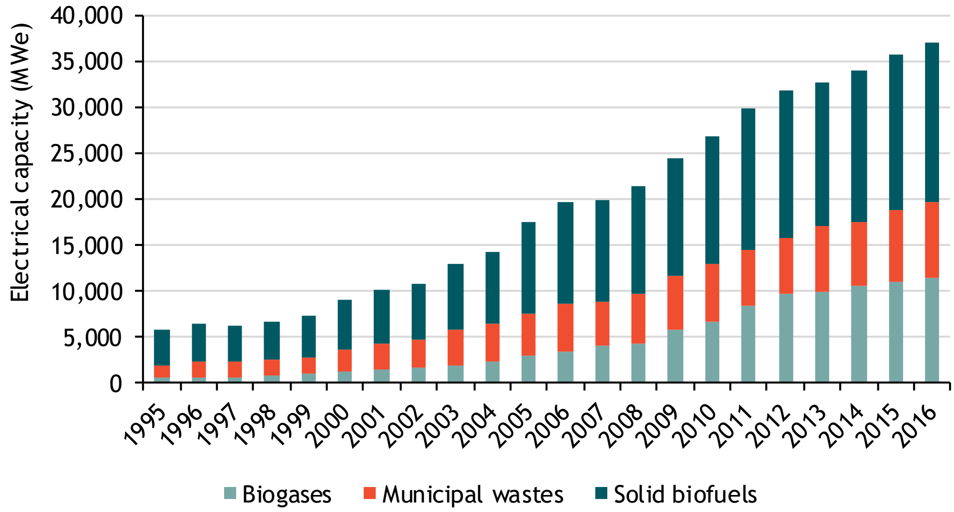
Solid biofuel-plants are used more in countries that were the largest producers in the nineties, such as Sweden (22 % of total installed capacity), United Kingdom (17 %) and Finland (10 %). This development has largely to do with resource availability. In the cases of Sweden and Finland, where the share of solid biofuel-based plants of energy mix is larger, the resource base is large, whereas in the United Kingdom, imported bioenergy plays a major role. Plants using biogases are mostly located in three MS: Germany (51 %), the United Kingdom (15 %) and Italy (12 %). Other MS only have a minor share of biogas-based plants. This development is related to the different support mechanisms in place in the countries. Germany had for instance a high feed-in tariff for biogas in place. Capacity based on municipal wastes is more widely dispersed amongst all MS. This is because incineration of waste is primarily seen as a waste management measure. Thus, it is quite evenly applied among Europe as waste is generated in all MS.

Figure 5.1 Installed electrical capacity of bioenergy power plants in the EU



Source: Eurostat (2018)

Figure 5.2 Share of installed electrical capacity of bioenergy power plants in the EU by sub-technology



Source: Eurostat (2018)

There is no data available on installed capacity for heat generation.

5.2 Annual generation

While installed capacity is a commonly used indicator to measure the progress in deploying RE technologies, it can be somewhat misleading due to differences in capacity factors. Annual generation includes the effects of these differences and is therefore a valuable indicator to complement the statistics on installed capacities.

Annual generation figures for bioenergy should be interpreted somewhat differently than for technologies such as solar PV and wind energy. For solar PV and wind energy, the marginal costs for operating are negligible, whereas the operational costs for bioenergy are significant. As a result, generation from bioenergy capacities is not merely a function of installed capacities, but is also dependent on the costs of the feedstocks and the price of the energy sold. These factors can lead to bioenergy capacities not being fully utilised due to the lack of profit on the energy sold. On the other hand, it should be noted that bioenergy can be generated in capacities that are not only used for bioenergy production and are sometimes not designed for bioenergy production. Co-firing of biomass in coal-fired power plants is an example of such a case (see 'project spotlight' on the DEBCO project below).

Project spotlight: DEBCO

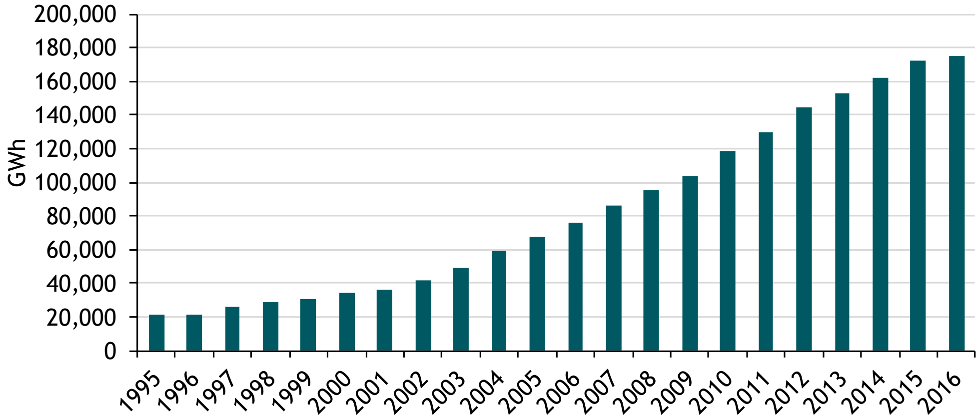
DEBCO is a project funded under FP7 that ran from 2008 to 2012. The project aimed to increase the short-term use of bioenergy by means of research, component testing and demonstration to develop the co-firing of biomass fuels. The project demonstrated different co-firing concepts in three power plants across the EU and performed tests in another three.

Two of the three power plants in which the technology was demonstrated, generate bioenergy by means of co-firing commercially. This way, the DEBCO project contributed to increased bioenergy generation.

More information on the project is available as a case study in the annex of this report.

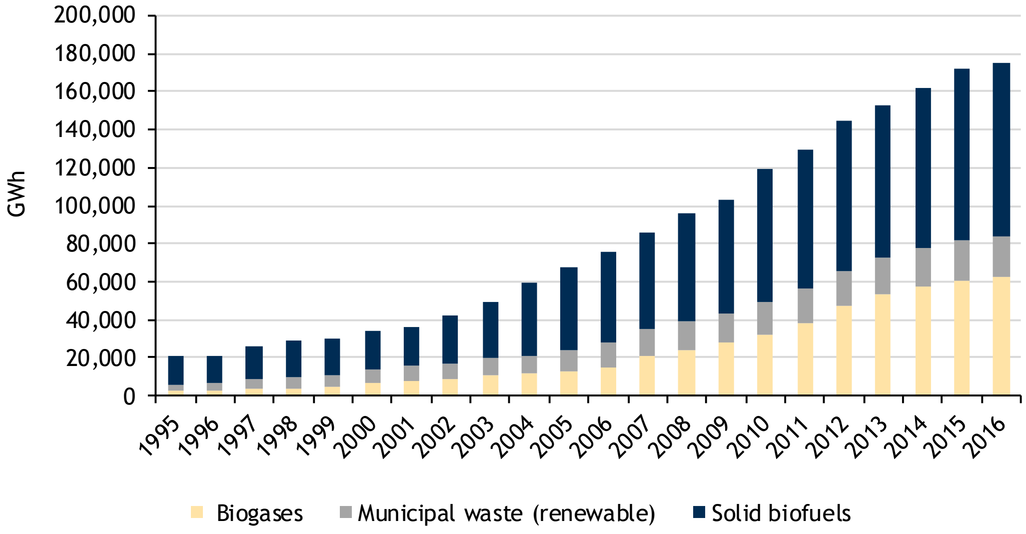
Annual generation of electricity from bioenergy grew even more than installed capacity: nearly eight-fold between 1995 and 2016 (see Figure 5.3). In 1995, when most capacity was based on solid biofuels, the EU generated 21.4 TWh. This has risen to 175.2 TWh in 2016. Figure 5.4 shows that most generation still comes from solid biofuels, but an increasing share comes from biogases.

Figure 5.3 Annual electricity generation in the EU from bioenergy



Source: Eurostat (2018)

Figure 5.4 Annual electricity generation in the EU from bioenergy by sub-technology

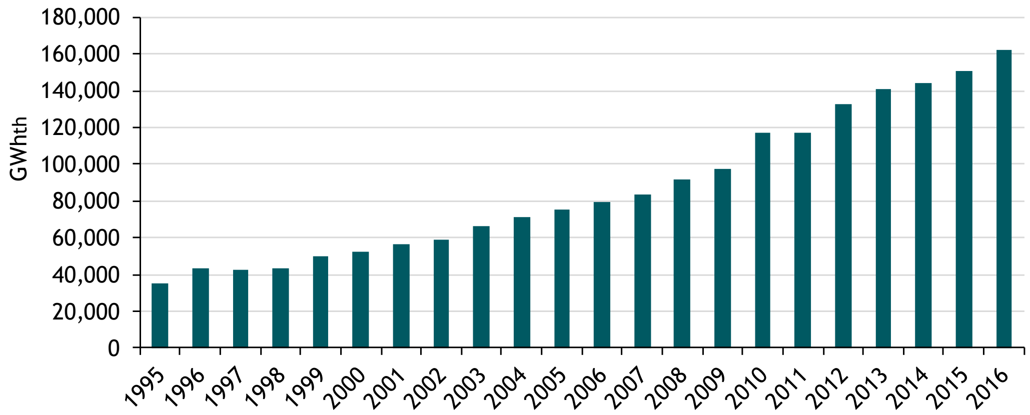


Source: Eurostat (2018)

Annual generation of heat from bioenergy also grew, from 3 036 ktoe to 13 975 ktoe (see Figure 5.5). in 1995, two-thirds of the heat generation was derived from solid biofuels (excl. charcoal), and one-third from municipal waste. Biogases played a minor role. In 2016, solid biofuels made up 74 % of heat generation, and municipal waste 21 %. Biogases still play a very small role, contributing 5 % to the overall heat generation from bioenergy.

The countries with the most heat generation from bioenergy in 1995 were Sweden (47 % of total EU generation), Denmark (15 %) and France (9 %). In 2016, they still produce a large part of the bioenergy-based heat in the EU (22 %, 11 % and 11 % respectively). They have been joined by Finland (14 %) and Germany (11 %) as countries with substantial shares of the total EU production. There are four MS that do not produce heat from bioenergy sources: Spain, Portugal, Ireland and Greece. In all other MS, with the exception of Bulgaria, heat generation increased between 1995 and 2016, growing between two-fold (Sweden) and 47-fold (Lithuania).

Figure 5.5 Annual heat generation in the EU from bioenergy



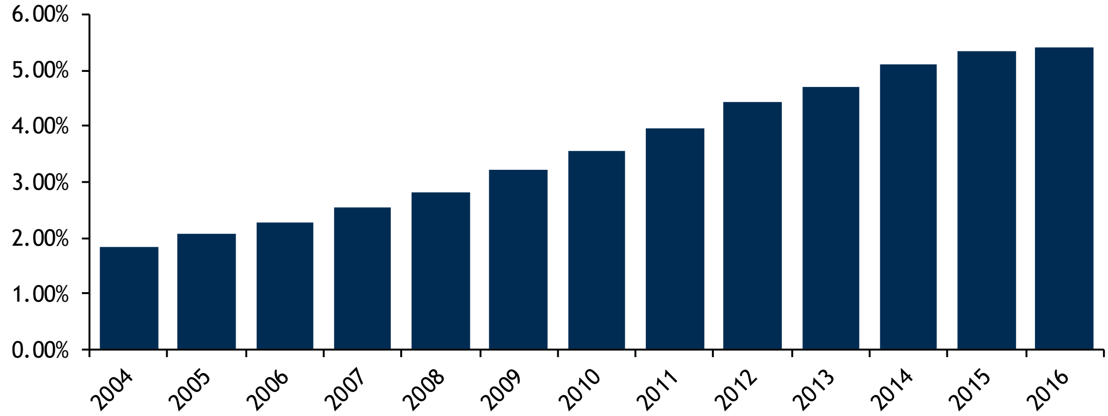
Source: Eurostat (2018)

5.3 Share of energy consumption

Share of energy consumption refers to the participation of bioenergy in the gross final energy consumed in each market sector (in the case of bioenergy, electricity and heat). This indicator allows us to analyse the participation of the bioenergy sector in the overall target of increasing the share of energy from RES in the EU's gross final energy consumption.

The share of gross final electricity consumption from bioenergy has risen from 1.8 % in 2004 to 5.4 % in 2016 (see Figure 5.6). Considering that the overall share of RE technologies in the EU electricity consumption is just below 30 % in 2016, the contribution of bioenergy to decarbonising the electricity sector has been significant, ranking behind hydro (11 %) and wind (10 %) but ahead of solar PV (3 %).

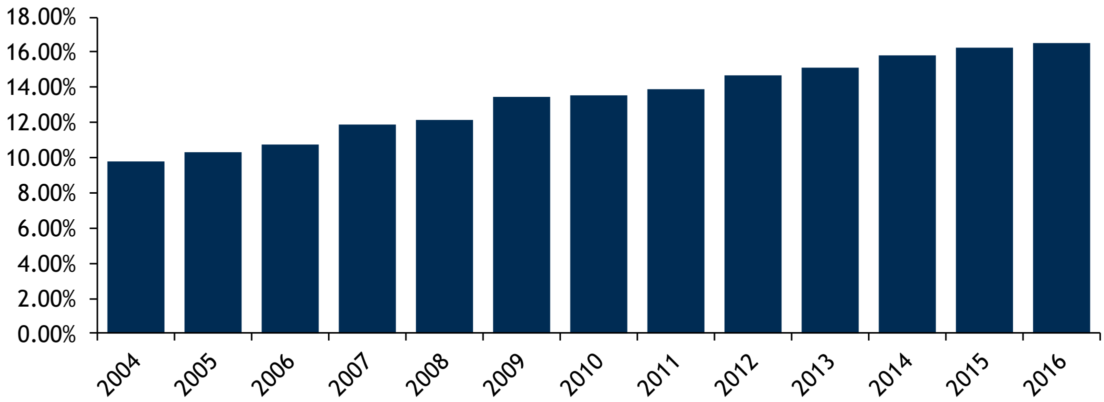
Figure 5.6 Share of gross final electricity consumption from bioenergy in the EU



Source: Eurostat (2018)

The share of bioenergy in the EU heat consumption also rose, from 10 % in 2004 to over 16 % in 2016 (see Figure 5.7). Bioenergy is the only RE technology with a substantial contribution to EU heat consumption, with the second largest contributor (solar thermal) only providing 0.4 % of EU heat consumption.

Figure 5.7 Share of gross final heat consumption from bioenergy in the EU



Source: Eurostat (2018)
Note: heat consumption covers derived heat, and final energy consumption in sectors other than transport.

One of the main concerns for growing the share of bioenergy in the energy mix is the lack of a sufficient sustainable supply of biomass. Therefore, the focus of EU-funded research has shifted to topics related to the supply of fuels (see section 2.1.2), including more efficiently utilising biomass (see S2BIOM in section 2.1.2 and CEUBIOM/CEE project spotlight box below) and exploiting non-utilised biomass (see MOBILE FLIP project spotlight box in section 3.1.3). This way, EU-funded research contributes to enabling increased bioenergy consumption within sustainable limits.

Project spotlight: CEUBIOM and BEE

CEUBIOM is a project funded by FP7 and it ran 2008-2010. It proposed a common methodology for gathering information on biomass potential using terrestrial and earth observations. Thus, it delivered a first proposal for a harmonised biomass potential assessment framework for bio-energy in Europe. Its 'twin project' BEE funded by FP7 was carried out during 2008-2010. BEE improved the accuracy and comparability of future biomass resource assessment for energy. These projects formed a background for the planning of a transition to renewable energy in the European Union and contributed to a better understanding and classification of the potential of biomass use for bioenergy in the EU and on national level.

Sources: https://cordis.europa.eu/docs/results/213/213634/final1-ceubiom-final-report.pdf; http://www.eu-bee.eu/

5.4 Industry turnover

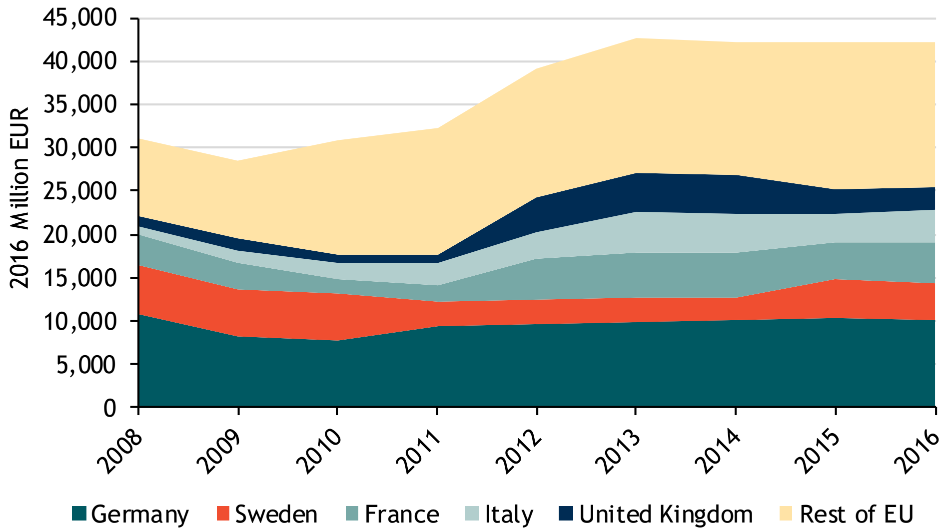
Industry turnover is the total amount invoiced from the market sales of goods and/or services supplied to third parties by all sellers in the bioenergy sector. Following the definition in EurObserv'ER, it focuses on the main economic activities of the supply chain including manufacturing, installation of equipment and operation and maintenance (O&M).

The estimated turnover for the bioenergy sector has grown from EUR 31 billion in 2008 to EUR 42 billion in 2016. The MS with the largest industry turnover were Germany, Sweden, France, the United Kingdom and Italy.

Germany saw a large increase of capacity in eastern Germany in 2009, and German firms set up subsidiary offices in other EU countries (France, Italy and Eastern Europe) thereafter. After 2012, the domestic biogas market stagnated, but turnover from activities outside Germany offset this stagnation. The German biogas sector has slowed down further in 2016 as new measures were introduced on the use of energy crops, with less lucrative feed-in tariffs and the discontinuation of premiums for producing electricity via biomethane.

The United Kingdom converted a number of coal-fired plants to biomass plants, which led to a sharp rise in turnover in the sector. It is now a top producer of biomass electricity, but it is dependent on imports of wood pellets for its production. Sweden has a highly developed forestry and machinery sector for harvesting and processing wood, as well as many bioenergy installations, which all contribute to its industry turnover. Production dropped in 2011, but has been increasing again in 2014. France has lately experienced a growing biogas market, thanks to a feed-in tariff for biomethane injection and a heat fund. It also has support schemes for other types of bioenergy, which increases industry turnover.

Figure 5.8 Bioenergy industry turnover in the EU



Source: EurObserv'ER reports 2010-2017.
Note: Data includes turnover from Solid biomass, biogas, and renewable municipal waste. Data is missing for Croatia for the years 2008-2011.

The turnover of the EU bioenergy sector industry turnover is one of the highest across all RE sectors, comparable to the wind energy sector and about four times as large as the biofuels and solar PV industries. The EU houses leading manufacturers of bioenergy production technology such as Windhager and Valmet which have benefitted from EU R&D funding in many ways (see company spotlight below).

Company spotlight: Windhager and Valmet

Windhager is one of the largest and most successful pellet boiler manufacturers in Europe. More than 50 000 households in Europe are already heated with pellet boilers from Windhager. The company participated in several EU-funded projects (e.g. BioMaxEff, UltraLowDust, FlexiFuel-CHX, FlexiFuel-SOFC) which contributed to increased efficiencies and decreased emissions for their residential biomass combustion products. Participating in these projects also increased the knowhow at Windhager, opened up new sales opportunities and allowed for the development of a new patented combustion system.

Valmet is a leading global developer and supplier of technologies, automation and services for the energy industries and has been involved in around five EU-funded bioenergy R&D projects. They offer process technology for combustion and gasification systems, modular power plants, heat plants and air emission control. For Valmet, EU projects have been very useful in developing new solutions at the pre-commercial phase and through making their technology and solutions known in a wider context. For example, development of new boiler systems has enabled the use of more technically challenging biomass fuels in multi-fuel combustion. Furthermore, participating in EU projects has had significant added value for the company in terms of knowledge transfer through the whole value chain and has opened new opportunities for development.

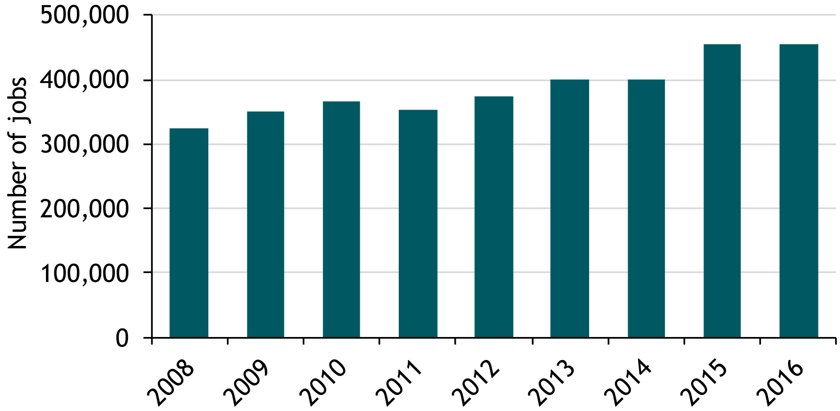
Sources: Interviews with employees of both companies

5.5 Jobs

Employment is an important indicator to understand the socio-economic impact of RE technology deployment. Linking jobs to R&D funding is difficult due to the number of confounding factors, but it is possible to make a connection between RE deployment and jobs. Different methods exist for estimating employment figures. A consistent time-series was only available for 2008-2016.

The number of bioenergy jobs in the EU has grown steadily over the past years, from 325 000 in 2008 to more than 450 000 in 2016. Over three-quarters of these jobs are related to solid biomass. Biogas accounted for 17 % of total bioenergy-related jobs in 2016, and renewable municipal waste 6 %.

Figure 5.9 Evolution of EU jobs in bioenergy



Source: EurObserv'ER (2010-2017).
Note: Data includes jobs from Solid biomass, biogas, and renewable municipal waste. Data from Croatia is missing for years 2008-2011. Accounts for direct and indirect jobs in bioenergy in the EU MS.

Compared to the global bioenergy sector, the leading role of the EU bioenergy sector becomes more clearly visible. With global jobs in bioenergy estimated to be just over a million, the EU share is around 40 %, which underlines the important position of the EU industry in the bioenergy sector.[16]

5.6 Imports/exports

International trade can provide a measure of the market uptake of bioenergy technologies and development of the bioenergy sector itself. It allows us to examine the extent of the external market for these goods, with increasing exports leading to increased growth of the domestic sector. Similarly, increased activity in the sector will lead to an increase in demand for intermediate goods used in the manufacture of renewable energy technologies, a proportion of which may be imported. Increasing imports of these intermediate goods also provide an indication of the growth within the technology sectors.

The EU bioenergy industry is a net exporter of bioenergy technology, with a positive trade balance of approximately EUR 5 billion in 2015 (see Figure 5.10). The export and import volumes have been relatively stable over the years, indicating success in maintaining the EU's leading position. It should be noted that these figures exclude feedstock trade volumes. These are excluded because of the scope of

[16] IRENA (2017) – Renewable Energy and Jobs, Annual Review 2017. Calculation based on the sum of the number of jobs in the solid biomass and the biogas sector.

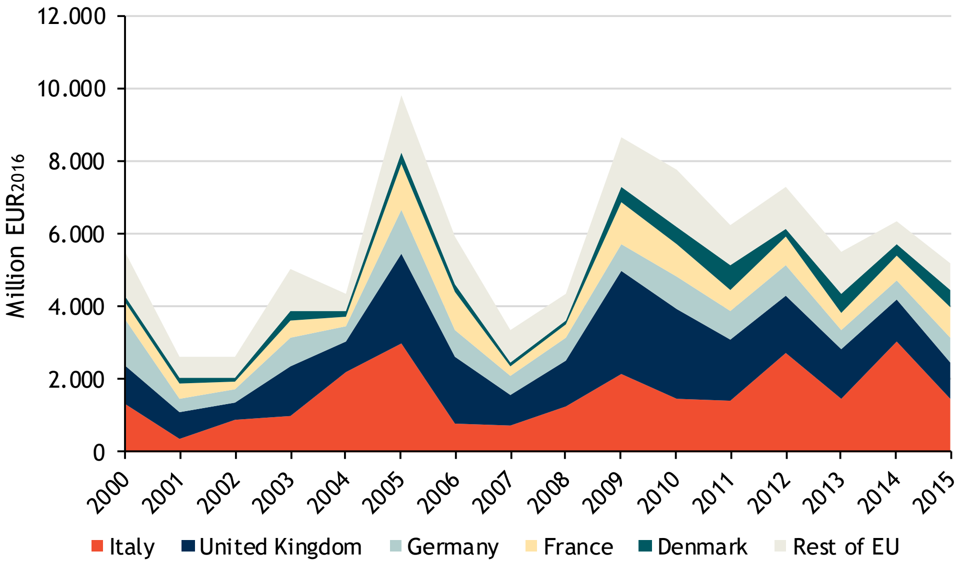
this study, which focuses on R&D on energy technologies but not on the developments in industries such as agriculture and forestry.

Figure 5.10 Trade balance for Bioenergy components in the EU

Source: Based on Comext (2018), Lako, P (2008), Eurostat (2018), Wind, I (2009), and Jha, V (2009).
Data for 1999 and 2016 was 0 for all countries so it was excluded.
For an explanation of the methodology used, see Annex C.

Most EU exports to the rest of the world originate from Italy, United Kingdom, Germany, France and Denmark (see Figure 5.11). This overlaps partly with the main MS in terms of R&D funding (Germany, Denmark) and partly with the main MS in terms of industry turnover (Italy, France, Germany, United Kingdom). However, part of the trade volumes for bioenergy components are also fulfilled by companies in adjacent industries that could supply the bioenergy industry based on capacities that have not been developed for the bioenergy industry specifically.

Figure 5.11 Total value of exports of Bioenergy components from the EU (extra EU28 trade)



Source: Based on Comext (2018), Lako, P (2008), Eurostat (2018), Wind, I (2009), and Jha, V (2009).
Data for 1999 and 2016 was 0 for all countries so it was excluded.
For an explanation of the methodology used, see Annex C.

5.7 Conclusions

The contribution of bioenergy to EU energy consumption has increased steadily over the past 20 years. Bioenergy had relatively large capacities already in the early years of RE deployment, thanks to the high maturity of the technology at that time, and has maintained a significant position in the EU energy mix, contributing 5.4 % of electricity generation and 16.5 % of heat generation. Solid biofuels are responsible for most of the bioenergy production but biogas has increased its share. EU-funded R&D has contributed to the growth in bioenergy generation through promoting the use of biomass-based fuels and improving the efficiency of bioenergy generation and its fuel supply chain.

The EU bioenergy industry is one of the largest RE industries in the EU, with approximately EUR 40 billion turnover per year and over 400 000 jobs. Globally, the EU industry accounts for 40 % of all bioenergy jobs. Combined with a trade surplus of EUR 5 billion/year, it is clear that the EU bioenergy energy sector is a global leader. EU-funded R&D contributed to this leading position by improving existing technologies and developing new technologies in close collaboration with leading EU industry players.

6 Conclusions

Bioenergy has been one of the main RE technologies in terms of R&D funding in the EU, receiving 17 % of EU funds and 19 % of MS funds for RE technologies over the past 20 years. Internationally, the EU has a strong academic position with leading R&D budgets and EU authors contributing to more than 40 % of all publications worldwide. The EU Framework Programmes made a clear contribution to the EU's academic leadership by funding projects that delivered many publications and stimulating collaboration and knowledge sharing across the EU.

The costs of bioenergy technology have remained relatively stable since the early 2000s but are at a level that is competitive with fossil fuel-generated electricity. Due to the large variety in technologies and the large impact of factors not related to the technology itself, such as feedstock prices, the effect of technology development on the cost-competitiveness of bioenergy is hard to isolate.

EU-funded R&D contributed to the development of various bioenergy technologies, including combustion, gasification and pyrolysis. Through the EU support, the efficiency, performance and emissions of these technologies were improved and newer technologies were demonstrated. Additionally, EU-funded R&D contributed to increased sustainable utilisation of bioenergy, delivered standards for next generation energy carriers and recently started to focus on the role of bioenergy in the new energy mix, for instance as a storage solution for intermittent energy generation. Overall, this contributed to the development of a rich portfolio of bioenergy technologies of which the EU industry benefits.

The EU bioenergy sector has exhibited steady growth in terms of installed capacities and energy generated, currently supplying approximately 5 % of electricity and 16.5 % of heat consumed in the EU. The EU industry has established a strong position globally, with 40 % of global jobs and a large trade surplus. The only outlier is the EU share of global patents, which has been in continuous decline over the past 20 years. But as jobs and industry turnover are still growing, the EU bioenergy industry can be considered a global leader, which has been partly enabled by the support through the EU Framework Programmes.

Annex 6A - Case studies

Case study: DEBCO

Author:	Heidi Saastamoinen	Approver:	Silvia Gasperetti, project co-ordinator of DEBCO
Project title:	FP7- Demonstration of Large Scale Biomass CO-Firing and Supply Chain Integration - DEBCO		
Lead partner:	During the project: Enel Engineering and Research, Via Mantova 24, 00198 Rome, Italy. Enel Engineering and Research has been incorporated since 2017 in Enel Produzione spa, Viale Regina Margherita 125, Rome		
Project location:	Coordinated in Italy, research conducted across multiple sites in Europe.		
Technology area/s:	Bioenergy		
Start and end date:	January 2008 to December 2012		
Project cost:	EUR 6 941 512.47	EC funding:	EUR 4 166 823.05
Other funding sources:	Private funding		
Quantifiable outputs and impacts:	Different co-firing concepts successfully demonstrated in three power plants in Europe; two of these in commercial operation with the new co-firing concepts Numerous project publications		
Further information:	Project website is no longer available . Project Coordinator – Mrs Silvia Gasperetti, project co-ordinator, Enel Engineering and Research. TNO. Visiting address, A. Pisano 120, 56122 Pisa Italy. T +39 050 6185903. E silvia.gasperetti@enel.com Mr Manolis Karampinis, Centre for Research and Technology Hellas (CERTH). Egialias 52, 15125 Marousi Greece. T +30 211 1069500. E karampinis@certh.gr		

Project description

The project DEBCO involved an extensive programme of research, component testing and demonstration to develop further the co-firing of biomass fuels and Refuse Derived Fuels (RDF) with coal in existing power plants as a means for using renewable fuels in the short term. It responded to the need for further operational experience in high share biomass co-firing using different type of fuels.

In particular, the DEBCO project focused on three demonstration plants around Europe: Fusina (co-firing of hard coal with RDF), Rodenhuize IV (repowering to wood pellets firing) and Kardia I (co-firing of lignite with agrobiomass). The project implemented different types of activities depending on the needs of each plant. These included:

- biomass availability and logistics investigation;
- pilot-scale combustion tests and testing of components;
- simulation studies (e.g. CFD modelling);

- short and long-term co-firing demonstrations at the plant, including dedicated measurement campaigns and implementation of monitoring equipment (e.g. corrosion and ash deposition probes);
- monitoring air emissions;
- investigations on co-firing ash utilisation;
- overall techno-economic evaluations.

Additionally, the project aimed to update the knowledge base on co-firing technologies, increase the public awareness, knowledge and acceptance of the concept of biomass co-firing in existing and new coal fired power plants, pave the way for advanced co-firing implementation in Eastern European countries, report the practical experience and technical know-how developed in the project in a series of guidebooks, and present the major project results to stakeholders, legislative bodies, utility and fuel supplier associations, and R&D centres.

The DEBCO project brought together a consortium consisting of four utilities, three engineering and manufacture companies, six R&D and academic institutions, and four SMEs and other organisations. The project coordination was assigned to Enel Engineering and Research (Italy).

Outputs and impacts

A direct output of the DEBCO project was the successful demonstration of different co-firing concepts at three power plants in Europe; a short summary is provided in Table A.1.

Table A.1 This table needs a caption

Power plant	Main fossil fuels (starting)	Targeted co-firing fuel	Starting co-firing thermal share (%)	Targeted co-firing thermal share (%)	Successfully demonstrated	Co-firing commercial operation after the project
Rodenhuize IV (Belgium)	Hard coal, Blast Furnace Gas (BTG)	Wood pellets	25	100	Yes (180 MWe from wood pellets)	Yes
Fusina (Italy)	Hard coal	Refuse Derived Fuel (RDF)	2.5	5.0	Yes (16 MWe from RDF)	Yes
Kardia I (Greece)	Lignite	Agrobiomass (herbaceous)	-	10.0	Yes (30 MWe from agrobiomass)	No

In addition, short-term co-firing tests were successfully performed the following power plants within DEBCO:

- Meliti power plant (330 MWe) in Greece: co-firing of lignite with agrobiomass at 10 % thermal share;
- Dorog power plant (40 MWe) in Hungary: co-firing of hard coal with different types of biomass (saw dust, sunflower hull, sunflower pellets, wood chips) up to 75 % thermal share;
- Rokita combined heat and power plant (100 MWth/22 MWe) in Poland: co-firing of hard coal with different types of biomass (wood, rape seed, crude glycerol, SRF) up to 30 % thermal share.

The Guidebook is the result of the techno-economic analysis and outlines the efficient use of biomass and RDF in fossil-fired power plants. The research institutions and universities provided the training activities. 19 papers and presentations based on the project outcomes were given at international conferences and workshops, two scientific papers were published in international peer-reviewed journals. Articles appeared in publications such as the International periodical European Energy Innovation Magazine, the Parliament Magazine issue on EU Sustainable Energy Week, and the international VGB journal as well as IFRF's fortnightly newsletter 'Monday Night Mail'. More than 85 participants representing 14 countries were at the Final Workshop of the Project.

Co-firing technology is non-standardised, as each application is tailored to the technologies already installed at an existing plant and adapted considering the overall framework conditions (e.g. biomass availability and legal framework). However, DEBCO has successfully demonstrated that co-firing is a viable and cost-effective alternative for the reduction of carbon dioxide (CO_2) emissions from existing coal-fired plants under different conditions.

There are two main barriers for the wider implantation of co-firing. The first is related to issues of biomass sourcing/availability. Co-firing applications, even at low thermal shares (10 %) at large coal plants require enormous amounts of biomass (more than 100 000 t/y). For certain types of biomass resources (e.g. agrobiomass), there may be local availability but a lack of business structures to meet such a large demand. This was the main barrier for the commercial operation of the Greek co-firing demonstration beyond the project duration.

The other key barrier is the policy framework. In some countries, co-firing is not recognised as a renewable energy technology and hence does not benefit from the support that other types of bio-electricity can expect. This can put a stop to the deployment of co-firing, as there are no financial incentives for utilities to embark on such an initiative.

Outlook and commercial application of the outputs

The DEBCO project was successfully completed in December 2012. The project successfully demonstrated different co-firing concepts (e.g. RDF co-firing, agrobiomass co-firing, wood pellets repowering) in different types of power plants; therefore, it is assumed that any current and future implementations of the co-firing technology along these lines will built upon the experiences of the DEBCO project.

In particular, there have been several industrial repowering projects of existing coal-fired power plants to wood pellets firing in Europe (e.g. Drax and Tilbury – both in the UK). This suggests that there is commercial interest for co-firing technology provided that the regulatory framework is favourable.

There was no direct follow up project for DEBCO at an EU level; however, several other projects have built on and expanded on the experiences of the DEBCO (e.g. the FP7 SECTOR project that included co-firing activities with torrefied biomass). A direct follow-up of the project was a national funded project in Greece: 'ENER-BIO: Energetic utilization of solid and liquid biofuels for the power sector'. It was funded by the General Secretariat for Research and Technology through NSRF - Cooperation (09-SYN-32-596) and expanded on the co-firing activities implemented at the Greek power plants.

DEBCO is still a point of reference for VGB Power Tech[17]. It defines the key elements of the co-firing, and biomass combustion technology. Some of the findings regarding storing of biomass is used in VGB-

[17] https://www.vgb.org/en/mission.html

Standard[18] on fire and explosion protection in biomass-fired power plants and in numerous VGB presentations on biomass.

The role of EU funding

The DEBCO project was co-funded by the European Commission within the Seventh Framework Programme for research, technological development and demonstration. The Horizon 2020 programme has now replaced the 7th Framework programme. The project had a total budget of more than EUR 6 million and EU funded 60 % of the project cost, while the industrial partners provided the remaining of the funding in the form of in-kind and cash contributions.

Without EU funding, it would not have been possible to bring together such a diverse team with a wide geographical coverage (partners originated from eight different EU Member States). Utilities benefitted from the participation of specialised R&D partners and technology providers; by having access to their specific capacities (e.g. simulations, measurement teams) it was possible to accumulate more varied and more specialised knowledge on the co-firing activities investigated on each site. On the other hand, R&D partners benefitted from the opportunities to be involved in novel technical experiments on real-scale applications.

The diverse geographical scope of the project also enabled to research the potential of co-firing technologies in Europe as well as to knowledge transfer between partners from different Member States; this would not have been possible in a purely industrial co-firing project focusing on a specific site.

Full project participant list

Organisation	Country	Type
Enel Ingegneria e Ricerca	Italy	Private company
Electrabel SA	Belgium	Utility company
Public Power Corporation	Greece	Utility company
Tractebel Engineering	Belgium	Private company
MATUZ, Magyar Tuzelestechnical Korlatolt Felelozsegu Tarsasag	Hungary	Private company
IFK University of Stuttgart	Germany	Academic institute
Laborelec	Belgium	Research institute
Ricerca Sul Sistema Energetico - RSE SPA	Italy	Research institute
Stichting Energieonderzoek Centrum Nederland (ECN)	Netherlands	Research institute
Centre for Research and Technology Hellas/Ethniko Kentro Erevnas Kai Technologikis Anaptyxis (CERTH)	Greece	Research institute
Agriconsulting SPA	Italy	Private company
VGB PowerTech E.V.	Germany	Technical Association
IFRF - Fondazione Internazionale per la Ricerca Sulla combustion - Onlus	Italy	Research institute
Doosan Power Systems Limited	United Kingdom	Private company
Politechnika Wroclawska	Poland	Academic institute
PCC Rokita SA	Poland	Private company
Alstom Boiler Deutschland GmbH	Germany	Private company

[18] https://www.vgb.org/shop/technicalrules/vgb-standards.html

Case study: INFRES

Author:	Heidi Saastamoinen	**Approver:**	Antti Asikainen, project co-ordinator of INFRES
Project title:	Innovative and effective technology and logistics for forest residual biomass supply in the EU (INFRES)		
Lead partner:	Natural Resource Institute Finland, Latokartanonkaari 9, 00790 Helsinki, Finland		
Project location:	Coordinated in Finland, research conducted across multiple sites in Europe.		
Technology area/s:	Bioenergy		
Start and end date:	January 2012 to August 2015		
Project cost:	EUR 4 356 975 04	**EC funding:**	EUR 3 085 051
Other funding sources:	Cash contributions from each partner		
Quantifiable outputs and impacts:	22 press releases, 33 media briefings, 18 articles in popular press, 29 peer-reviewed articles, 33 oral presentations in scientific conferences, 23 result reports, 12 newsletters, 33 posters presented, 4 videos published, 2 workshops, 1 market ready product, 23 demonstrations		
Further information:	The project website is no longer working. Documents related to INFRES can be found here. Project Coordinator – Prof. Antti Asikainen, project co-ordinator, LUKE Natural Resources Institute Finland. Visiting address, Yliopistonkatu 6, 80100 Joensuu, Finland. T +358 29 5323250. E antti.asikainen@luke.fi		

Project description

Globally, biomass is expected to play a leading role in renewable energy production. Forest biomass supply systems are in rapid development phase. Many new machines, equipment for existing machines and working methods have been developed and introduced to enhance the performance of forest biomass feedstock supply.

The EU-funded INFRES project developed and demonstrated technological and logistical solutions, which reduced the fossil energy input of biomass supply by 20 % and reduced the raw material losses by 15 %. Due to the novel technologies and efficient exchange of best practices between the countries in the consortium and other countries with similar natural conditions, the volume of forest biomass supply for energy and biorefining can be substantially higher in the future. The objective of INFRES was to accelerate the development of forest based biomass supply to reach the ambitious targets for forest energy set by many European Union Member States.

The previous study COST Action FP0902[19] widened the understanding of what ought to be done in forest bioenergy sector to make better use of the existing technologies, which gave the incentive to INFRES. The main driver for the INFRES project were the issues observed by the key research institutes in the forest biomass supply chain. The INFRES consortium included 12 private companies, one utility

19 http://www.cost.eu/COST_Actions/fps/FP0902

company, eight research institutes, and three academic institutes. The companies in the consortium and those involved in demonstrations were the direct beneficiaries of the project.

Outputs and Impacts

The project successfully identified bottlenecks in Europe's fuel biomass supply chains. The bottlenecks could be of an infrastructural, technological, organisational, logistical or social nature. In addition, the most common supply chains for wood based fuels were identified and a technology matrix tool developed that identifies the most promising innovations in the fuel supply. The tool helps to compare different supply chain configurations with current and future machinery in terms of costs, fuel consumption and CO_2 emissions. The mathematical optimization approach determines the most suitable supply strategy for a whole region and therefore enhances policy making.

The most suitable places for fuel wood storage were chosen and drying models for stemwood and logging residues were developed. The drying models enable operators to follow the drying performance of stored woody feedstock and help a supplier to deliver good quality material. The assessment of fuel chip quality was further developed, by testing different cameras that identify the shape and size of chips, as well as the moisture content of the material. Near Infrared Spectroscopy was found as a promising alternative for assessing fuel quality at a plant. The resulting technology and methods are exploitable by larger plants throughout Europe.

INFRES demonstrated the viability of the innovative concepts developed within the INFRES partnership by showing the key stakeholders how these concepts could be successfully applied to their specific work conditions. INFRES encouraged cooperation and information exchange between research institutes and SMEs by engaging them into a joint effort to achieve the common objective. Through a large number of demonstrations, real-life data was collected for modelling purposes. All demonstrations involved at least one research institute and SME working together. Involvement of demonstration partners outside the INFRES consortium increased the visibility of the demonstrations. During 2012 and 2015, no other projects offered so many opportunities for trans-border knowledge exchange in the field of biomass supply chains. The participants gained experience and their capacity to organise attractive demos rapidly grew.

The demonstrations included efficient processing of forest residues (new handling and chipping technologies), low impact stump wood harvesting, harvesting of small trees for energy, logistics development such as the different aspects of post-harvest handling, including transportation, storage and moisture content management.

One of the innovative concepts that was demonstrated was a new patented hybrid technology chipper, Kesla C 860 H, chipping pulpwood and logging residues. It was developed and studied as an INFRES case study. Productivity, fuel consumption, the quality of the chips and noise of the chipping operation was measured, analysed and compared with conventional tractor-powered and truck-mounted chipper, and the hybrid chipper was found to have the highest productivity.

Another example of successful demonstration in INFRES was the full suspension carriage by Valentini. The new carriage increases the viability of biomass recovery and in general the financial and environmental sustainability of wood harvesting from remote mountain forests. It was designed for full load suspension without the help of a diesel engine. By removing the on-board diesel engine, the overall fuel consumption was reduced by 20 %. Valentini's carriage also enables operating two identical carriages in tandem. Compared to a motorised alternative, the new tandem carriage is 40 % lighter and 33 % cheaper to purchase.

In addition, a novel service model in forest chip supply (i.e. TCS Opti software) was developed, and the results suggested that up to 20 % savings in transport distances and 13 % savings in transport costs could be obtained in the study area. Two logistical software packages were tested in Germany to examine the potential of modern map and GPS navigation-based fleet management tools in biomass operations. These tools are associated with better material flow control to customers and excellent recording of all transport activities and can therefore achieve cost savings.

The INFRES assessment quantified impacts associated with selected scenarios, featuring new technologies and increased biomass harvesting, compared to business - as - usual operations. The aim was to calculate economic impact in terms of costs and revenue of different alternatives and for selected user groups (e.g. forest owners), to quantify environmental impacts such as energy use and generation, GHG emissions and balances, transport and social impact such as employment, wages, salaries, and accident rates for the INFRES forest biomass supply chains. The key finding was that annual supply of forest biomass could be increased from 40.6 million m^3 to 161.5 million m^3 in 2020 and further 168.6 million m3 in 2030 by utilising materials from pre-commercial thinning, harvest residues and stumps. Potential fuel savings for the INFRES innovations in harvesting range from 12 % to 24 %, in chipping up to 18 %, and in transport between 12 % and 21 %.

In INFRES, the barriers to innovation that can stop or delay the introduction of new products and concepts into practice were identified. The implementation potential of new products studied in INFRES as well as their probability and the desirability of adoption were assessed with a Delphi survey.

Outlook and commercial application of the outputs

The cost and productivity data related to biomass supply chains collected in INFRES was delivered for the public tools developed in following EU-funded project S2Biom[20] and have been utilised later in data systems and simulations in different forms. The methods of decreasing the costs of the forest biomass supply chain by decreasing raw material losses developed in INFRES, led to further research within the BEST project[21] consortium (BEST – Sustainable Bioenergy Solutions For Tomorrow) in which the development work continued.

One theme, which was raised via INFRES, was the storage and quality control of stemwood and logging residues. The subject was already under research in Northern Europe, but via INFRES, the experimenting extended to Central and Southern Europe. Due to INFRES the quality prediction models became European-wide research boom and since then models have been further developed. The research has led to shortened storage times due to observed losses in long storage.

The size of the cargo space in transport equipment began to increase during the INFRES project due to changes in legislation. In Finland, the legislation changed in 2013. The cost-effectiveness of the

[20] https://www.s2biom.eu/en/
[21] http://bestfinalreport.fi/

increased size of the transport equipment was researched in the project in Finland and Sweden. In Sweden, the transition to larger cargo space was accelerated due to the project findings.

The role of EU funding

The INFRES project was co-funded by the European Commission within the Seventh Framework Programme for research, technological development and demonstration. The Horizon 2020 programme has now replaced the 7th Framework programme. The project had a total budget of more than EUR 4 million and the EU funded represented 71 % of the project cost, while the project partners provided the remaining of the funding themselves.

INFRES allowed for wider testing of biomass forest technology which was initially developed for certain European regions/countries. Such equipment exchange across wider geographically areas would not have been possible without the EU funding for INFRES.

Full project participant list

Organisation	Country	Type
Luke, Natural Resources Institute Finland	Finland	Research institute
VTT Technical Research Centre of Finland	Finland	Research institute
The Finnish Forest Research Institute, Metla	Finland	Research institute
Swedish University of Agricultural Sciences	Sweden	Academic institute
University of Natural Resources and Life Sciences, Vienna	Austria	Academic institute
The National Research Council (Cnr)	Italy	Research institute
European Forest Institute	Finland	Research institute
University of Freiburg	Germany	Academic institute
Forest Science and Technology Centre of Catalonia (CTFC)	Spain	Research institute
The Forestry Research Institute of Sweden	Sweden	Research institute
IFER - Institute of forest Ecosystem Research	Czech Republic	Research institute
B.T.G. Biomass Technology Group BV	Netherlands	Private company
Valentini Snc di Valentini Ilario Ec	Italy	Private company
Pezzolato Officine Construzioni Meccaniche SPA	Italy	Private company
Ellettari Luca Sas di Ellettari Luca EC	Italy	Private company
Ecomond Oy	Sweden	Private company
Skogstekniska Klustret Ekonomisk Forening (The Cluster of Forest Technology)	Sweden	Utility company
Serveis del Consorci Forestal De Catalunya SCCL	Spain	Private company
Johann Schwarz	Austria	Private company
Kesla Oyj	Finland	Private company
Konepaja Antti Ranta	Finland	Private company
Fallert Ortenauer Holzenergia GMBH&CO KG	Germany	Private company
Forstware Informationssysteme GMBH	Germany	Private company
Schleimer Transport	Germany	Private company

Case study: MOBILE FLIP

Author:	Heidi Saastamoinen	**Approver:**	Tarja Tamminen
Project title:	Mobile and Flexible Industrial Processing of Biomass (MOBILE FLIP)		
Lead partner:	VTT Technical Research Centre of Finland Ltd., P.O. Box 1000, FI-02044 VTT, Finland		
Project location:	Coordinated in Finland, research conducted in multiple organisations in Europe		
Technology area/s:	Bioenergy		
Start and end date:	January 2015 to December 2018		
Project cost:	EUR 9 698 843.45	**EC funding:**	EUR 8 606 175
Other funding sources:	Cash/in-kind funding from the project partners		
Quantifiable outputs and impacts:	6 articles in journals, 4 thesis/dissertations, 4 workshops, 8 non-scientific publications, 2 newsletters, 3 trainings, 72 conference presentations given, 4 videos, 2 patents applied		
Further information:	Project website Project Coordinator – Dr. Tarja Tamminen, project co-ordinator, VTT Technical Research Centre of Finland. Visiting address, Vuorimiehentie 3, 02150 Espoo. T +358 40 532 4962 E tarja.tamminen@vtt.fi		

Project description

Mobile and Flexible Industrial Processing of Biomass (MOBILE FLIP) develops and demonstrates mobile processes for the treatment of underexploited agro- and forest based biomass resources into products and intermediates. The mobile process concepts for local use have been designed around the key technologies pelletizing, torrefaction, slow pyrolysis, hydrothermal pre-treatments and carbonisation. The processes are evaluated in terms of raw material flexibility, as biomass resources are typically scattered and seasonal. The products vary depending on the process concept, being typically fuels as such or for co-combustion (pellets, torrefied pellets, biocoals), biochars for soil remediation, biodegradable pesticides for agricultural or forestry use or chemicals for wood panel industry and sugars and hydrolysable cellulose as intermediate for the sugar platform. Some of the products are marketable as such, while some others are intermediates to be further valorised by integrated large industries. In the latter case, the developed mobile unit pre-extracts the valuable components or densifies the biomass to reduce transportation costs. Over-the-fence integration to large industries will be one means to ensure the availability of utilities, such as steam and electricity, whereas in some mobile process concepts the utilities can be produced at site for internal or external uses. The driving force for this project was to support industries that are active in the biomass valorisation field, and efficient exploitation of the biomass side streams. The project is still ongoing (as of June 2018).

Direct beneficiaries of the project are the device manufacturers for treatment of agro- and forest based biomass in the consortium and the industries involved with the device production as well as further valorisation of the products. The forest owners could obtain additional income by using the improved mobile processes to produce marketable products with underexploited biomass. The market introduction of the improved processes can increase the jobs in rural areas.

MOBILE FLIP is a collaborative project under European Union's Horizon 2020 research and innovation programme involving twelve partners from five different EU countries. The consortium included five engineering and manufacture companies, six R&D institutions, and one university. Project coordination was assigned to VTT Technical Research Centre of Finland. The project consortium encouraged researchers to share their knowledge and expertise in particular techniques and methods.

Outputs and impacts

Five case studies of processes related to local treatment of underexploited biomass have been developed and four of the processes are demonstrated as part of the cases studies. The device manufacturers are their processes in these demonstrations. Although the demonstrations are still ongoing (as of June 2018), they seem successful based on the result to date. The mobile units' flexibility in terms of raw materials was examined. The processes cannot exploit all sorts of underexploited biomass, but relevant side streams for each process can be found. The project is not only related to fuel supply for bioenergy, but it is also related to other possible products that can be used for example soil amendment, fillers in resin or sugar refining.

The development of the processes in MOBILE FLIP has directly benefitted the companies that have been involved with the project to further develop their processes. The processes developed are not completely new, but the improvements will enable them to be exploited locally. One of the targets of the development is to find the right size for each mobile processes, as they cannot be too large to treat small biomass side streams, but not too small to be profitable since the production has to cover the investment and operating costs.

Different biomass raw materials, in terms of their potential for different end uses were evaluated - the project included studies on the availability and logistics of agro- and forest-based biomass resources. The raw materials analysed have been under-exploited, due to a variety of reasons, one of which is that they are found in quite remote locations, so it can be relatively expensive to transfer them to major industrial sites.

The processes for biomass side streams' utilization studied in the project were compared to the current state of utilization. In some cases, the residues would otherwise not be used, but in most cases they can be used. For instance, brewery-spent grain (BGS) can be processed to biochars that can be used for ethanol production as was done in the project, but it is also a good animal feed. The project searches for the higher value applications for the raw material.

The demonstrations and their results in MOBILE FLIP include:

- VTT and Raussin Energia Oy developed the process for producing biochar with Slow Pyrolysis of forest residues and wheat straw. The produced biochar can be used for combustion to produce heat and power at site, which reduce the need for external energy in decentralised application. The main use of biochar studied in the project was, however, for soil amendment, in which the project has exceeded the objectives in terms of characterizing biochar quality (new concept developed) and activating the biochars for high value applications. A patent related to fractionated recovery of condensables by Raussi (no 20175575-Suomi) has been accepted and the process was verified by demonstration. The process is expected to enter the market by the end of 2018;

- France SME ETIA developed mobile torrefaction and drying unit Termbio® to produce biomass pellets for fuel. Torrefied pellets can be used for power and heat production, for combustion in large-scale units, gasification and conversion to liquid fuels to produce green energy. The product is suitable for the local market, which decreases the transportation costs;
- A concept of 'Pellet mill with addition of fluid' by SPC and Bioenergy i Luleå AB has been verified in the project and a patent has been applied for (Patent application No. 1650681-8). its entry to the market entry depends on the willingness of commercial partners in the project;
- Estonian SME BioGold OU has developed a container-sized continuous hydrothermal treatment device to pre-treat the biomass with tailored solutions for the feeding and product output in continuous operation mode, which boosts the production. The product of hydrothermal treatment can be utilised in biogas production.

The environmental performance of mobile units was found to be highly dependent on the emissions from electricity production for the processes and raw material acquisition chain. The decreased need for biomass transportation makes the mobile systems emit less CO_2 compared to stationary plants, if the process is connected to the electricity grid instead of diesel generator. The products from mobile plants that use brewer's spent grain or wheat straw can in many case be used locally, which again decreases emissions related to transportation.

In Slow Pyrolysis there is liquid by product stream that has been classified as hazardous waste. Now, due to the improvements taken place in the project, a novel solution for using liquid fractions have been found. The bio-based liquids can be used in manure acidification process or in plant protection instead of synthetic pesticides and this was verified in the project. However, present EU legislation related to the use the liquid fractions is a well-known barrier to market entry.

Outlook and commercial application of the outputs

Since the project and demonstrations have not yet ended (as of June 2018), the final report and additional results are not yet complete. Scientific articles are expected - especially related to biochars. The feasibility study and Life Cycle Analyses of the studied processes will be published, and they are expected to be of considerable interest. In the pipeline, there is also follow-up project related to demonstration of logistics of biomass residues.

The project has produced a lot experimental data that can be used in standardization. One project partner RAGT Energie is actively participating in standardisation concerning pellets' production. This has been an advantage for the project since the latest knowledge on prerequisites for product pellets that meet the standards for energy recovery has been readily available.

The outlook of the project depends on the market conditions for the processes and products developed. Biochars are now in the market spotlight and their markets are expected to grow, provided demand increases for the technologies developed. Pellets are a bio-based option in solid fuel markets and a standard product. The need to replace solid fossil fuels could increase market size, which could affect to the demand of mobile solutions as well. At first in Biogold, the target was the production of bioethanol. However during the project it was considered a profitable option, and the process was further developed so that it could be linked with waste side stream pre-treatment for biogas plants.

The role of EU funding

The MOBILE FLIP project was co-funded by Horizon 2020 programme. The EU funded 89 % of the project cost, while the industrial partners provided the remaining funding in the form of in-kind and cash contributions.

Without EU funding, the companies in consortium would have been able to develop their business as usual, but the improvements in the scale done in the MOBILE FLIP project would not have been possible. EU funding allowed greater promotion of business.

Full project participant list

Organisation	Country	Type
VTT Technical Research Centre of Finland	Finland	Research Institute
Commissariat a l Energie Atomique et aux Energies Alternatives	France	Research Institute
Institut, Technologique FCBA (Foretcellulose Bois-Construction Ameublement	France	Research Institute
Natural Resources Institute Finland, LUKE, (Maa ja Elintarviketalouden Tutkimuskeskus)	Finland	Research Institute
Swedish University of Agricultural Sciences	Sweden	Academic Institute
RISE- The Swedish Research Institute	Sweden	Research Institute
BioGold OU	Estonia	Private Company
Chimar Hellas AE	Greece	Private Company
Raussin Energia Oy	Finland	Private Company
Sweden Power Chippers AB	Sweden	Private Company
Evaluation Technologique Ingenierie et Applications	France	Research Institute
RAGT Energie SAS	France	Private Company

Annex 6B - Literature

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Annex 6C – Methodological note on imports and exports

The value of the following components were assessed for bioenergy:

Table C-1 HS6 product codes relevant to the bioenergy sector

HS6 code	Brief product description
840681	Steam turbines and other vapour turbines, of an output exceeding 40 MW
840682	Steam turbines and other vapour turbines, of an output not exceeding 40 W
841280	Other engines and motors
841182	Other gas turbines, of a power exceeding 5 000 kW
841620	Other furnace burners, including combination burners
841931	Dryers: for agricultural products
841940	Distilling or rectifying plant
850161	AC generators (alternators): of an output not exceeding 75 kVA (kilovolt ampere)
850162	AC generators (alternators): of an output exceeding 75 kVA but <= 375 kVA
850163	AC generators (alternators): of an output exceeding 375 kVA but <= 750 kVA
850164	AC generators (alternators): of an output exceeding 750 kVA

Source: Comext database and Jha (2009)

Annex 6D - List of EU-funded projects

Table D.1 Bioenergy EU-funded projects

Acronym	Rcn	Project Title	EC Funding (2016 EUR)	Programme	Topic
3A-BIOGAS	67208	Three step fermentation of solid state biowaste for biogas production and sanitation (3A-BIOGAS)	1001206	FP5-EESD	1.1.4.-6.
3A-BIOGAS	71076	Biogas production from biomass in the solid state for increasing the proportion of renewable energy sources.	29535	FP5-EESD	1.1.4.-5.
3CBIOTECH	98742	Cold Carbon Catabolism of Microbial Communities underprinning a Sustainable Bioenergy and Biorefinery Economy	1574889	FP7-IDEAS-ERC	ERC-SG-LS9
ABRICOS	54149	Advanced biomass reburning in coal combustion systems (ABRICOS)	1968478	FP5-EESD	1.1.4.-5.
ABWET	193986	Advanced Biological Waste-to-Energy Technologies	3928748	H2020-EU.1.3.1.	MSCA-ITN-2014-EJD
ABWET	193986	Advanced Biological Waste-to-Energy Technologies	255664	FP7-PEOPLE	MSCA-ITN-2014-EJD
ACCENT	78495	Acceleration of the Cost-Competitive Biomass Use for Energy Purposes in the Western Balkan Countries	189441	FP6-INCO	INCO-C
AD700-2	70779	Phase 2. advanced 700° c pf power plant (AD700-2)	7072082	FP5-EESD	1.1.4.-5.
ADAW	107284	Saponification pre-treatment and biosensors based control system for slaughterhouse waste anaerobic digestion improvement	1094516	FP7-SME	SME-2012-1
ADD-ON	196657	A demonstration plant of enhanced biogas production with Add-On technology	1418291	H2020-EU.3.5.;H2020-EU.2.3.1.	SC5-20-2014
AD-WINE	101646	High performance Anaerobic digesters for the treatment of medium size wineries' effluents	816644	FP7-PEOPLE	FP7-PEOPLE-2011-IAPP
AD-WISE	104778	Automated system based on on-line VFA sensors for an optimised control of anaerobic digestion plants	960657	FP7-SME	SME-2012-1
AER-GAS	70786	A new approach for the production of a hydrogen-rich gas from biomas - an absorption enhanced reforming process (AER-GAS)	1753557	FP5-EESD	1.1.4.-5.
AER-GAS II	78774	Biomass fluidised bed gasification with in situ hot gas cleaning	2131215	FP6-SUSTDEV	SUSTDEV-1.2.5
AGROBIOGAS	84915	An integrated approach for biogas production with agricultural waste	2490519	FP6-SME	SME-2
AgroPellet	196458	Development of a pelletising machine to process multiple-source agricultural mixes	50125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
AGROPTI-GAS	89231	Demonstration of an optimised production system for biogas from biological waste and agricultural feedstock	3707644	FP5-EESD	
ALGAENET	101720	Renewable energy production through microalgae cultivation: Closing material cycles	726171	FP7-PEOPLE	FP7-PEOPLE-2011-IRSES
AMMONIA REMOVAL	51937	Development of selective catalytic oxidation "sco" technology and other high temperature nh3 removal processes for gasification power plant ('AMMONIA REMOVAL')	1171287	FP5-EESD	1.1.4.-5.
ANDIGNET	71298	Establishment of a network for the treatment and energy valorisation, by means of anaerobic digestion, of the residues generated by the citrus-processing industries	204578	FP5-IST	IPS-2000-1.2

Acronym	Rcn	Project Title	EC Funding (2016 EUR)	Programme	Topic
ANDIGNET	52009	Study for the establishment of a network of competent partners for the treatment and the energy valorisation, by means of anaerobic digestion, of the residues generated by the citrus-processing industries	0	FP5-INNOVATION-SME	
ANDI-POWER-CIFRU	89221	An anaerobic digestion power plant for citrus fruit residues	2336570	FP5-EESD	
ARBRE-TYPHOON	57531	Completion of the Arbre Plant with the Typhoon Gas Turbine	3307974	FP5-EESD	1.1.4.-5.1.3
ASHMELT	101254	Development of a practical and reliable ash melting test for biomass fuels, in particular for wood pellets	1488967	FP7-SME	SME-2011-2
BAYHEX	57583	Construction and testing of a bayonet tube high temperature heat exchanger for advanced power generation cycles	3342969	FP5-EESD	1.1.4.-5.1.2
BEE	86785	Biomass Energy Europe	2026866	FP7-ENERGY	ENERGY-2007-3.7-01
BENWOOD	92055	Coordination Actions in Support Of Sustainable And Eco-Efficient Short Rotation Forestry In CDM Countries	1103824	FP7-KBBE	KBBE-2008-1-2-07
BETA-EBM	108226	Biomass Energy Technology Assessment - Environmental Burden Minimisation	226186	FP7-PEOPLE	FP7-PEOPLE-2012-IOF
BGGE	89210	13MW CHP plant based on biomass Gasifier with gas engines	2541038	FP5-EESD	
BGGE	57494	13 MW CHP Plant Based on Biomass Gasifier with Gas Engines	2756645	FP5-EESD	1.1.4.-5.2.1
BICEPS	85631	Biogas integrated concept a European Program for sustainability	8069859	FP6-SUSTDEV	SUSTDEV-1.1.4
BICOGUSS	87154	Biogas fired co-generation-plant combined with an underground seasonal heat store	378010	FP5-EESD	
BIFFIO	110696	Cooperation between the aquaculture and agriculture sectors with the intent to use animal manure and fish faeces for sustainable production and utilization of renewable energy and recovered nutrients	1758950	FP7-SME	SME-2013-2
BIFIC	54376	Biomass/waste fbc with inorganics control (BIFIC)	1496298	FP5-EESD	1.1.4.-5.
BIGPOWER	75521	Advanced Biomass Gasification for High-Efficiency Power	2057031	FP6-SUSTDEV	SUSTDEV-1.2.5
BIGPOWER	75546	T Research Capacity of TUBITAK-MRC Institute of Energy in the Fields of Integrated Biomass Gasification with Power Technologies	810707	FP6-INCO	INCO-2004-ACC-RSTP
Bin2Grid	194456	Turning unexploited food waste into biomethane supplied through local filling stations network	711242	H2020-EU.3.3.7.;H2020-EU.3.3.3.1.;H2020-EU.3.3.2.	LCE-14-2014
BIO_MGT	86353	Innovative small scale polygeneration system combining biomass and natural gas in a micro gas turbine	1982638	FP6-SUSTDEV	SUSTDEV-1.1.4
BIO-AEROSOLS	51203	Aerosols in fixed-bed biomass combustion - formation, growth, chemical composition, deposition, precipitation and separation from flue gas (BIO-AEROSOLS)	1878003	FP5-EESD	1.1.4.-6.
BIOASH	73980	Ash and aerosol related problems in biomass combustion and co-firing (BIOASH)	2892897	FP6-SUSTDEV	SUSTDEV-1.2.5
bioburner	204366	Sustainable Hybrid Dual Burner	50000	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
BIOCAT	100971	Clean Air Technology for Biomass Combustion Systems (BioCAT)	1054793	FP7-SME	SME-2011-1
BIOCHIPFEEDING	110624	Wood chip feeding technology of the future for small-scale biomass boilers	1102685	FP7-SME	SME-2013-1

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BIOCOGEN	59860	Biomass cogeneration network (BIOCOGEN)	511589	FP5-EESD	1.1.4.-5.
BIOCURE	57561	Upgrade to CHP of a Biomass-Fired District Heating Plant in Denmark, Using a Combination of Gasification, a Novel Gas Tre	3083193	FP5-EESD	1.1.4.-5.2.1
BIOELECTRICITY CROPS	86908	Big scale demonstration of energy crops utilisation for bioelectricity generation - target B	1101596	FP5-EESD	
BIO-ENERGY CHAINS	59853	Bio-energy chains from perennial crops in south europe (BIO-ENERGY CHAINS)	2407032	FP5-EESD	1.1.4.-6.
Bioenergy4Business	194448	Uptake of Solid Bioenergy in European Commercial Sectors (Industry, Trade, Agricultural and Service Sectors) – Bioenergy for Business	1544566	H2020-EU.3.3.7.;H2020-EU.3.3.3.1.;H2020-EU.3.3.2.	LCE-14-2014
BIOFERLUDAN	194763	BIOFERLUDAN: COST-EFFECTIVE HUMIC FERTILIZERS TROUGH DIGESTATE TREATMENT AT INDUSTRIAL BIOGAS PLANT	50120	H2020-EU.3.5.;H2020-EU.2.3.1.	SC5-20-2014-1
Biofficiency	206499	Highly-efficient biomass CHP plants by handling ash-related problems	4603760	H2020-EU.3.3.2.	LCE-07-2016-2017
BIOFLAM	67576	Application of liquid biofuels in new heating technologies for domestic appliances based on cool flame vaporization and porous medium combustion (BIOFLAM)	3169826	FP5-EESD	1.1.4.-6.
Biofrigas	207984	Turning manure into fuel: a container based LBG plant for small to medium scale farms	49157	H2020-EU.3.5.;H2020-EU.2.3.1.	SMEInst-11-2016-2017
BIOGAS BY BIOAUGMENT	57640	Optimised Biogas Production and Resource Recovery through Bio-Augmentation in a Joint Plant Treating Poultry and Pig Wa	670748	FP5-EESD	1.1.4.-5.2.1
BIOGAS CHCP	85723	Biogas based polygeneration for combined heat, cooling and power applications	3097717	FP6-SUSTDEV	SUSTDEV-1.1.4
Biogas2PEM-FC	105799	Biogas Reforming and Valorisation Through PEM Fuel Cells	1162200	FP7-SME	SME-2012-1
BiogasAction	199320	BiogasAction: Promotion of sustainable biogas production in EU	1999885	H2020-EU.3.3.7.;H2020-EU.3.3.3.1.;H2020-EU.3.3.2.	LCE-14-2015
BIO-GASCAT-POWER	57582	A 1mwe Biomass Fluidised Bed Gasifier Power Plant with Catalytic Conversion of Tars	2511146	FP5-EESD	1.1.4.-6.5.3
BIO-GASCAT-POWER	89219	A 1mwe biomass fluidized bed Gasifier power plant with catalytic conversion of tars	2511146	FP5-EESD	
BIOGASMAX	85619	Biogas market expansion to 2020	8868503	FP6-SUSTDEV	SUSTDEV-1.1.5
BIOHPR	58158	Biomass heatpipe reformer (BIOHPR)	2568126	FP5-EESD	1.1.4.-5.
BIOHYDROGEN	52666	A novel bioprocess for hydrogen production from biomass for fuel cells	2006434	FP5-LIFE QUALITY	1.1.1.-5.
BIO-HYDROGEN	75021	Development of a Biogas Reformer for Production of Hydrogen for PEM Fuel Cells	1023960	FP6-SME	SME-1
BIOHYP	79115	Hydrogen production by dark fermentation of biomass resources	181532	FP6-MOBILITY	MOBILITY-2.1
BIOKENAF	69034	Biomass production chain and growth simumation model for kenaf	1654389	FP5-LIFE QUALITY	1.1.1.-5.
BIOMAN	105078	Economically efficient biogas production from manure fibres and straw	1420009	FP7-SME	SME-2012-1
BIOMASS USE IN BRIAN	87889	Thermal utilization of virgin and residual biomass in Brianza (Italy) for district heating and electric co-generation	382938	FP6-SUSTDEV	SUSTDEV-1.1.1

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Biomasud Plus	199960	Developing the sustainable market of residential Mediterranean solid biofuels.	1971610	H2020-EU.3.3.7.;H2020-EU.3.3.3.1.;H2020-EU.3.3.2.	LCE-14-2015
BIOMAX	61331	Maximum Biomass Use and Efficiency in Large-scale Cofiring	1101137	FP5-EESD	1.1.4.-5.1.1
BIOMAX	86825	Maximum biomass use and efficiency in large-scale co-firing	1048842	FP5-EESD	
BIOMAXEFF	100478	Cost efficient biomass boiler systems with maximum annual efficiency and lowest emissions	4450776	FP7-ENERGY	ENERGY.2010.4.2-1
BIOMOB	92999	Biomass Mobilisation	1116664	FP7-REGIONS	REGIONS-2009-1
BIONICO	198047	BIOgas membrane reformer for deceNtralIzed hydrogen produCtiOn	3155509	H2020-EU.3.3.8.2.	FCH-02.2-2014
BIONORM	60344	Pre-normative work on sampling and testing of solid biofuels for the development of quality management (BIONORM)	4408546	FP5-EESD	1.1.4.-6.
BIONORM II	81405	Pre-normative research on solid biofuels for improved European standards	2892248	FP6-SUSTDEV	SUSTDEV-1.2.5
BioPellets	205062	Integrating food waste into wood pellets to convert waste grease to a useful biofuel.	50000	H2020-EU.3.5.;H2020-EU.2.3.1.	SMEInst-11-2016-2017
BIOPOWER	86915	Bioelectricity by cofiring biomass in Suomenoja pulverised coal fired boiler	2713538	FP5-EESD	
BIO-PRETREAT	78840	Effect of Pre-treatments and/or Additives to the Operational Problems during the Fluidised Bed Gasification of High-Alkali Biomass for the Production of a Hydrogen-rich Gas Stream	177272	FP6-MOBILITY	MOBILITY-2.1
BIO-PRO	73984	New Burner Technologies for Low Grade Biofuels to Supply Clean Energy for Processes in Biorefineries (BIO-PRO)	2742263	FP6-SUSTDEV	SUSTDEV-1.2.5
BIOPROS	74782	Solutions for the safe application of wastewater and sludge for high efficient biomass production in Short-Rotation-Plantations	2475473	FP6-SME	SME-2
BIORELOAD	210410	INNOVATIVE BIOLOGICAL PRE-TREATMENT TO INCREASE THE METHANE YIELD OF LIGNOCELLULOSIC AGRO-INDUSTRIAL WASTE IN BIOGAS PLANTS	49157	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
BioRES	194408	Sustainable Regional Supply Chains for Woody Bioenergy	1870075	H2020-EU.3.3.7.;H2020-EU.3.3.3.1.;H2020-EU.3.3.2.	LCE-14-2014
BIOROBUR	108653	Biogas robust processing with combined catalytic reformer and trap	2505676	FP7-JTI	SP1-JTI-FCH.2012.2.3
BIOROBURplus	207658	Advanced direct biogas fuel processor for robust and cost-effective decentralised hydrogenproduction	2945709	H2020-EU.3.3.8.2.	FCH-02-2-2016
BIOSAFOR	81337	Biosaline agroforestry: remediation of saline wastelands through the production of biosaline biomass (for bioenergy, fodder and biomaterials)	1419410	FP6-INCO	INCO-2002-A2.3
BIO-SNG	85629	Demonstration of the production and utilization of Synthetic Natural Gas (SNG) from solid biofuels	3404210	FP6-SUSTDEV	SUSTDEV-1.1.5
BIO-STIRLING	57758	Small-Scale Chp Plant Based on a Hermetic Four-Cylinder Stirling Engine for Biomass Fuels	1471645	FP5-EESD	1.1.4.-5.2.1
BIOSURF	194453	BIOmethane as SUstainable and Renewable Fuel	1877594	H2020-EU.3.3.7.;H2020-EU.3.3.3.1.;H2020-EU.3.3.2.	LCE-14-2014
BioValue	196404	Quality determination of solid biofuels in real time	1638972	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014

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BioVill	199956	Bioenergy Villages (BioVill) - Increasing the Market Uptake of Sustainable Bioenergy	1998918	H2020-EU.3.3.7.;H2020-EU.3.3.3.1.;H2020-EU.3.3.2.	LCE-14-2015
BIOWALK4BIOFUELS	94338	Biowaste and Algae Knowledge for the Production of 2nd Generation Biofuels	3141744	FP7-ENERGY	ENERGY.2009.3.2.2
BIOWARE	58415	Clean energy recovery from biomass waste & residues (BIOWARE)	1724461	FP5-EESD	1.1.4.-5.
BIOWELL	81636	Increased renewable energy recovery from biomass by highly efficient disruption process	1526779	FP6-SME	SME-1
BM-SCREW TYPE ENGINE	87180	Biomass-fired chp plant based on a screw-type engine cycle	687959	FP5-EESD	
BPV	197153	EXTRACTING VALUE FROM BYPRODUCTS OF THE FOOD INDUSTRY	50125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
BRISK	100346	The European Research Infrastructure for Thermochemical Biomass Conversion	9430616	FP7-INFRASTRUCTURES	INFRA-2011-1.1.15.
CargoMill	199313	The CARGOMIL, an innovative self propelled all terrain vehicle for mobilising "where and when the biomass is".	50125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
CASTLE	104635	Careers in Sustainability Excellence	3913611	FP7-PEOPLE	FP7-PEOPLE-2012-ITN
CATDEACT	58414	Influences from biofuel (co-) combustion on catalytic converters in coal fired power plants - target action h (catdeact)	2043350	FP5-EESD	1.1.4.-5.
CATHLEAN	68941	Catalytic hybrid lean-premixed burner for gas turbines (CATHLEAN)	3022282	FP5-EESD	1.1.4.-5.
CERES	98065	Cereal Excess as a Renewable Energy Resource	907970	FP7-SME	SME-1
CEUBIOM	86249	CLASSIFICATION OF EUROPEAN BIOMASS POTENTIAL FOR BIOENERGY USING TERRESTRIAL AND EARTH OBSERVATIONS	1496525	FP7-ENERGY	ENERGY-2007-3.7-01;ENERGY-2007-7.3-01
CH-EU-BIO	85612	Development of co-firing power generation market opportunities to enhance the EU biomass sector through international cooperation with China	657068	FP6-SUSTDEV	SUSTDEV-1;SUSTDEV-1.1.8
CHP	196161	Upscaling and commercialization of a highly efficient wood pellets fired steam engine CHP for heat and power generation	50125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
CHRISGAS	73979	Clean Hydrogen-rich Synthesis Gas	11744666	FP6-SUSTDEV	SUSTDEV-1.2.5
CLEAN ENERGY FROM BI	54742	Biomass-gasification and fuel-cell coupling via high-temperature gas clean-up for decentralised electricity generation with improved efficiency (CLEAN ENERGY FROM BIOMASS)	2048015	FP5-EESD	1.1.4.-5.
COFITECK	86357	Co-firing -from research to practice: technology and biomass supply know-how promotion in Central and Eastern Europe	566681	FP6-SUSTDEV	SUSTDEV-1;SUSTDEV-1.1.8
COMPETE	84921	Competence platform on energy crop and Agroforestry systems for arid and semi-arid ecosystems - Africa	1731959	FP6-INCO	INCO-2004-A2.3
CONTROL-AD4H2	82305	Control of Anaerobic digestion processes for optimisation of Hydrogen production	158364	FP6-MOBILITY	MOBILITY-2.1
COPOWER	73978	Synergy Effects of Co-processing of Biomass with Coal and Non-toxic Wastes for Heat and Power Generation (COPOWER)	2548452	FP6-SUSTDEV	SUSTDEV-1.2.5
CORBI	59866	Mitigation of formation of chlorine rich deposits affecting on superheater corrosion under co-combustion conditions (CORBI)	1644129	FP5-EESD	1.1.4.-5.

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CORROSION	54374	Fireside corrosion in coal-fired utility boilers (CORROSION)	2318666	FP5-EESD	1.1.4.-5.
COSYNAT	197174	Clean, Versatile and Cost-effective Waste-to-Energy Solution	50125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
CROPGEN	73977	Renewable energy from crops and agrowastes (CROPGEN)	2595856	FP6-SUSTDEV	SUSTDEV-1.2.5
CYCLOMB	209698	Disruptive Cyclone-based technology for effective and affordable particulate matter emission reduction in biomass combustion systems	1220879	H2020-EU.3.;H2020-EU.2.	FTIPilot-01-2016
DEBCO	90325	Demonstration of Large Scale Biomass Co-Firing and Supply Chain Integration	4650679	FP7-ENERGY	ENERGY-2007-2.2-04
DEBS	205069	Dall Energy Biomass System	50000	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
DEMETER	205474	Demonstrating more efficient enzyme production to increase biogas yields	4629586	H2020-EU.3.2.6.	BBI.D7-2015
DEMOCLOCK	100472	Demonstration of a cost effective medium size Chemical Looping Combustion through packed beds using solid hydrocarbons as fuel for power production with CO2 capture	5570096	FP7-ENERGY	ENERGY.2010.6.1-1
DEMO-GAS	57659	Demonstration of a 500 Kw Fixed Bed Chp Gasifiersystem Including a Novel Tar Cracker	1225105	FP5-EESD	1.1.4.-6.5.3
DEP-PROJECT	57734	Power plant based on fluidised bed fired with poultry litter	4100764	FP5-EESD	1.1.4.-5.2.1
DE-TAR	67146	Degradation of tarwater from biomass gasification (DE-TAR)	1344938	FP5-EESD	1.1.4.-5.
DIRECTFUEL	95914	Direct biological conversion of solar energy to volatile hydrocarbon fuels by engineered cyanobacteria	4037627	FP7-ENERGY	ENERGY.2010.3.5-1
DOMOHEAT	85668	Tertiary heating systems using agro, forest and wood residues	1099499	FP6-SUSTDEV	SUSTDEV-1.1.1
DOP-ECOS	99982	Optimal Design and Operation of Microbial Ecosystems for Bioenergy Production and Waste Treatment	105007	FP7-PEOPLE	FP7-PEOPLE-2011-CIG
DRY GAS CLEANING	51193	Biomass gasification for chp with dry gas cleaning and regenerative heat recovery (DRY GAS CLEANING)	828454	FP5-EESD	1.1.4.-5.
E R O B	60335	Development of an improved energy recovery of biogas by cooling and removal of harmful substances.	465944	FP5-EESD	1.1.4.-5.
EAP-FLAME	95977	The Effect of Adding H2, CO, CO2 and H2O to Premixed Hydrocarbon Flames - Numerical Characterization and Modelling	250745	FP7-PEOPLE	FP7-PEOPLE-2009-IEF
ECHAINE	70546	Energy wood production chains in europe (ECHAINE)	1850109	FP5-EESD	1.1.4.-5.
EcoBioMass	210105	EcoBioMass – harvesting forest energy biomass in the 21st century	1277630	H2020-EU.3.2.1.;H2020-EU.2.3.1.;H2020-EU.3.2.4.;H2020-EU.3.2.2.	SMEInst-07-2016-2017
ECOPYREN3	107225	"INTEGRATION OF ECOLOGICAL PROCESSES IN FOREST MODELS TO ASSESS LONG-TERM EFFECTS OF MANAGEMENT AND GLOBAL CHANGE ON FORESTS IN SOUTHWESTERN EUROPE"	100784	FP7-PEOPLE	FP7-PEOPLE-2012-CIG
EFFIGAS	210431	Innovative self-controlling biomass gasification technology to improve the biogas efficiency achieving a top quality syngas	49157	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
ELECTHANE	196702	Microbiological conversion of renewable electricity and CO2 to a natural gas quality bio-fuel	50125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
ENDOPHYTES	99386	Molecular basis of beneficial plant-endophyte interaction - sustainable agriculture from within	182762	FP7-PEOPLE	FP7-PEOPLE-2010-IOF

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ENERCOM	90318	Polygeneration of energy, fuels and fertilisers from biomass residues and sewage sludge	2822484	FP7-ENERGY	ENERGY-2007-8.2-01
ENERCORN	94491	DEMONSTRATION OF A 16MW HIGH ENERGY EFFICIENT CORN STOVER BIOMASS POWER PLANT	6570688	FP7-ENERGY	ENERGY.2008.2.2.2
ENERDEC	67412	Maximum energy yield from organic wastes and decontamination to a high quality organic fertilizer by a microbiological hybrid process (ENERDEC)	1080410	FP5-EESD	1.1.4.-6.
ENERGATTERT	86808	Optimisation of the energy valorisation biomass matter according to the philosophy of a natural park	713481	FP5-EESD	
ENV-BIO	105267	Technical and environmental analysis of advanced strategies for the energy valorisation of biomass"	304771	FP7-PEOPLE	FP7-PEOPLE-2012-IRSES
EN-X-OLIVE	107786	Supporting SME driven olive industry to comply with EU directives	2304410	FP7-SME	SME-2
ESCHAINS	84537	Energy supply chains design and management for higher efficiency and sustainable futire	46278	FP6-MOBILITY	MOBILITY-4.1
EU CHINA BIOTECH	86804	Accompanying measure to assist technology transfer of Eu biomass / biomass waste utilisation technologies to China	899205	FP5-EESD	
EU-AGRO-BIOGAS	85626	European biogas initiative to improve the yield of agricultural biogas plants	4512118	FP6-SUSTDEV	SUSTDEV-1.1.1
EU-BR-IDGE	57650	Eu-Brazilian Industrial Demonstration of Gasification to Electricity	0	FP5-EESD	1.1.4.-5.2.1
EuroPruning	105073	Development and implementation of a new, and non existent, logistics chain for biomass from pruning	3439839	FP7-KBBE	KBBE.2012.1.2-01
EU-ULTRALOWDUST	100476	Next generation small-scale biomass combustion technologies with ultra-low emissions	3029441	FP7-ENERGY	ENERGY.2010.4.2-1
FBCOBIOW	67559	Safe co-combustion and extended use of biomass and biowaste in chp fb plants with accepted emissions (FBCOBIOW)	1886337	FP5-EESD	1.1.4.-5.
FB-COMBUSTION	65063	Cocombustion of biomass and fossil fuels (FB-COMBUSTION)	77155	FP5-EESD	1.1.4.-5.
FLEXHEAT	75646	Flexible premixed burners for low-cost domestic heating systems	1605108	FP6-INCO	INCO-C.1
FLEXI BURN CFB	94480	Development of High Efficiency CFB Technology to Provide Flexible Air/Oxy Operation for Power Plant with CCS	7088418	FP7-ENERGY	ENERGY.2008.6.1.1
FlexiFuel-CHX	199622	Development of a fuel flexible and highly efficient ultra low emission residential-scale boiler with coupled heat recuperation based on flue gas condensation	3514398	H2020-EU.3.3.2.4.;H2020-EU.3.3.2.2.;H2020-EU.3.3.2.1.	LCE-02-2015
FOCUS	110942	Advances in FOrestry Control and aUtomation Systems in Europe	3061517	FP7-NMP	NMP.2013.3.0-2
FORBIO	200560	Fostering Sustainable Feedstock Production for Advanced Biofuels on underutilised land in Europe	1941581	H2020-EU.3.3.7.;H2020-EU.3.3.3.1.;H2020-EU.3.3.2.	LCE-14-2015
FORENERGY	89223	Forest energy - A solution for the future power needs	2085130	FP5-EESD	
GAREP	197171	Novel GAsification REactor for combined heat and power Plant	50125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
GAS BIOREF	100466	Gasification of Biofuels and Recovered Fuels	9028742	FP7-ENERGY	ENERGY.2009.2.2.1

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GASASH	69507	Improvement of the economics of biomass/waste gasification by higher carbon conversion and advanced ash management - target action h (GASASH)	1540950	FP5-EESD	1.1.4.-5.
GASFARM	205039	SMALL-SCALE ANAEROBIC DIGESTION FOR AFFORDABLE, EFFICIENT AND SUSTAINABLE MANAGEMENT OF FARMS WASTE	50000	H2020-EU.2.3.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
GASPRO-BIO-WASTE	96913	Universal Gasification Process Analyser for Bio Mass and Organic Waste Treatment	1214954	FP7-SME	SME-1
GRASSMARGINS	101133	Enhancing biomass production from marginal lands with perennial grasses	3148758	FP7-KBBE	KBBE.2011.3.1-02
GREEN-FUEL-CELL	73958	SOFC Fuel cell fueled by biomass gasification gas	3708509	FP6-SUSTDEV	SUSTDEV-1.1.1;SUSTDEV-1.2.5
greenGain	194429	Supporting Sustainable Energy Production from Biomass from Landscape Conservation and Maintenance Work	1833964	H2020-EU.3.3.7.;H2020-EU.3.3.3.1.;H2020-EU.3.3.2.	LCE-14-2014
GREENSYNGAS	85766	Advanced Cleaning Devices for Production of Green Syngas	3034132	FP7-ENERGY	ENERGY-2007-3.2-03
H2AD-aFDPI	199494	H2AD - Innovative and scalable biotechnology using Microbial Fuel Cell and Anaerobic Digestion for the treatment of micro-scale industrial and agriculture effluents to recover energy from waste	2143289	H2020-EU.2.3.1.;H2020-EU.2.1.4.	BIOTEC-5b-2015
HarvPell	208185	Upscale and redesign of a mobile harvesting and pelletizing disruptive all-in-one machine	49157	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
HIAL	59862	Hial - biofuels for chp plants - reduced emissions and cost reduction in the combustion of high alkali biofuels (HIAL)	2374982	FP5-EESD	1.1.4.-5.
HiEff-BioPower	205806	Development of a new highly efficient and fuel flexible CHP technology based on fixed-bed updraft biomass gasification and a SOFC	4997371	H2020-EU.3.3.2.	LCE-07-2016-2017
HOMEBIOGAS	211469	Turning food industry's organic wastw into value	1577682	H2020-EU.3.5.;H2020-EU.2.3.1.	SMEInst-11-2016-2017
Homebiogas	205047	The Domestic Biogas System - Turning Waste into Value	50000	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
HOTDISC	61323	Novel Reactor System for Utilisation of Unprocessed Biomass and Waste Fuels to Replace Fossil Fuels	1541184	FP5-EESD	1.1.4.-5.2.1
HyTime	101993	Low temperature hydrogen production from second generation biomass	1643961	FP7-JTI	SP1-JTI-FCH.2010.2.4
HYVOLUTION	75525	Non-thermal production of pure hydrogen from biomass	11714677	FP6-SUSTDEV	SUSTDEV-1.2.5
IMPROVE RES ACCEPTAB	89175	Improving the acceptability of Res in Romanian wood industry, for energy production through an appropriate management	147565	FP5-EESD	
INFRES	104506	Innovative and effective technology and logistics for forest residual biomass supply in the EU	3156203	FP7-KBBE	KBBE.2012.1.2-01
InnoPellet	201671	Self-supporting biofuel sludge pellet producing system for small and medium sized sewage plants	1510950	H2020-EU.3.5.;H2020-EU.2.3.1.	SC5-20-2015
INORGASS	96565	Determination of the Fate of Inorganic Components upon Gasification of Sewage Sludge	241250	FP7-PEOPLE	FP7-PEOPLE-2009-IEF
INTCON	59847	Inteligent process control system for biomass fuelled industrial power plants - (INTCON)	970255	FP5-EESD	1.1.4.-6.
ISAAC	199962	Increasing Social Awarness and ACceptance of biogas and biomethane	1480535	H2020-EU.3.3.7.;H2020-EU.3.3.3.1.;H2020-EU.3.3.2.	LCE-14-2015

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KUDURA	208021	Upscaling of a portable hybrid solution for power supply, smart waste-to-energy	49157	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
LAMNET	60219	Latin america thematic network on bioenergy	1285863	FP5-INCO 2	
LEGUVAL	111096	Valorisation of legumes co-products and by-products for package application and energy production from biomass	1791815	FP7-SME	SME-2012-2
LIFT-OFF	70448	Multi Agricultural Fueled Staged Gasifier With Dry Gas Cleaning - Target Action H	1919885	FP5-EESD	1.1.4.-6.5.3
LIFT-OFF	86922	Multi agricultural fuelled staged gasifier with dry gas cleaning - target action H	1761243	FP5-EESD	
LIGNODECO	92994	Optimized pre-treatment of fast growing woody and nonwoody Brazilian crops by detailed characterization of chemical changes produced in the lignin-carbohydrate matrix	3235086	FP7-KBBE	KBBE-2009-3-4-02
LOGISTEC	104296	Logistics for Energy Crops' Biomass	3580098	FP7-KBBE	KBBE.2012.1.2-01
LOW EMISSION BIO-ORC	89230	Fuzzy logic controlled Chp plant for biomass fuels based on a highly efficient Orc-process	1107434	FP5-EESD	
MBF	57614	Mixed Bio-Fuel 38Mwe Power Plant Project	2012244	FP5-EESD	1.1.4.-5.2.1
MIGREYD	86919	Modular Igcc concepts for in-refinery energy and hydrogen supply	2329299	FP5-EESD	
MOBILE FLIP	193455	Mobile and Flexible Industrial Processing of Biomass	8627690	H2020-EU.2.1.5.3.	SPIRE-02-2014
MON-CHP	87159	Optimised biomass chp plant for monaghan integrating condensing economiser technology	3677935	FP5-EESD	
MOND	67198	Accompanying measure on critical technology selection and conference for renewable energy recovery from biomass generated within the european leather sector - (MOND)	284091	FP5-EESD	1.1.4.-5.
MULTI FUEL GASIFICAT	87178	Testing the gasification of secondary fuels for high-efficiency energy conversion	1138369	FP5-EESD	
NANOSTIR	86576	Optimisation of solid biofuel operated Stirling CHP units by means of nano technological coatings	332904	FP6-SUSTDEV	SUSTDEV-1.1.4
NESSIE	86898	New small scale innovative energy biomass combustor	1811995	FP5-EESD	
NEXTGENBIOWASTE	85621	Innovative demonstrations for the next generation of biomass and waste combustion plants for energy recovery and renewable electricity production	13653986	FP6-SUSTDEV	SUSTDEV-1.1.1
NOO2	110486	NOO2 - Development of an efficient oxygen elimination technology for reducing oxygen content in landfill gas for fuel quality	1081414	FP7-SME	SME-2013-1
NOVACAT	54140	Tar decomposition by novel catalytic hot gas cleaning methods (NOVACAT)	999260	FP5-EESD	1.1.4.-5.
NTPleasure	208631	Non-Thermal PLasma Enabled cAtalysis-Separation system for UpgRading biogasto mEthane-NTPleasure	192158	H2020-EU.1.3.2.	MSCA-IF-2016
OPET CHP / DHC	86969	Opet Chp/dh cluster	1685752	FP5-EESD	
OPTICOMB	67588	Optimisation and design of biomass combustion systems (OPTICOMB)	1538401	FP5-EESD	1.1.4.-5.
OPTICORR	58678	Optimisation of in-service performance of boiler steels by modelling high temperature corrosion	1307552	FP5-GROWTH	1.1.3.-5.
OPTIFUEL	205787	Smart and reliable solid biofuel quality control solution	1189339	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017

Acronym	Rcn	Project Title	EC Funding (2016 EUR)	Programme	Topic
OPTIFUEL	194686	A reliable and transparent solid biofuels online quality control system	50120	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
OPTIMA	101188	Optimization of Perennial Grasses for Biomass Production	3148439	FP7-KBBE	KBBE.2011.3.1-02
OptiMADMix	195673	Optimized Mesophilic Anaerobic Digestion Mixing	183455	H2020-EU.1.3.2.	MSCA-IF-2014-EF
OPTIMISC	101300	Optimizing Miscanthus Biomass Production - OPTIMISC	3147659	FP7-KBBE	KBBE.2011.3.1-02
OPTI-VFA	109955	"Novel monitoring and process control system for efficient production of VFA and biogas in anaerobic digestion plant"	1159013	FP7-SME	SME-2013-1
ORION	104276	ORganic waste management by a small-scale Innovative automated system of anaerobic digestION	3046686	FP7-SME	SME-2011-2
PAPER	57500	Pyrolytic Advanced Process for Energy and Recycling	2625376	FP5-EESD	1.1.4.-5.2.1
p-DRIVE	199293	Pyrolysis of Derived Residues of waste, providing Improved gas for Vehicle Engines	50125	H2020-EU.2.3.1.;H2020-EU.3.4.	IT-1-2015-1
PELLETON	199255	PELLETON – a device for production of pellets from biomass and agricultural waste for energy purposes	50125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
PHASEPLIT	191142	Two-phase Acid/Gas Anaerobic Reactor for Industrial Wastewater of Food & Drink SME industries	1126697	FP7-SME	SME-2013-1
Phoenix	199420	People for tHe eurOpean bioENergy mIX	1380443	H2020-EU.1.3.3.	MSCA-RISE-2015
Phyto2Energy	109842	Phytoremediation driven energy crops production on heavy metal degraded areas as local energy carrier	923834	FP7-PEOPLE	FP7-PEOPLE-2013-IAPP
PigHeat	205883	Utilizing Pig By-products as Heat Source to Save Recycling and Energy Cost.	1389196	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
PIGMAN	81609	A sustainable solution for pig manure treatment: Environmental compliance with the integrated pollution prevention and control directive	1462640	FP6-SME	SME-1
PLAGASMIC	104546	Advanced Microwave Plasma Gasification of pig and cow manure for cost-effective biogas generation	1161177	FP7-SME	SME-2012-1
PLANTPOWER	89269	PlantPower - Living plants in microbial fuel cells for clean, renewable, sustainable, efficient, in-situ bioenergy production	4408613	FP7-ENERGY	ENERGY.2008.10.1.1
PLASCARB	185458	Innovative plasma based transformation of food waste into high value graphitic carbon and renewable hydrogen	3814417	FP7-ENVIRONMENT	ENV.2013.6.3-1
Plasmapower	205104	PlasmaPower: hydro-catalytic plasma gasification for high-efficiency energy generation	50000	H2020-EU.2.3.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
POLAR	86963	Low cost absorption refrigeration cycle for efficient energy utilisation by small biogas CHP facilities	882418	FP5-EESD	
POLYSTABILAT	94471	Polygeneration through gasification utilising secondary fuels derived from MSW	4765618	FP7-ENERGY	ENERGY-2007-8.2-01
Poul-AR	196703	Poultry manure valorization	50120	H2020-EU.3.5.;H2020-EU.2.3.1.	SC5-20-2014-1
POWERCLEAN	69614	Thematic network on clean power generation (POWERCLEAN)	1285916	FP5-EESD	1.1.4.-5.
POWERFLAM2	86945	Studies Of Fuel Blend Properties In Boilers And Simulation Rigs To Increase Biomass And Bio-waste Materials Used For Co-firing In Pulverised Coal Fired Boilers	2216941	FP5-EESD	
POWER-GRADE CHARCOAL	107555	Large-scale production of charcoal for use in coal fired power and co-generation plants	517232	FP6-SME	SME-1

Acronym	Rcn	Project Title	EC Funding (2016 EUR)	Programme	Topic
PROBIO	72219	Production of biogas and fertilisers out of wood and straw	544148	FP6-SME	SME-1
PROBIOPOL	85673	Promoting and supporting implementation of biogas-polygeneration: a systematic approach towards sustainable energy consumption in Romania	391805	FP6-SUSTDEV	SUSTDEV-1;SUSTDEV-1.1.8
PROCOMO	72282	Protective coatings with combined monitoring system to control process conditions in boilers	722406	FP6-SME	SME
PROPANERGY	85750	Integrated bioconversion of glycerine into value-added products and biogas at pilot plant scale	2035686	FP7-ENERGY	ENERGY-2007-3.3-02
PYROGAS	102284	The integration of intermediate pyrolysis and vapour gasification to create and effective and efficient biomass-to-energy system for combined heat and power	1107543	FP7-PEOPLE	FP7-PEOPLE-2011-IAPP
PyroTRACH	209932	Pyrogenic TRansformations Affecting Climate and Health	1966099	H2020-EU.1.1.	ERC-2016-COG
READY	86928	Reshment with advanced energy yield	2224863	FP5-EESD	
RECOMBIO	94494	Recovered Fuels combined with Biomass	4373838	FP7-ENERGY	ENERGY.2008.2.2.2
Record Biomap	199162	Research Coordination for a Low-Cost Biomethane Production at Small and Medium Scale Applications	499921	H2020-EU.3.3.2.	LCE-19-2015
RENEGAS	198565	RENewable AdvancEd GAsification FeedstockS	50125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1
Res2Pel	196155	Innovative treatment process for biogenic waste and residual materials to manufacture compactedfuels as pellets or briquettes	50125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
ROBIOT	211315	Improving the sustainability of bioenergy production with a Robot for Biomass Quality Management	49157	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
ROD-PICKER	105408	Automatic harvesting system for SRC nurseries	1313614	FP7-SME	SME-2012-1
ROKWOOD	106232	European regions fostering innovation for sustainable production and efficient use of woody biomass	1653893	FP7-REGIONS	REGIONS-2012-2013-1
S2BIOM	109514	Delivery of sustainable supply of non-food biomass to support a “resource-efficient” Bioeconomy in Europe	4030992	FP7-ENERGY	ENERGY.2013.3.7.1
SEAWEED AD	99329	Anaerobic Digestion of Seaweed for Biofuels	221759	FP7-PEOPLE	FP7-PEOPLE-2010-IEF
SECTOR	101152	Production of Solid Sustainable Energy Carriers from Biomass by Means of Torrefaction	7740218	FP7-ENERGY	ENERGY.2011.3.7-1
SECURE	95992	Sustainable European Community Biofuel Industries and Systems (SECURE)	187227	FP7-PEOPLE	FP7-PEOPLE-2009-IEF
SECURECHAIN	194442	Securing future-proof environmentally compatible bioenergy chains	1814110	H2020-EU.3.3.7.;H2020-EU.3.3.3.1.;H2020-EU.3.3.2.	LCE-14-2014
SEDIS	71342	SEWAGE SLUDGE WITH ENERGY RECOVERY THROUGH DOWNSCALED FLUIDISED BED GASIFICATION AND CHP UNITS	1583647	FP5-IST	IPS-2000-1.2
SEEMLA	199961	Sustainable exploitation of biomass for bioenergy from marginal lands in Europe	1629884	H2020-EU.3.3.7.;H2020-EU.3.3.3.1.;H2020-EU.3.3.2.	LCE-14-2015
SEFCO	52723	quality of secondary fuels for pulverised fuel co-combustion (SEFCO)	920266	FP5-EESD	1.1.4.-5.
SIMWOOD	110708	Sustainable Innovative Mobilisation of Wood	6037284	FP7-KBBE	KBBE.2013.1.2-07

Acronym	Rcn	Project Title	EC Funding (2016 EUR)	Programme	Topic
SINTRAN	194727	Safe and INtegrated thermal TRANsformation of humid organic waste resulting in green energy and valuable remainders	50120	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
SLAGMOD	51196	Slagging and fouling prediction by dynamic boiler modelling (slagmod)	1572043	FP5-EESD	1.1.4.-5.
SMART TANK	96926	Farm and Agriculture Stabilised Thermophilic Anaerobic Digestion	865508	FP7-SME	SME-1
SOLREF	73987	Solar Steam Reforming of Methane Rich Gas for Synthesis Gas Production (SOLREF)	2581353	FP6-SUSTDEV	SUSTDEV-1.2.6
SRF-OZO	186021	Impact of poplar bioenergy cultivation on ozone and volatile organic compound emissions	228347	FP7-PEOPLE	FP7-PEOPLE-2013-IIF
STAR-AGROENERGY	100302	Scientific & Technological Advancement in Research on Agro-Energy: an integrated approach to renewable energy generation according to sustainability criteria	3538742	FP7-REGPOT	REGPOT-2011-1
STRAWGAS	51194	Straw gasification for co-combustion in large chp plants ('STRAWGAS')	690716	FP5-EESD	1.1.4.-5.
SUGAR	85135	Value-added chemicals and hydrogen from biomass	31355471	FP6-MOBILITY	MOBILITY-1.3
SUNBIOPATH	92954	Towards a better sunlight to biomass conversion efficiency in microalgae	3245872	FP7-KBBE	KBBE-2009-3-2-02
SUPERHYDROGEN	59845	Biomass and waste conversion in supercritical water for the production of renewable hydrogen	1905963	FP5-EESD	1.1.4.-6.
SYNERGY	206535	Plugplay gasification plant for onsite conversion of otherwise unusable waste into renewable energy	50000	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
SYNGAS	108879	Numerical Characterization and Modelling of Syngas Combustion	233097	FP7-PEOPLE	FP7-PEOPLE-2012-IEF
SYSTEMIC	210180	Systemic large scale eco-innovation to advance circular economy and mineral recovery from organic waste in Europe	7727251	H2020-EU.3.5.4.	CIRC-01-2016-2017
TARGET	54146	The influence of tar composition and concentration on fouling, emission and efficiency of micro and small scale gas turbines by combustion of biomass derived low calorific valued gas (TARGET)	1246690	FP5-EESD	1.1.4.-5.
TES	196516	Total Energy System: innovative in-farm cogeneration plant for manure valorisation viable even for small farms	50125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
THERCHEM	105802	Thermochemical pre-treatment technology for residues from breweries and other biomass to enhance anaerobic digestion	728421	FP7-SME	SME-2012-1
TRIG	85719	Tri-generation; CHP and cooling, with integrated flue gas-condensation based on solid biomass fuels	1242073	FP6-SUSTDEV	SUSTDEV-1.1.4
ULCOS	74430	Ultra-Low CO2 steelmaking	24721863	FP6-NMP	NMP-2003-3.4.5.1
UNIfHY	104612	UNIQUE gasifier for hydrogen Production	2254422	FP7-JTI	SP1-JTI-FCH.2011.2.3
UNIQUE	85737	Integration of particulate abatement, removal of trace elements and tar reforming in one biomass steam gasification reactor yielding high purity syngas for efficient CHP and power plants	3006415	FP7-ENERGY	ENERGY-2007-2.2-01
uP_running	199958	Take-off for sustainable supply of woody biomass from agrarian pruning and plantation removal	1992920	H2020-EU.3.3.7.;H2020-EU.3.3.3.1.;H2020-EU.3.3.2.	LCE-14-2015
USELA	196225	Useful energy from contaminated landfill gas	50120	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2014-1
VALORGAS	94057	Valorisation of food waste to biogas	3773408	FP7-ENERGY	ENERGY.2009.3.2.2

Acronym	Rcn	Project Title	EC Funding (2016 EUR)	Programme	Topic
VISCON	51201	Visual sensing for optimised control of burner bank performance and enhanced plant lifetime ('VISCON')	1498631	FP5-EESD	1.1.4.-5.
WACOSYS	86546	Monitoring and control system for wastewater irrigated energy plantations	706522	FP6-SME	SME
WAWAROMED	54427	Wastewater recycling of olive mills in mediterrenean countries - demonstration and sustainable reuse of residuals	1206327	FP5-INCO 2	
WOOD-EN-MAN	58715	Wood for energy- a contribution to the development of sustainable forest management.	2031985	FP5-LIFE QUALITY	1.1.1.-5.
ZeoBio-NG	204383	Innovative biogas upgrading system based on novel Zeolite adsorbent technology for producing Bio-based Natural Gas	50000	H2020-EU.2.3.1.;H2020-EU.2.1.1.;H2020-EU.3.3.	SMEInst-09-2016-2017
No acronym	54924	Small-scale total energy systems powered by biomass and wastes	30138	FP5-EESD	1.1.4.-5.
No acronym	72317	Developing domesting gas boiler with sensor supported combustion of different qualities of natural gas, hydrogen enriched natural gas and biogas	30756	FP5-EESD	1.1.4.-5.
No acronym	51745	Development of a new design methodology and of a prototype, based on artificial intelligence for an small scale biomass boiler with high efficiency and low emission	29936	FP5-EESD	1.1.4.-5.
No acronym	61578	Membrane anaerobic reactor system	29535	FP5-EESD	1.1.4.-1.
No acronym	51744	Development of an improved energy recovery of biogas by cooling and removal of harmful substances	30499	FP5-EESD	1.1.4.-5.
No acronym	64625	Clean and efficient waste incineration, waste-to-energy and biomass combustion (CLEANWEB)	0	FP5-JRC	M04;S10;P01

Table D.2 EU-funded projects of multiple RES technologies, where Bioenergy is one of the funded technologies

Acronym	Rcn	Project Title	EC Funding (2016 EUR)	Programme	Topic	RE technologies
BIODISH	51191	Development of a ceramic hybrid receiver for biogas fired dish-stirling-systems for electric power supply ('BIODISH')	587161	FP5-EESD	1.1.4.-5.	Solar Thermal, Bioenergy
BIOGO-FOR-PRODUCTION	110962	Catalytic Partial Oxidation of Bio Gas and Reforming of Pyrolysis Oil (Bio Oil) for an Autothermal Synthesis Gas Production and Conversion into Fuels	9108153	FP7-NMP	NMP.2013.1.1-1	Bioenergy, biofuels
BIOSOD	86964	Development of an autonomous biomass-solar thermally driven distillation system	1097073	FP5-EESD		Solar Thermal, Bioenergy
BIOTROLL	67151	Integrated biological treatment and agricultural reuse of olive mill effluents with the concurrent recovery of energy sources	1954799	FP5-LIFE QUALITY	1.1.1.-5.	Bioenergy, biofuels
CO-PRODUCTION BIOFUE	67138	Integrated biomass utilisation for production of biofuels target action h and j (CO-PRODUCTION BIOFUELS)	8290814	FP5-EESD	1.1.4.-6.	Bioenergy, biofuels
ECO-CITY	85713	Joint ECO-City developments in Scandinavia and Spain	13784223	FP6-SUSTDEV	SUSTDEV-1;SUSTDEV-2003-CONCERTO	Wind, Bioenergy
ENANAMMIC-BIOF	92496	Engineering Anaerobic Mixed Microbial Communities for Biofuels Production	48718	FP7-PEOPLE	PEOPLE-2007-2-2.ERG	Bioenergy, biofuels
Enerbox	197583	Sustainable and Standalone Oxyhydrogen powered heat generator box	50125	H2020-EU.2.3.1.;H2020-EU.3.3.	SIE-01-2015-1	Bioenergy, Solar PV
EURECONF	57676	European Re Conferences 2001/2002: Integrated Initiative for Pv, Wind & Biomass Technologies for European Competitiveness on the World Re Markets	630072	FP5-EESD	1.1.4.-5.2.1	Wind, solar PV, bioenergy
EURECONF	86850	European re- conferences 2001/2002: integrated initiative for Pv, wind & biomass technologies for European competitiveness on the world re- markets	630072	FP5-EESD		Wind, solar PV, bioenergy
FLEXFUEL	87887	Demonstration of a flixible plant processing organic waste, manure and/or energycrops to bio-ethanol and biogas for transport	4628085	FP6-SUSTDEV	SUSTDEV-1.1.5	Bioenergy, biofuels
GLYFINERY	85764	Sustainable and integrated production of liquid biofuels, bioenergy and green chemicals from glycerol in biorefineries	4190818	FP7-ENERGY	ENERGY-2007-3.3-02	Bioenergy, biofuels
GREEN SOLAR CITIES	85686	Global renewable energy and environmental neighbourhoods as solar cities	7294590	FP6-SUSTDEV	SUSTDEV-1	Solar Thermal, Bioenergy
HPC4E	199142	HPC for Energy	2003172	H2020-EU.2.1.1.	EUB-2-2015	Wind, bioenergy
MacroFuels	199672	Developing the next generation Macro-Algae based biofuels for transportation via advanced bio-refinery processes	5999893	H2020-EU.3.3.3.1.;H2020-EU.3.3.3.3.	LCE-11-2015	Bioenergy, biofuels
NOE-BIOENERGY	73983	Overcoming Barriers to Bioenergy (NOE-BIOENERGY)	9890245	FP6-SUSTDEV	SUSTDEV-1.2.5	Bioenergy, biofuels
PREMIA	87881	R&D, demonstration and incentive programmes effectiveness to facilitate and secure market introduction of alternative motor fuels	1236281	FP6-SUSTDEV	SUSTDEV-1.1.5	Bioenergy, biofuels
PYROCHAR	110941	PYROlysis based process to convert small WWTP sewage sludge into useful bioCHAR	1148939	FP7-SME	SME-2013-1	Bioenergy, biofuels

Acronym	Rcn	Project Title	EC Funding (2016 EUR)	Programme	Topic	RE technologies
REELCOOP	109511	Research Cooperation in Renewable Energy Technologies for Electricity Generation	5211510	FP7-ENERGY	ENERGY.2013.2.9.1	Solar PV, Solar Thermal, Bioenergy
SECRHC-PLATFORM	100483	Support to the activities of the European Technology Platform on Renewable Heating and Cooling	1049463	FP7-ENERGY	ENERGY.2010.4.5-1	Geothermal, solar thermal, bioenergy
SOLENALGAE	199416	IMPROVING PHOTOSYNTHETIC SOLAR ENERGY CONVERSION IN MICROALGAL CULTURES FOR THE PRODUCTION OF BIOFUELS AND HIGH VALUE PRODUCTS	1441875	H2020-EU.1.1.	ERC-StG-2015	Bioenergy, biofuels
SUNSTORE 4	94908	Innovative,multi-applicable-cost efficient hybrid solar (55%)and biomass energy(45%) large scale (district) heating system with long term heat storage and organic Rankine cycle electricity production	6633766	FP7-ENERGY	ENERGY.2009.4.5.1	solar thermal, bioenergy
No acronym	71003	Clean and Efficient Energy from Waste and Biomass	0	FP6-JRC	2.3.2	Bioenergy, biofuels

Annex 7

Technology Sector Report Biofuels

(Deliverable D2.7)

Authors:
Onne Hoogland (Trinomics)
Elske Veenstra (Trinomics)
Perla C. Torres Vega (Trinomics)
Muhammad Saad Qureshi (VTT)

1 Introduction

This report is one in a series of eight technology reports for the study *Impacts of EU actions supporting the development of renewable energy (RE) technologies*, prepared for the European Commission. The report has two objectives: 1) describing how EU research and development (R&D) funding for the biofuels technologies has impacted the biofuels sector in the EU, and 2) describing more broadly the development of the biofuels sector to which the EU R&D funding has contributed. It is based on a compilation of data from several databases, a questionnaire sent to coordinators of EU-funded R&D projects, case studies, interviews and literature research. The methodology applied in this study is documented in a separate deliverable.[1] Where relevant, limitations and assumptions are mentioned throughout this report.

Biofuels are fuels derived from organic matter, especially biomass and/or renewable waste. Biofuels are largely used for transportation, however bio-oils can also be used for power, cooling and heat generation. The definition of biofuels is similar to that of bioenergy, but in this study the distinction is made between *liquid* biofuels - which are considered in this report on biofuels - and *solid* and *gaseous* biomass fuel - which are considered in the report on bioenergy.

The EU transport sector emits about a quarter of the total greenhouse gas emissions, and emissions are increasing. GHG emission reduction is challenging in transportation, but initiatives such as sustainable blending of biofuels are achievable in the short term. This solution is much faster to implement than deploying electric vehicles in the transport system and has generated significant interest from many countries during the last decades. Presently, an increasing number of countries are looking into electric vehicles and hydrogen and some have plans to prohibit (bio)fuelled cars in the long term. However, biofuels will continue to play a vital role in the global transition, as it will remain to be the only viable option for transport modalities that are difficult to electrify, such as aviation, shipping and heavy-duty road transport. Demand for sustainable biofuels for these transport modalities is likely to grow in the future.

Both R&D funding and policies have driven a fast increase in the use of first generation biofuels in the EU. The blending mandate under the Renewable Energy Directive (RED-1) from 2009 created a market for biodiesel and bioethanol. In response to the critical discussion about deriving 'first' generation biofuels from edible products, 'second' and 'third generation' biofuels are under development, which are often more generally referred to as 'advanced biofuels'. The focus of EU R&D has been on developing production technologies for these advanced biofuels.

The EU 2030 climate and energy policy framework, including the new Renewable Energy Directive (RED-2) and LULUCF (Land Use, Land Use Change and Forestry) policies, are creating new markets for advanced biofuels. In addition, the EU Bioeconomy Strategy and Circular Economy Action Plan can also promote higher value bioproducts. These policies set requirements for feedstocks, including limiting the use of food crops as a feedstock, so the possible use of alternative raw materials is a topic of considerable R&D. Wood-based biomass, by-products and wastes of the forest or food industries, or dedicated energy crops, can increase the biomass supply for biofuel production. In the future, new types of biomass, like algae or microalgae, may also become available.

[1] Trinomics (2018) - Study on impacts of EU actions supporting the development of renewable energy technologies – Literature review and methodology (Deliverables D1.1 and D1.2)

2 Historical R&D funding

2.1 EU R&D funding

The European Commission has supported biofuel technologies with over EUR 590 million during FP5-7 and H2020, which has been used to support more than 130 projects. Another EUR 48 million was provided to projects that focused on combinations of biofuels and bioenergy (see Table 2.1 and Annex D for a full list of projects). This makes biofuels the third largest recipient of EU RE R&D funding, after solar PV.

Table 2.1 EU funding per framework programme (1998 to mid-March 2018, 2016 million euros[2])

Framework programme	Biofuels		Biofuels and other renewable energy sources	
	EU funding	Number of projects	EU funding	Number of projects
FP5	18.68	9	10.25	2
FP6	54.51	12	15.75	4
FP7	340.42	79	14.50	4
H2020[3]	177.40	39	7.44	2
Total EU funding	**591.01**	**139**	**47.94**	**12**

Source: CORDIS (2018)

2.1.1 Top recipients

Table 2.2 shows the top recipients of R&D funding from FP7 and H2020, and highlights the diversity of organisations that have received R&D funding. These include research institutes, universities, manufacturing companies and project developers from various MS. The top recipients, Clariant and Swedish Biofuels, received more than EUR 20 million in funding each. Table 2.3 shows that most FP7 and H2020 funding was allocated to parties in Germany, Italy and the Netherlands, each receiving over EUR 35 million from FP7 and H2020 (until the end of 2017).

Table 2.2 Top 10 recipients of EU funding by organisation (in 2016 euros).

Rank	Organisation	Type of organisation	Funding
1	Clariant Produkte (Deutschland) GmbH	Manufacturer	22 652 720
2	Swedish Biofuels AB	Project developer	21 687 112
3	Arcelormittal Belgium NV	Manufacturer	14 279 177
4	Energochemica Trading AS	Project developer	13 441 418
5	Biochemtex Spa	Project developer	12 479 143
6	Centre national de la Recherche Scientifique CNRS	Research institute	10 501 043
7	Fraunhofer Gesellschaft zur Foerderung der Angewandten Forschung E.V.	Research institute	9 448 475
8	VTT Technical Research Centre of Finland	Research institute	7 643 997
9	BTG Biomass Technology Group BV	Project developer	5 241 065
10	Universiteit Gent	University	5 138 807

Source: CORDIS (2018)
The source data covered H2020 funding and 75 % of FP7 funding. No data was available for recipients of FP5, FP6 and part of the FP7 funding. Projects under 'multiple RE technologies' are not included in this table.

[2] Historical values have been inflation adjusted to arrive at 2016 constant values. This has been done to show the values of budgets, prices and other monetary indicators without the impact of varying price levels over the years so that they can be compared over time more accurately.
[3] Funding from H2020 is still ongoing. The tables and graphs presenting EU R&D funding in this section include funding until mid-March 2018 (unless specified otherwise).

Table 2.3 Top 10 recipients of EU funding by country (in 2016 euros)

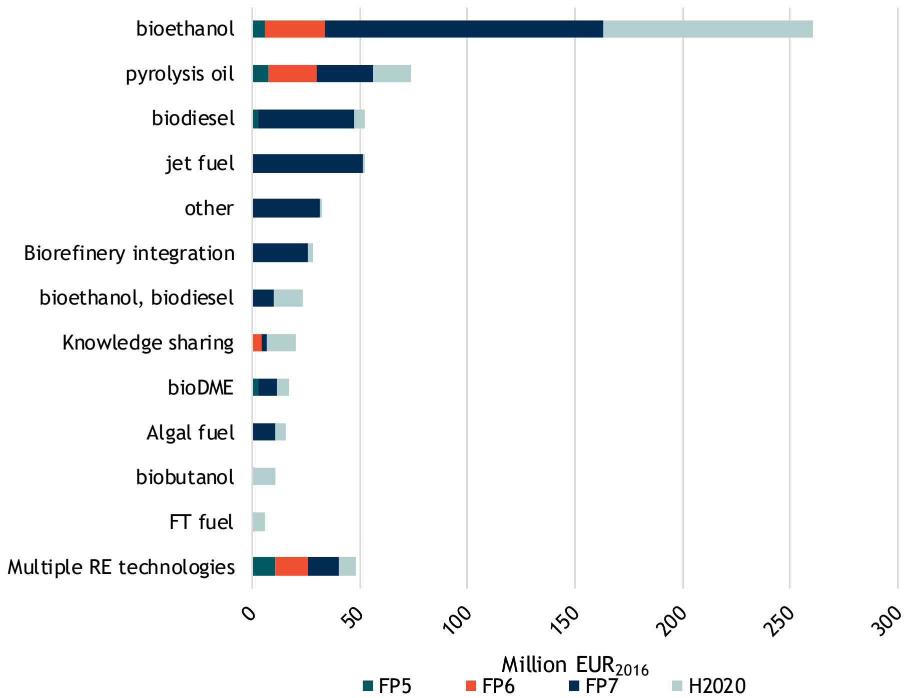
Rank	Country	Funding
1	Germany	68 071 766
2	Italy	41 392 069
3	Netherlands	36 625 622
4	United Kingdom	32 112 041
5	France	29 173 098
6	Sweden	28 768 744
7	Belgium	28 424 238
8	Spain	23 304 896
9	Slovakia	17 170 293
10	Finland	16 651 887

Source: CORDIS (2018)
The source data covered H2020 funding and 75 % of FP7 funding. No data was available for recipients of FP5, FP6 and part of the FP7 funding. Projects under 'multiple RE technologies' are not included in this table.

2.1.2 Evolution of research topics

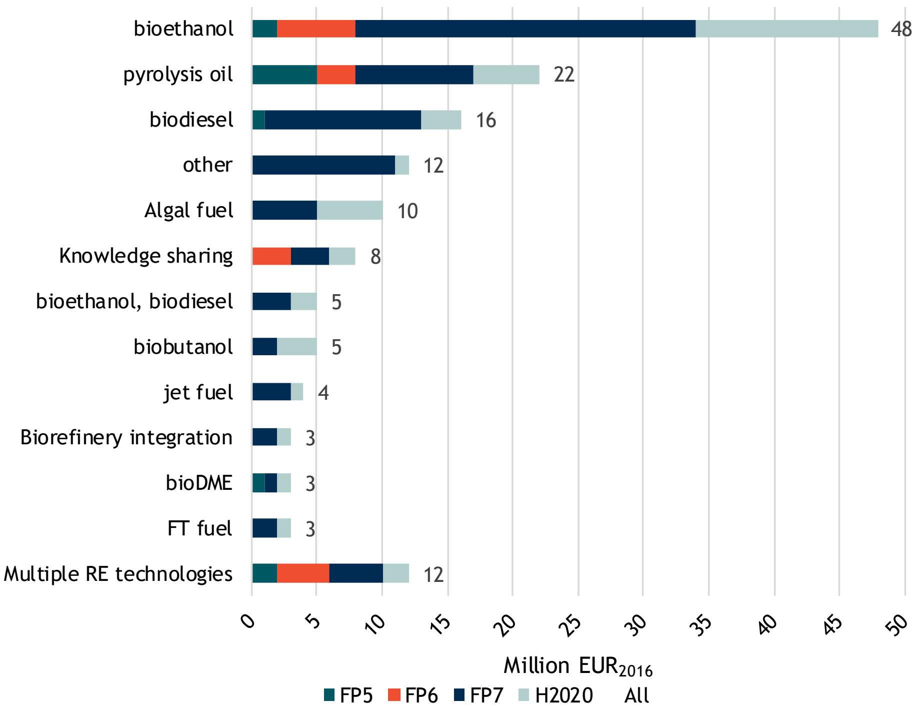
The industry has undertaken R&D on an expanding range of biofuels, of which many received EU funding (see Figure 2.1). By far, the majority of funding from the FPs was allocated to fermentation technologies for the production of bioethanol. Bioethanol also had the higher number of research projects funded (see Figure 2.2). Other important fields of research looked at technologies to produce biodiesel, pyrolysis oil, jet fuel and at biorefinery integration. Under FP7 and H2020, several projects were funded that specifically looked at transesterification (for the production of biodiesel and jet fuel), gasification (for the production of biodiesel, bioDME and Fischer-Tropsch fuel), and catalysis (for various biofuels). Projects classified as 'other' include research on combustion, pre- and post-treatment, standardisation and coordination projects.

Figure 2.1 EU funding per sub-technology/area (2016 million euros)



Source: CORDIS (2018)
The area 'multiple RE technologies' includes projects in which biofuels is one of multiple RE technologies.

Figure 2.2 Number of projects per sub-technology/area



Source: CORDIS (2018)
The area 'multiple RE technologies' includes projects in which biofuels is one of multiple RE technologies.

Biofuel development in recent years has progressed through three generations of technology. Initially, a lot of R&D efforts were made in the production of ethanol from first-generation, food-based crops. Given the debate of food versus fuel, the focus was then shifted to sustainable lignocellulosic biomass (dry plant matter based feedstock). First generation biofuels were generally produced through bio-chemical routes (i.e. fermentation of food crops using enzymes and transesterification of fatty materials to biodiesel). A lot of research was done on enzyme-based processing routes and some research is still continuing, for example on algae oil and fermentation of cellulosic biomass. Advanced biofuels, such as cellulosic ethanol, algal biofuels, and biofuels for aviation, are at different stages of technological maturity. EU R&D funding has grasped opportunities for innovation and technological advancement across the entire spectrum, contributing to the advancement of Technology Readiness Levels (TRLs):

- Cellulosic ethanol is closest to commercialisation from the advanced biofuels, which the EU funding contributed to. Several funded projects moved the TRL levels from 2 to 8, and many biochemical pathways were developed. Projects such as FP6 NILE and FP7 Eurobioref improved the enzymatic hydrolysis technique bringing the TRL to 5. The FP7-funded Sunliquid demonstrated on a pilot scale the production of cellulosic ethanol using an innovative fermentation process, without the need for externally added enzymes. After this successful project, a flagship cellulosic ethanol plant was announced with a production capacity of 50 000 tons/year to be built in Romania, which receives funding from the H2020 LIGNOFLAG project;

- Algae technology is at the early demonstration scale and still in the process of optimising energy efficiency. The European Commission has supported the promising technology with grants for several R&D and demonstration projects, of which some have successfully demonstrated a sustainable process for biofuels from microalgae (e.g. FUEL4me, DEMA). A special FP7 algae cluster has shown the feasibility of cultivating algae to produce fatty acid methyl ester (FAME) biodiesel (e.g. BIOFAT, ALL Gas, InteSusAL);

- EU-funded projects in support of pyrolysis oil have successfully demonstrated the technology. Several research projects were funded, for example the FP6 Biocoup project which looked at the co-processing of biofuels in standard refinery units and the FP7 Bioboost project which improved the cost efficiency of pyrolysis oil production, moving the technology from TRL 3 to 5. The FP7 Empyro project demonstrated the production of pyrolysis oil. This has strengthened the confidence of investors, and the construction of the first fast pyrolysis plant on an industrial scale has been announced to be constructed in Finland;

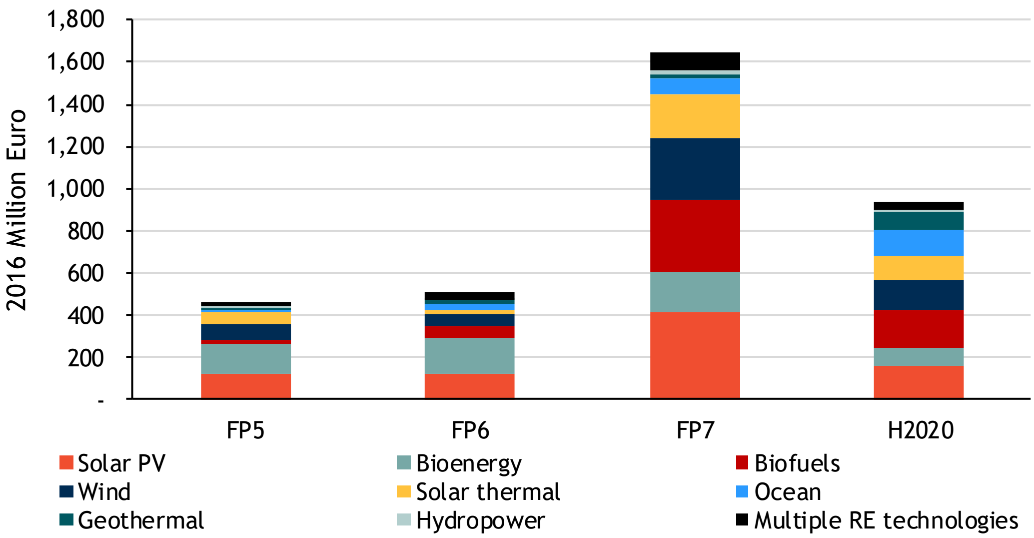
- Aviation biofuels have progressed from small pilot plants for biokerosene in 2010 to plants that can produce thousands of tons in 2015, which are being used by commercial flights. Several important EU-funded projects contributed to advancements in jet biofuels. FP7 ITAKA project investigated the production of biojet fuel from camelina oil and demonstrated the fuel use in real flights. Several large research projects have started under H2020, which focus on the production of biojet from waste sources, aiming to advance the subsector further;

- EU-funded projects contributed to the sector’s need for an integrated biorefinery approach to produce biofuels and value added chemicals. Several projects worked on this, such as FP7 EuroBioref and FP7 BIOREF-INTEG.

2.1.3 Share of total RE technology funding

Biofuel projects received more than 16 % of the EUR 3.6 million awarded under FP5, FP6, FP7 and H2020 programmes to RE technologies. In FP5, it received only 4 % of total funding, but in FP7 the share increased to 21 % of the total RE funding. Overall, biofuels became one of the technologies that received the most R&D funding from the EU, preceded only by solar PV and bioenergy.

Figure 2.3 Share of funding for each technology sector in proportion to overall funding



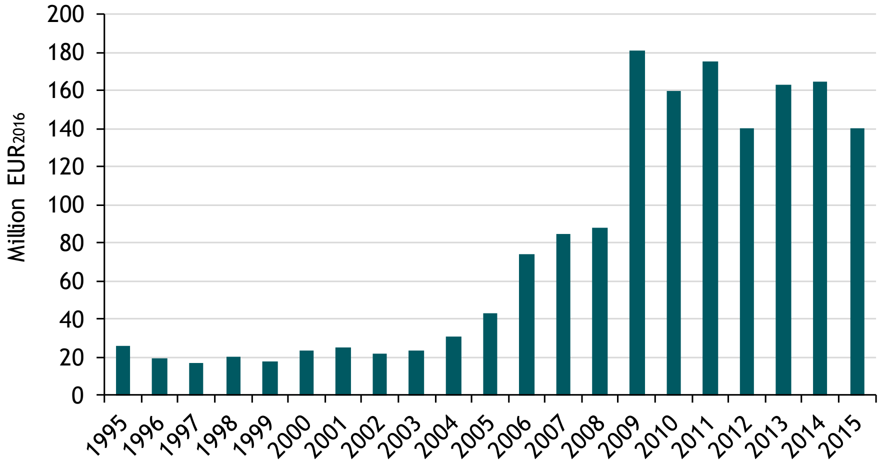
Source: CORDIS (2018)
The area ‘multiple RE Technologies’ includes projects that cover R&D on multiple renewable energy technologies.

2.2 Member State R&D funding

2.2.1 Evolution over time

R&D funding by Member States (MS) increased from EUR 37 million per year on average between 1995 and 2008 to EUR 161 million per year on average between 2009 and 2015 (see Figure 2.4). This is three times the average annual EU R&D funding between 2009-2015 (EUR 53 million). MS R&D funding for biofuels peaked in 2009, after which it declined to a relatively stable level from 2010 onwards.

Figure 2.4 Annual MS R&D funding in the EU for biofuels

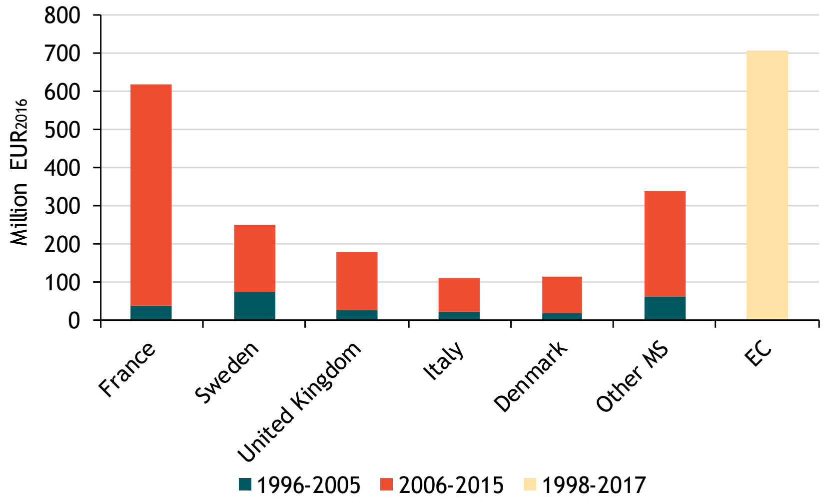


Source: Based on data from OECD/IEA (2018)
Note: Data for 20 EU countries was available in this source: The EU15 plus Czech Republic, Estonia, Hungary, Poland, Slovakia. Data from the source's larger category 'biofuels', was grouped according the definition of biofuels in this study: biofuels data includes sub-categories 'liquid biofuels'. Budgets from the unallocated categories 'Other biofuels' and 'Unallocated biofuels' that were higher than EUR 1 million were split between biofuels and bioenergy technologies using a 5-year ratio of the historical budgets of the respective MS. When no historic ratio was found for a MS, the average EU ratio was used to allocate the budgets. Data for the sub-category 'liquid biofuels' was not available for Poland during all the years in the period analysed, for the Netherlands for years 1995 to 2004, for Italy for the years 2010 to 2015, for the UK for years 1995 to 2005, 2008 and years 2010 to 2012. During those years the MS' budgets derived solely from unallocated funding.

2.2.2 Largest MS funders

The largest funders of R&D for biofuels are France, Sweden, the UK, Italy and Denmark (see Figure 2.5). Together they have provided 79 % of total MS funding. All MS provided significantly higher funding to biofuels during the period 2005 to 2015 than in the period 1995 to 2004. EU legislation and international climate objectives have increased the level of interest in biofuels.

Figure 2.5 Biofuels R&D budgets of the main Member States (1996-2015) and the EC (1998-2017)



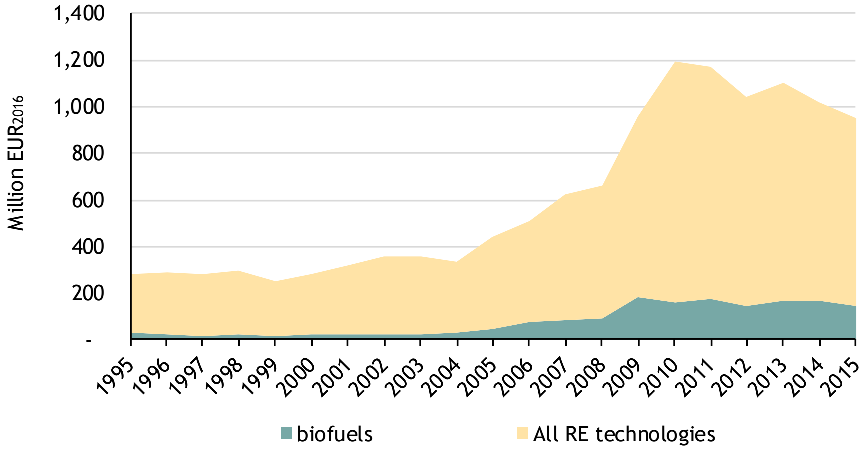
Source: OECD/IEA (2018), Eurostat (2018) and CORDIS (2018)
Note: National budgets for 2016 were excluded from the analysis because they are early estimates and lack reliability/coverage. EC funding includes projects in which biofuels is one of multiple RE technologies. MS R&D funding data for the sub-category 'liquid biofuels' was not available for Poland during all the years in the period analysed, for the Netherlands for years 1996 to 2004, for Italy for the years 2010 to 2015, for the UK for years 1996 to 2005, 2008 and years 2010 to 2012. During those years the MS' budgets derived solely from unallocated funding in the large 'biofuels' category. Time window of comparison between MS and EC funding is shifted 2 years due to data availability of MS budgets for the scope of analysis (FP5-H2020).

2.2.3 Comparison of total RE technology funding

In the period of 1995 to 2015, Member States allocated 13 % of their national R&D funding for RE technologies to biofuels (see Figure 2.6). From 1995 to 2008, the share of funding for biofuels was relatively low, with shares between 6 % and 15 % of the MS budgets for all RE technologies. From 2009 onwards, the share of biofuels increased, with shares between 13 % and 29 %.

In absolute numbers, MS R&D budgets for biofuels have also increased considerably, growing from EUR 17 million a year to more than EUR 140 million a year. Overall, biofuels has been one of the key RE technologies supported by Member States, ranking behind solar PV, bioenergy and wind energy.[4]

Figure 2.6 National R&D funding for biofuels and for all RE technologies



Source: Based on data from OECD/IEA (2018)
Note: Data for 20 EU countries was available in this source: The EU15 plus Czech Republic, Estonia, Hungary, Poland, Slovakia. Data for Italy was not available for 2015, for the Netherlands for 2004 and data for Poland was not available before 2009 for any RE technologies.

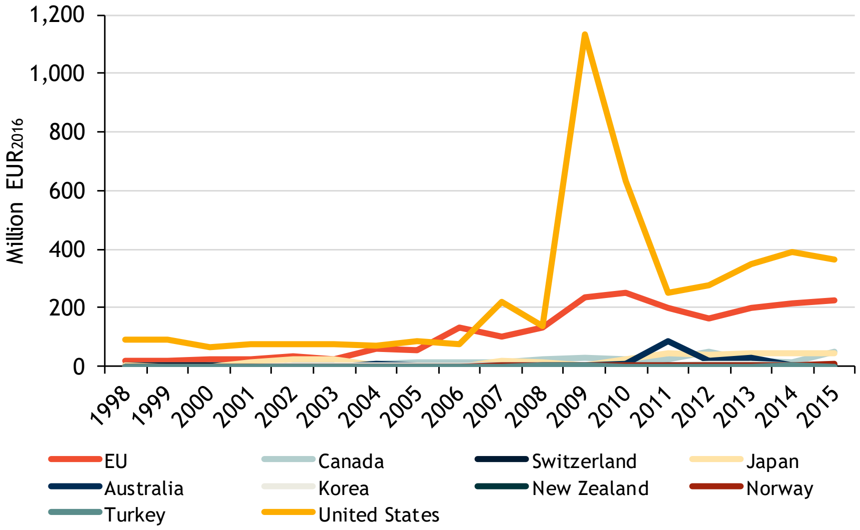
[4] Own elaboration based on data from OECD iLibrary.

2.3 Private and international R&D funding

2.3.1 International public R&D funding

Funding from the EU and MS combined for biofuels is larger than in other countries, with the exception of the United States. The United States provided EUR 220 million per year on average between 1995 and 2015 and the EU EUR 101 million. The peak of the US budget in 2009 was brought about by the Recovery Act, which supported many clean energy technologies as a stimulus to the US economy. Other countries with significant R&D budgets for biofuels are Japan, Canada and Australia. Australia's average R&D funding was EUR 8.3 million per year, with an exceptionally high R&D budget for biofuels in 2011 of EUR 86.5 million.

Figure 2.7 Comparison of international R&D funding for biofuels



Source: OECD/IEA (2018)
Note: EU covers EU and MS funding. National budgets for 2016 were excluded from the analysis because they are early estimates and lack reliability/coverage. Data covers 20 EU countries: the EU15 and Czech Republic, Estonia, Hungary, Poland, Slovakia and the European funding programmes FP5, FP6, FP7 and H2020. For countries outside the EU, national budgets were available for Australia, Canada, Japan, Korea, New Zealand, Norway, Switzerland, Turkey and the US.

2.3.2 Private R&D funding

Increased biofuel demand has also driven private R&D on biofuels and relatively large investments in biofuel production plants, particularly those integrated into existing oil refining, pulp, or other industries. Corporate R&D funding for biofuels is in the range of USD 0.2 billion to USD 0.4 billion for Europe. This is higher than public R&D budgets of around EUR 0.2 billion, and it is broadly similar to corporate R&D funding in the USA (USD 0.1 billion to USD 0.6 billion), although the estimates vary significantly per year. Overall, these figures underline the importance of the EU biofuels industry for the development of biofuels technologies.

Table 2.4 Corporate R&D budgets for biofuels in Europe and the US

Region	Corporate R&D budgets (USD billion)		
	2015	2016	2017
Europe	0.2	0.4	0.2
US	0.2	0.6	0.1

Source: Frankfurt School-UNEP Centre/BNEF - Global Trends in Renewable Energy Investment, 2016-2018 editions

2.4 Conclusions

The biofuels sector received a considerable amount of R&D funding from the EU and MS. Germany received by far the most EU R&D funding under FP7 and H2020, while France had by far the largest domestic R&D budget. Attention grew in MS, likely aided by new EU legislation that supports the blending of biofuels. Presently, an increasing number of countries are looking into electric vehicles and hydrogen and some have plans to prohibit (bio)fuelled cars in the long term. However, biofuels will continue to play a vital role in the global transition, as it will remain to be the only viable option for transport modalities that are difficult to electrify, such as aviation, shipping and heavy-duty road transport. Internationally, the EU is the second biggest funder, surpassed only by the United States. R&D focuses on various technologies, such as fermentation, transesterification, gasification and catalysis, to produce a wide array of biofuels. EU R&D funding has thus grasped opportunities for innovation and technological advancement across the entire spectrum of biofuels, contributing to the advancement of TRLs for many advanced biofuels, such as cellulosic ethanol, algae technology, pyrolysis oil, and aviation biofuels.

3 Research effectiveness

R&D projects can lead to patents, publications, spin-offs and several other, less concrete but potentially important direct outputs such as standardisation and knowledge exchange. Such impacts are the most direct impacts of R&D funding and therefore provide the cleanest view on the effectiveness of research budgets spent. In this section we discuss patents and publications and the relation to R&D funding for the biofuels sector.

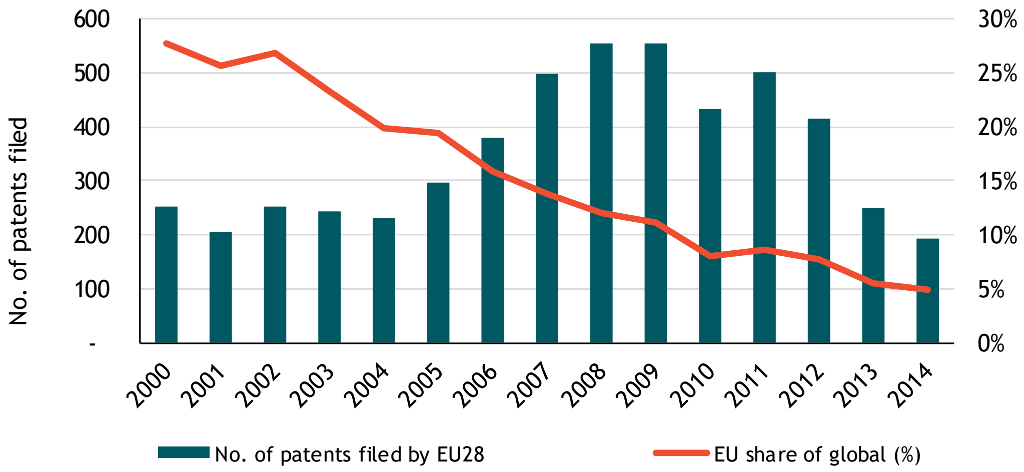
3.1 Patents

Patents are a commonly used indicator to measure the output of R&D funding as data is readily available, in a standardised form, and a direct measurement of the output of R&D funding. However, some limitations have to be taken into account, such as the fact that filing a patent is not an objective of all research projects and that the economic value of patents differs strongly.

3.1.1 Evolution over time

Figure 3.1 shows the evolution of patents filed for biofuels technologies in the EU. The number of EU patents increased until 2009, after which it decreased again to pre-2007 levels.

Figure 3.1 Evolution of biofuels patents filed by EU countries



Source: IRENA INSPIRE (2017)

There is a downward trend in EU's share of global patents. This is not only due to the decrease of EU-filed patents in absolute terms (the share dropped from 28 % in 2000 to 11 % in 2009), but also because the number of patents filed outside of the EU increased during the period.

More than 1 200 patents were filed in Germany, which made it the MS with the most EU patents (24 % of the total number), followed by Spain (14 %), Denmark (10 %), France (9 %) and the United Kingdom (8 %). These MS also received considerable R&D funding, either from domestic R&D budgets (Denmark), from the EU FPs (Germany), or from domestic and EU funding (France and the United Kingdom). The latter three MS are also the biggest exporters of biofuels components (see section 5.6).

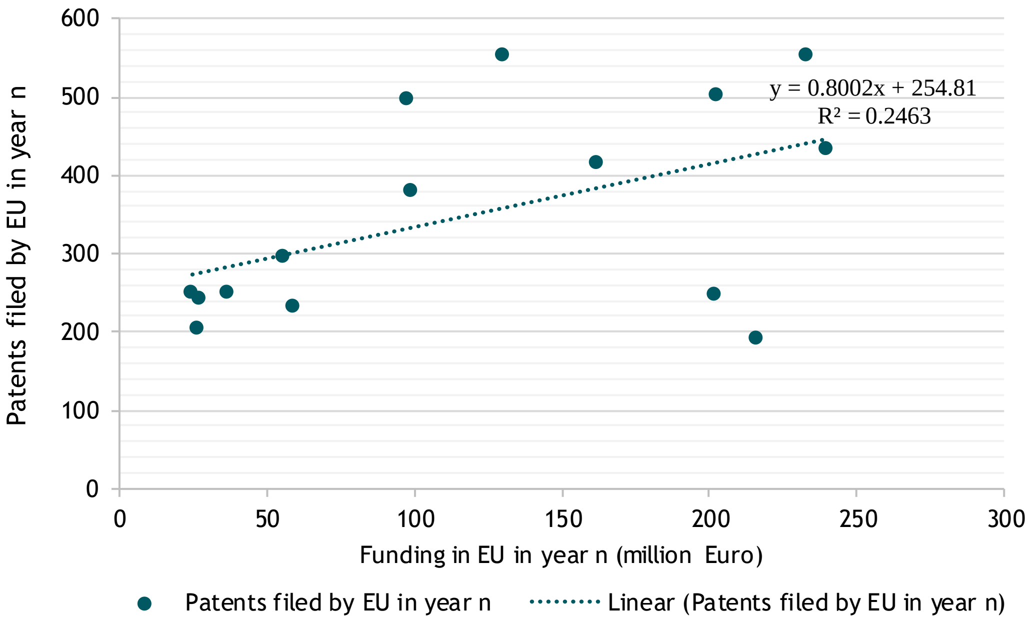
Other MS with large EU and MS R&D budgets, Sweden and Italy, didn't file many patents (4 % and 2 % of the total filed patents, respectively). Their research activities were more focused on publications (see Section 3.3 below).

3.1.2 *Effectiveness of R&D funding in producing new patents*

In theory, higher R&D budgets in a region are expected to lead to an increase in the number of patents filed from that region. The extent to which this relation exists in the biofuels sector provides insight into the objectives of the research (is it targeted at technology development, so more likely to result to a patent application?) and the effectiveness of the research (was it successful in developing the technology so resulting in a patent application?).

Figure 3.2 shows that there is no clear correlation between the total amount of patents filed and the amount of EU R&D funding (MS + EU combined). This is in line with the findings for other RE sectors and underlines that patent applications are generally not a primary objective of a research project. Biofuels has the lowest correlation from all RE technologies.

Figure 3.2 Effectiveness of R&D funding in producing new patents



Notes: We tested a delay of 0, 1, 2, 3, 4 and 5 years for the patents filed from year 2000 to 2014. 2015 data of patents was excluded because the source (IRENA) mentioned it is common to have delays of 3 years from a patent application and the year is reflected in the database. The correlation went up when 2015 data was excluded. A delay of 0 years between funding year and patents filed showed the highest correlation (R^2 = 0.2463).

3.1.3 *Contribution of EU funding*

Although it may not be the main focus of EU-funded research, FP and Horizon2020 funding has contributed to the creation of patents in several research projects. From the 22 projects that responded to our questionnaire, 4 projects reported a patent application as a result of EU funding. The boxes below give two illustrations of FP-funded projects that had one or more patents as direct outcome of their research.

Project spotlight: ITAKA: Initiative Towards sustainable Kerosene for Aviation

ITAKA is a FP7 project funded under the call for development and testing of advanced sustainable bio-based fuels for air transport. The projects, which finalised in October 2016, focused on the development of commercial biojet fuel value chains in Europe between feedstock growers, biofuel producers, distributors and the airlines as final consumers. The main achievement of the project has been the introduction of biojet fuel at Oslo airport. Since the end of 2015 all commercial flights from Oslo use biojet fuel. The project reported a patent application as an important outcome of its research.

Project spotlight: BIOCOUP

The FP6-funded research project BIOCOUP (Co-processing of Upgraded Bio-liquids in Standard Refinery Units) which aimed to identify the necessary steps to effectively co-feed biomass feedstock to standard oil refinery. It also explored ways in which biomass could be transformed into chemicals and energy. The project resulted in over 35 scientific journal publications, 45 scientific conference presentations, over 100 communications outside the consortium, and 4 patents. In particular, the patent on integrated biomass pyrolysis for flexible processing of bio-based feedstock into bio-oil was an important outcome from the BIOCOUP project. Key technical achievements of the project included:

- Successful elucidation of the co-refining concept of bio-oil in standard refinery with lab scale FCC or continuous hydro-processing units;
- The possibility to continuous upgrade pyrolysis oil from biomass at relatively mild conditions using a novel catalyst that renders upgraded pyrolysis oil with improved properties;
- Several different biomass to chemical platforms utilizing novel catalysts were explored.

The efforts to standardise the pyrolysis oil quality indicators is one of the important key milestone of the project, which in a broader perspective will continue to serve the needs for the wider adaptability of bio-oil in industrial and commercial settings.

See annex A for a detailed case study of the BIOCOUP project.

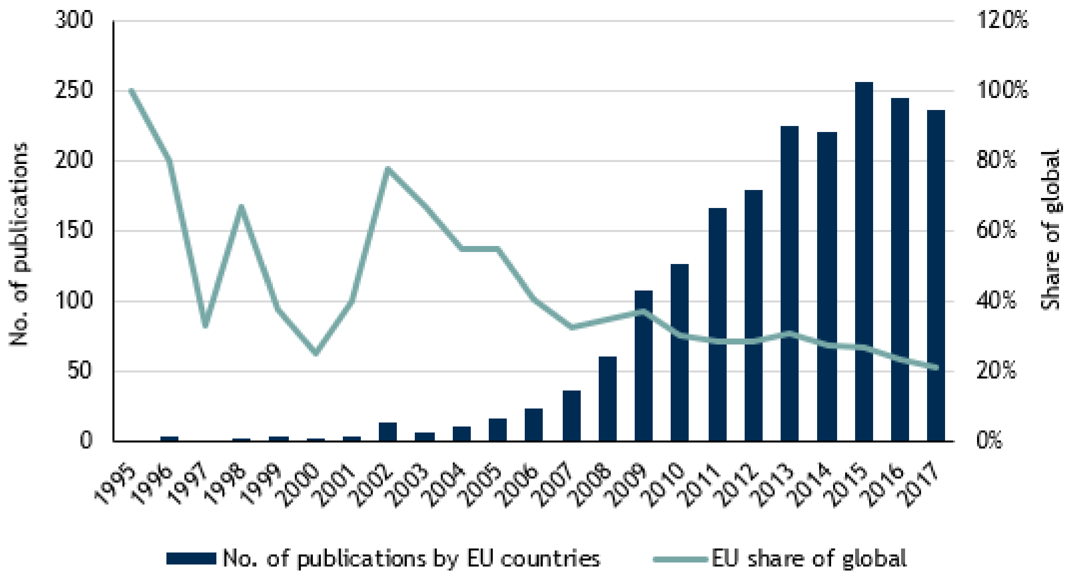
3.2 Publications

Publications of research papers are a useful indicator to measure the output of R&D funding. Publications have a close relation with public R&D funding, allowing us to differentiate the effect of public R&D funding from private R&D funding. Publications are categorised by country on the basis of the address of the author. If it has authors from different regions, the publication is counted for both regions.

3.2.1 Evolution over time

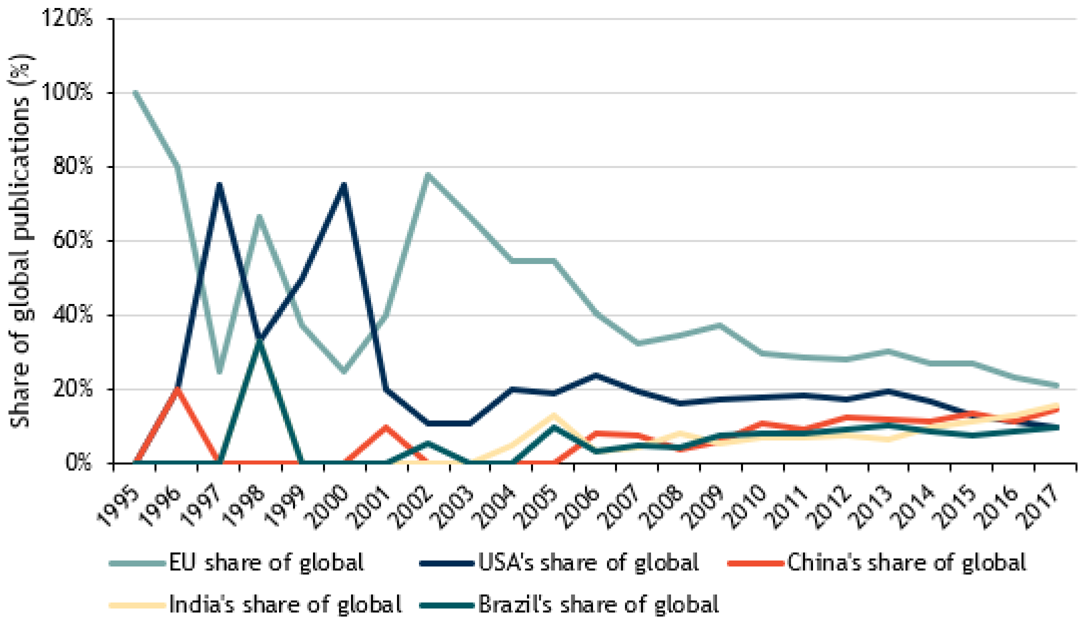
Figure 3.3 shows the profile of biofuels publications by EU-based authors over the years. The number of publications on biofuels had an upward trend over the years, similar to that of EU R&D funding for biofuels. EU-based authors were involved in 28 % of the global publications between 1995 and 2017, making it the global leader. Outside of the EU, the largest number of publications had authors from the US (15 %), China (12 %), and India (10 %), and Brazil (9 %). In recent years, China, India and Brazil have increased the numbers of publications significantly, reaching between 70 and 100 publications per year, while still remaining at a distance from the EU (+/- 200 publications per year).

Figure 3.3 Evolution of biofuels publications by EU countries



Source: Web of Science (2018), using keywords: 'bioethanol' and 'energy' or 'biodiesel*' and 'energy' in the title, topics and abstract of scientific articles between 1995-2017. The share of global refers only to those publications with an address listed. 0.2 % of the global publications had no address listed in that period of time.*
Notes: One article can have multiple authors (therefore, also multiple countries). The count is the number of articles in which at least one author listed an EU MS as their address.

Figure 3.4 Comparison of the share of biofuels global publications between key countries



Source: Web of Science (2018)
Notes: The shares of the different countries/regions are not cumulative since one article can have multiple authors (therefore, also multiple countries).

Within the EU, Spain is leading with 322 publications between 1995 and 2017, followed by the UK (309), Italy (293) Germany (204), and France (148). These MS received significant EU R&D funding or had large domestic R&D budgets, which indicates a correlation between R&D funding and publications.

The Technical University of Denmark leads the ranking of institutions contributing to biofuels publications (see Table 3.1). Although it did not receive a large amount of funding under FP7 and H2020, Denmark is the 5th largest MS funder for biofuels, so this could have played a role in the high number of publications. France, the largest MS funder, and is the home of two of the top organisations, the Centre National de la Recherche Scientifique CNRS and the Institut National de la Recherche Agronomique INRA, which together published almost 80 papers. CNRS is also one of the top 10 recipients of EU funding, ranking 6^{th}. There are four other institutions that are in the top EU organisations contributing to biofuels publications, and also in the top 30 recipients of EU funding. Wageningen University, University of Padua, Consejo Superior de Investigaciones Cientificas and Ghent University all received a significant amount of EU funding, and contributed to 43, 41, 28 and 24 publications respectively.

Table 3.1 Top organisations in the EU contributing to biofuels publications

Rank	Institutions	Country	No. of publications	EU funding rank
1	Technical University of Denmark	Denmark	58	*30+*
2	Centre National de la Recherche Scientifique CNRS	France	50	6
3	Lund University	Sweden	45	*30+*
4	Wageningen University Research	Netherlands	43	13
5	University of Padua	Italy	41	27
6	Imperial College London	UK	37	*30+*
7	Helmholtz Association	Germany	35	*30+*
8	Institut National de la Recherche Agronomique INRA	France	35	*30+*
9	Consiglio Nazionale delle Ricerche CNR	Italy	32	*30+*
10	Autonomous University of Barcelona	Spain	28	*30+*
11	Consejo Superior de Investigaciones Científicas CSIC	Spain	28	30
12	University of Cambridge	UK	27	*30+*
13	Ghent University	Belgium	24	10
14	Polytechnic University of Bucharest	Romania	23	*30+*
15	University Hohenheim	Germany	23	*30+*

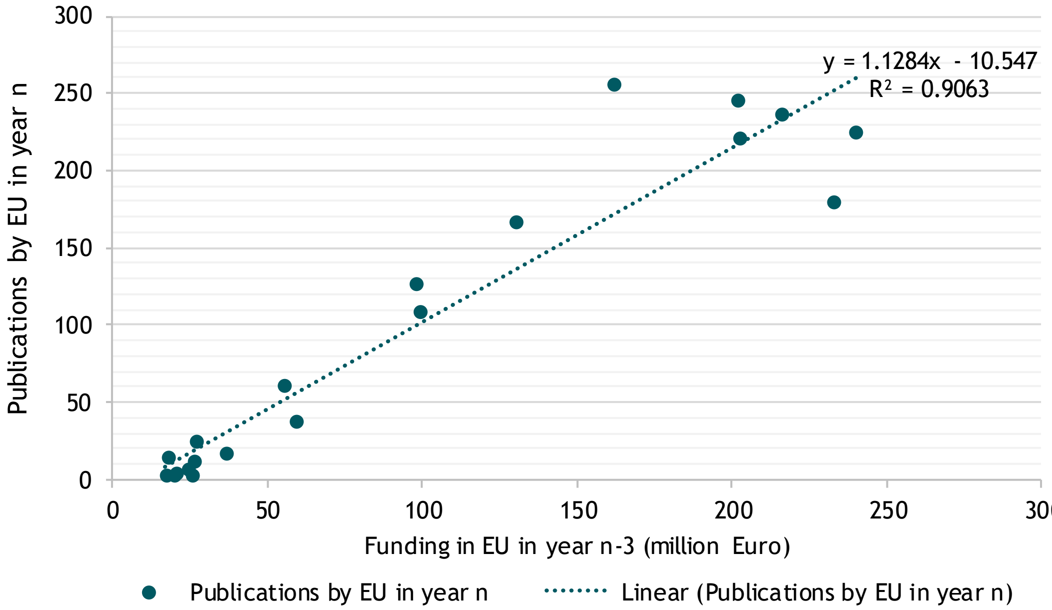
Source: Web of Science (2018)

3.2.2 Effectiveness of R&D funding in producing publications

In theory, higher R&D budgets in a region are expected to lead to an increase in the number of publications from that region. The extent to which this relation exists in the biofuels sector provides insight into the objectives of the research (does it aim for a publication?) and the effectiveness of the research (is it successful in realising a publication?).

Figure 3.5 compares the total number of EU publications to the amount of EU R&D funding (MS + EU combined), accounting for a time lag between the moment of funding and the publication. The number of publications correlates more closely to R&D funding than the number of patents does, indicating that publicly funded R&D projects in the biofuels sector have a higher focus on publishing and/or are more effective at publishing. This is in line with the findings for other RE sectors and underlines that publishing is often one of the primary objectives of a research project.

Figure 3.5 Effectiveness of R&D funding in producing publications



Notes: We tested the publication effectiveness of R&D funding for the period 1995-2015. Funding in EU includes EU funding and MS funding. We tested different delays (0, 1, 2, 3, 4 and 5 years) to evaluate which one had the highest correlation. After two years of delay, for each year of delay, the sample size was reduced by one number (e.g. with 0, 1 and 2 years of delay the sample size was 21 years, with 3 years of delay the sample size was 20 years) With no delays (n-0) years of delay, the R^2 is the lowest of all the ones tested (0.7873). The highest R^2 was found using 3 years of delay (0.9063).

3.2.3 Contribution of EU funding

Between 1995 and 2017, 234 publications on biofuels explicitly reported benefitting from EU funding sources, which is 12 % of the total number of EU publications in those years. Not all publications report their sources of funding, therefore it is likely that the real figure is higher. The EU funding sources used are not always specified and may therefore include funding from instruments other than the Framework Programmes for research and technological development.

The majority of project coordinators (15 out of 22) that replied to our questionnaire report publications as an outcome of their EU-funded research projects. An example of a highly successful research project is given in the box below.

Project spotlight: EUROBIOREF

The FP7-funded project EUROBIOREF (EUROpean multilevel integrated BIOREFinery design for sustainable biomass processing) aimed to integrate the fragmented European biomass industry, to maximise joint efforts to form a techno-economical bio-refinery. It encompassed the whole value chain of sustainable and economical biorefinery processes, starting from sustainable biomass harvesting to processing it into fuels and chemicals through various routes. The project generated significant knowledge on European land use for sustainable biomass cultivation, biomass logistics, biomass-derived platform molecules conversion to fuels and chemicals. It significantly reduced the cost-intensive steps in the value chain guided by a detailed LCA analysis. During the project, more than 300 dissemination activities were carried out at different levels, including academics, citizens, industrials and students. At least 33 patents were filed out, of which 10 were already granted during the project. At least 29 scientific papers were published during the project, and over 60 additional papers were produced subsequently.

See annex A for a detailed case study of the EUROBIOREF project.

3.3 Start-ups and spin-offs

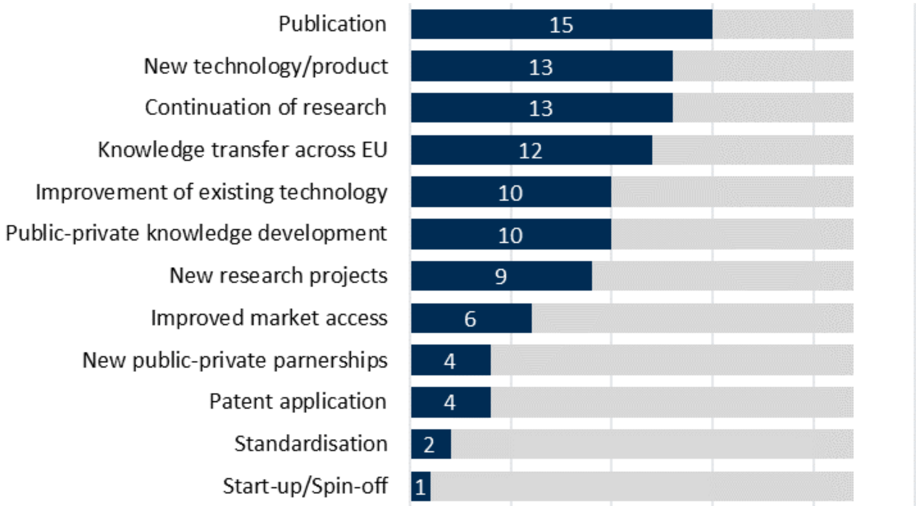
The creation of start-ups and spin-offs is another potential impact of research projects, which can function as an important link between the research and the development of a European industry. Start-ups and spin-offs are not reported consistently, however. Therefore, questionnaire results are used to provide insight into these impacts.

One of the projects that responded to the questionnaire reported the creation of a spin-off/start-up. In contrast to other RE technologies analysed, none of the biofuel projects in the scope of this study were funded via the SME instrument. This could be part of the explanation as to the low number of spin-offs/start-ups reported in the biofuels sector. In addition, the market barriers to new entries are much higher for SMEs in the biofuels sector.

3.4 Other research outputs

Research projects contribute to the development of the biofuels energy sector in various ways that are not captured in statistics on patents, publications and spin-offs. To get a better understanding of these other impacts, a questionnaire was sent out to project coordinators of EU-funded R&D projects. Figure 3.6 summarises the results of the questionnaire on the contributions that EU-funded projects have had on the development of the biofuels sector.

Figure 3.6 Impacts of EU-funding based on questionnaire results (out of 22 responses in total)



The responses show that EU R&D funding does not only contribute to new publications, but is also important for the development of new technologies or products, the continuation of research that would otherwise be discontinued, and the transfer of knowledge. This shows the importance of EU support to develop the European biofuels sector, which is still not developed enough to attract sufficient interest from private investors.

Knowledge transfer is a natural outcome of multinational consortia formed for the purposes of participating in EU-funded projects. Knowledge transfer for biofuels creates opportunities for the exchange of ideas and best-practices and helps harmonise knowledge across Member States. Cost reductions and joint knowledge development with the private sector were also often reported as outcomes. Cost reductions are an important indicator of the state of technology development and the extent to which it is competitive in the market place (see chapter 4). A few research projects also reported new public-private partnerships and the standardisation of practices as an outcome.

Project spotlight: BioDME

The project BioDME (Production of DME from Biomass and Utilisation as Fuel for Transport and for Industrial Use) had two main goals. The first goal was to produce DME from renewable sources known as BioDME. A BioDME demonstration plant was constructed in Sweden, beside a pulp mill with a production capacity of 4 tonnes/day. Almost 350 tonnes of DME was produced by the end of the project. The second goal was to operate a test fleet of heavy duty trucks on biomass DME rather than diesel fuel. Four filling stations were used for DME distribution across Sweden. A DME fuel injection system was designed by Delphi suited to the fuel properties of DME. Field tests were performed on 10 different Volvo trucks, which travelled more than a million km. The project also initiated a DME ISO standardisation process and developed several standards to maintain fuel quality.

The main impact was the successful demonstration of the use of BioDME. The efforts for standardisation of DME as a fuel will mobilise policy makers and relevant stakeholders to adopt BioDME as a potential biofuel. As a result of this project, the black liquor to DME route is ready for full scale implementation.

See annex A for a detailed case study of the BioDME project.

3.5 Conclusions

Many of the MS that received large amounts of R&D funding filed patents and published scientific papers on biofuels. The correlation is more apparent for publications than for patents, but case studies show that several FP-funded research projects have led to one or more patents. Some of the top recipients of EU R&D funding authored over 40 papers on biofuel technologies. The number of publications authored by the EU increased, but its global share decreased due to rising interest in biofuel technologies in other countries, such as India, China and Brazil. Still, the EU holds some of the leading research institutes, manufacturers and project developers in the sector, which is characterised by its wide array of technologies and specialisations. EU-funded research projects also had other outputs, such as the development of new and improved technologies or products, contributing to the advancement of TRLs, as well as knowledge transfer and public-private knowledge development, which all contribute to the development of the biofuels sector.

4 Technology development

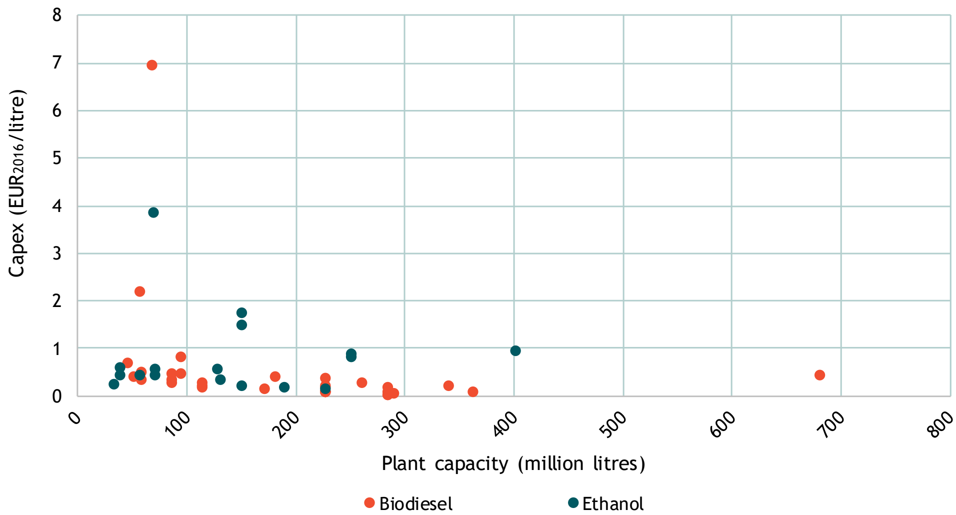
One of the core objectives of R&D funding on RE technologies is to contribute to the development of the technology to make it cost competitive and allow for increased uptake of the technology. The impacts on technology development can be assessed technologically, or from an economic point of view, looking at the costs, performance and competitiveness of the technology. This section focuses on key indicators that assess technology development from an economic point of view: capital expenditure (capex), operational expenditure (opex) and Levelised Cost of Energy (LCOE).

4.1 Capex

Capex (capital expenditure) refers to the initial investment costs of the biofuels projects. Cost-reducing innovations can contribute to a downward trend in capex, which in turn can make the sector more cost competitive and allow for increased uptake of the technology. One of the main limitations of this indicator is that capex is highly location- and technology-specific, and will therefore vary between projects. To be able to provide an overview of the evolution of the capex over time, we consider global historic estimations of capex, including the estimations of regions outside the EU.

Capex accounts for a small portion of the production costs for first generation biofuels: approximately 4 % for biodiesel plants and 10 % for ethanol plants.[5] Plant capacity is an important determinant factor for capex. Figure 4.1 shows that overall, the capex for biofuels production plants in the EU tends to decrease as the plant capacity increases. Overall, biodiesel plants in the EU have lower capex than ethanol plants.

Figure 4.1 Capex for biofuels production plants in the EU by project capacity



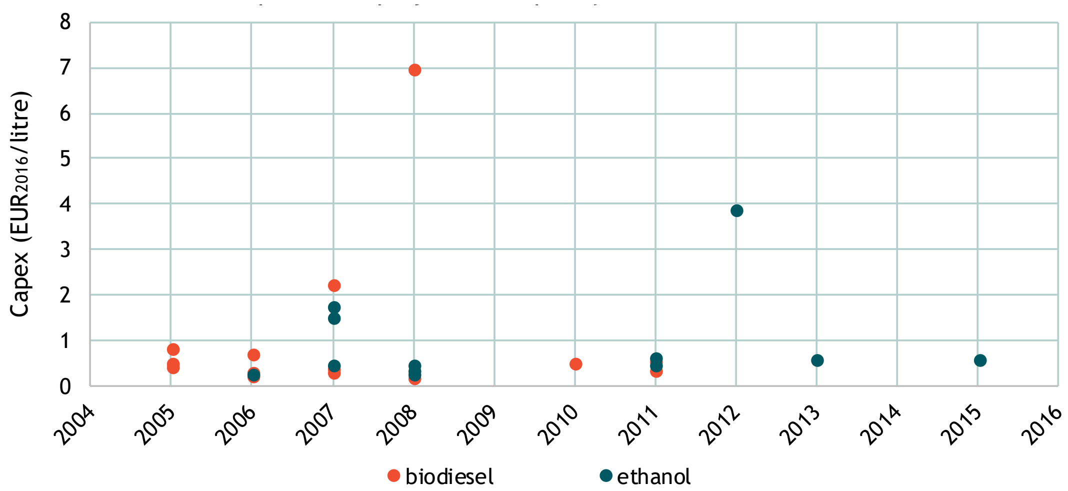
Source: IISD (2013), Ecofys (2012) and Ecofys and Passmore Group (2015)
Notes: The main source for this graph is a study by IISD (2013). The study did a survey of 88 biofuel facilities in the EU, from which 50 started operations in the last 20 years (16 ethanol and 34 biodiesel). Two plants were excluded from this graph because their unusual high reported capital costs and small plant capacity distorted the average capex of the respective year. The MS covered were France, Germany, Italy, Spain and the United Kingdom. Data collected by a desk research focused on European capex estimates was also included.

[5] International Institute for Sustainable Development (IISD), 2013, Biofuels—At What Cost? A review of costs and benefits of EU biofuel policies

Plant size is a major determinant of biofuel capex costs, therefore Figure 4.2 and Figure 4.3 show the evolution of capex of EU biofuel project divided in two groups of the most common plant capacities: plants with a capacity ranging from 20 to 150 million litres and 150 to 300 million litres.

The majority of the EU biofuels plants had a capacity from 20 to 150 million litres. The capex range of these was between EUR 0.19/litre to EUR 2.23/litre for biodiesel, with an outlier of EUR 7/litre in 2008 (see Figure 4.2). For ethanol plants the capex range was between EUR 0.25/litre to EUR 1.75/litre, with an outlier of EUR 4/litre in 2012.

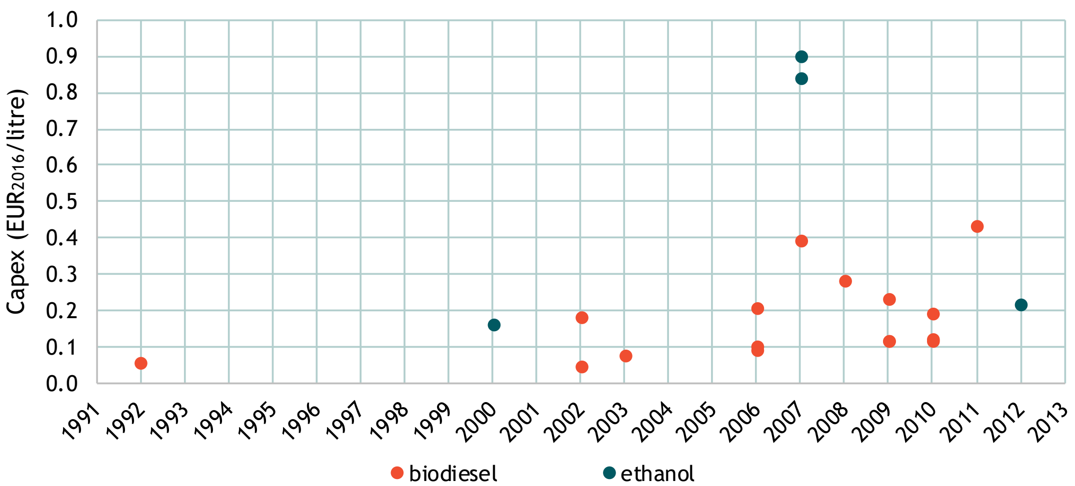
Figure 4.2 Evolution of capex of EU biofuels projects with a capacity ranging from 20 million litres to 150 million litres



Source: IISD (2013), Ecofys (2012) and Ecofys and Passmore Group (2015)

Average capex costs for biofuel plants in the EU with capacities between 150 and 300 million litres showed an increasing trend between 1992 and 2012 (see Figure 4.3). Biodiesel capex range oscillated between EUR 0.056/litre in 1992 to EUR 0.432/litre in 2011. Ethanol capex variations were wider, from EUR 0.16/litre in 2000 to EUR 0.9/litre in 2007, and down to EUR 0.22/litre in 2012.The higher capex for ethanol in 2007 belonged to the larger plants in this category (250 million litres), both located in France.

Figure 4.3 Evolution of capex of EU biofuels projects with a capacity ranging from 150 million litres to 300 million litres



Source: IISD (2013), Ecofys (2012) and Ecofys and Passmore Group (2015)

Only a few biofuel plants had capacities larger than 300 million litres, and these began operation between 2006 and 2009. These biodiesel plants were found in Spain and had capex costs between EUR 0.12/litre and EUR 0.46/litre. The only ethanol plant was located in the United Kingdom and had a capex cost of almost EUR 1/litre.

For advanced biofuels, current installed capacity is still very modest (see Section 5.1) and more plants will need to become operational to have stronger data on the capex, opex and LCOE. The capex is always higher when first commercial plants are installed. Many factors besides plant size will contribute to the reduction in capital required for next generation plants, such as the technological improvements, feedstock location, availability, optimised pre-treatment methods, process integrations, by-product minimisation and potential applications of by-products. One example is the Sunliquid project which uses the lignocellulosic biomass hydrolysis process to yield ethanol. One of the main elements of expenditure in the hydrolysis process is the enzyme cost. In the Sunliquid process, enzymes are created in-situ which considerably affects the capital requirement of the process. Furthermore, the integrated Sunliquid process also increases the ethanol production by almost 50 %.

Project spotlight: Sunliquid

The FP7 Sunliquid project lasted from 2014 to 2018. It demonstrated a pre-commercial industrial scale demo plant with the capacity of 1 000 tonnes/year for the production of lignocellulosic ethanol. The hydrolysis technology encompassing novel in-situ production of highly optimised enzymes yields high quality ethanol. The integrated production of enzymes ensures considerable reduction in production cost together with a considerable increase in ethanol production. The process is energy self-sufficient, s it uses energy generated from residual lignin fraction. In addition, the greenhouse gases reductions are estimated to be about 95 % compared to fossil fuels. Clariant, who is the coordinator of this project, has managed to sell the sunliquid license to Enivral in Slovakia for a cellulosic ethanol production with the capacity of 50 000 tonnes/year. A flagship cellulosic ethanol plant is also being built in Romania with 50 000 tonnes/year capacity and is supported by the H2020 project Lignoflag. Sunliquid plants will prove to be an important milestone in the cellulosic ethanol technologies.

Other advanced biofuel production processes still need to overcome technical barriers, such as the application of Fischer-Tropsch synthesis to produce biodiesel, sustainable jet fuels and biogasoline, and the production of biofuels from algae. Commercial-scale syngas fermentation and Fischer-Tropsch synthesis processes may emerge after 2020, at which stage cost reductions become more important. The initial capital costs for gasification processes will be high, but the opportunity for cost reductions is expected to be greater than for lignocellulosic fermentation processes.[6] Capex for the transesterification processes is lower, but it has a higher feedstock cost for cultivating algae. Algal oil transesterification will therefore have a higher capex than other advanced biofuel production processes. Capex estimates still have very large ranges due to different assumptions on the production, harvesting and extraction processes.

[6] IRENA 2016, Innovation Outlook: Advanced Liquid Biofuels

4.2 Opex

Opex (operational expenditure) includes fixed and variable costs for operation and maintenance (O&M) of the plants. Similar to capex, cost-reducing innovations can contribute to a downward trend in opex, which in turn can make the sector more cost competitive. Opex is less location-specific than capex, but can show large variations between sub-technologies. Only global figures were available for the opex.

The largest costs for ethanol and biodiesel production are raw materials (feedstock).[7] This is different from other RE technologies, where capex is the main component. Raw material availability, transport and pre-treatment required all adds up to the expenditure. These factors also make it difficult to compare opex of similar technologies. In some cases, the raw material might be readily available onsite and in other cases it might have to be transported from discrete locations.

For ethanol production, the cost of feedstock is one of the main drivers of opex, with a conversion efficiency between 30 % and 40 % on energy basis. Hence, the costs of handling and processing feedstock are also reflected in the overall production costs, ranging between 29 % and 32 % of the total costs.[8] The cost of enzymes also play an important role in the cost of producing ethanol. It can account for around 18 % to 19 % of total production costs. Over the last years, enzyme development has been a driver of cost reduction for cellulosic ethanol production. It has decreased the cost of enzyme per litre of ethanol from EUR 1.9/litre ethanol in 2000 to a range of 8.7-17.4 EURct/litre in 2016 (or EUR 4.3/GJ to EUR 8.6/GJ).[9] Compared with feedstock and enzymes costs, other O&M costs of ethanol plants are moderate, but also show a decreasing trend over the years.

4.3 LCOE

LCOE is an indicator to compare the project costs of different energy generation technologies.[10] LCOE is most commonly used in the context of electricity generation, with the 'E' denoting electricity. LCOE can however also be applied to fuel generating technologies, sometimes then denoted as Levelised Cost Of Fuel. In this document we use LCOE as Levelised Cost Of Energy, specifying per case if this concerns electricity or fuel.

Similar to capex and opex, cost-reducing innovations can contribute to a downward trend in LCOE, which in turn can make the technology more cost competitive. While LCOE is a relatively comprehensive measure of the technology's costs, it does not include all the costs for delivering energy, such as ancillary services and transmission and distribution costs.

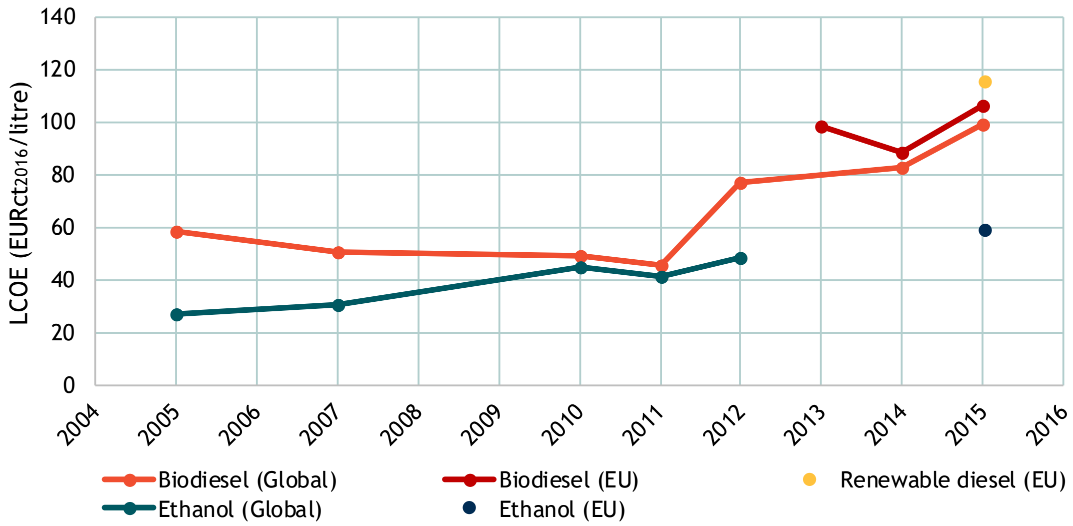
Similar to capex, the LCOE of biodiesel has been higher than ethanol over the years (see Figure 4.4). In the case of ethanol, the global average LCOE increased from 26.7 EURct/litre in 2005 to 48.6 EURct/litre in 2012. In the EU, LCOE was even higher, at 59 EURct/litre.

[7] International Institute for Sustainable Development (IISD), 2013, Biofuels—At What Cost? A review of costs and benefits of EU biofuel policies
[8] Landälv, I. and Waldheim. L., 2017, Building up the Future Cost of Biofuel, Sub Group on Advanced Biofuels (SGAB), SGAB-UN-031, European Commission
[9] Landälv, I. and Waldheim. L., 2017, Building up the Future Cost of Biofuel, Sub Group on Advanced Biofuels (SGAB), SGAB-UN-031, European Commission
[10] There are different ways of calculating the LCOE; the method applied here is explained in the methodology document.

The average global LCOE of biodiesel has increased from 58 EURct/litre in 2005 to 99 EURct/litre in 2015, while LCOE of biodiesel in the EU is higher, at between 89 and 106 EURct/litre between 2013 and 2015. For renewable diesel, the LCOE is higher than for biodiesel, at around 116 EURct/litre in 2015.

According to the IISD (2013), the likelihood of upcoming policy changes might have increased the cost of capital for biofuel plants, considering a higher risk of investment. This could have played a role in LCOE increase over the last years, by raising the discount rate and the annualised cost of capital with it.

Figure 4.4 Evolution of average biofuels LCOE for biofuel production in the world and in the EU



Source: REN21 (2005, 2007, 2010-2015) and Ecofys and Passmore Group (2015)
Notes: REN21 figures are expressed in 1 litre of diesel or petrol equivalent, while in Ecofys and Passmore Group (Renewable diesel EU in 2015, and Ethanol EU in 2015) the figures are expressed in litre of product.

4.4 Conclusions

Capex accounts for only a small portion of the production costs for first generation biofuels. The largest costs for ethanol and biodiesel production are raw materials (feedstock). This is different from other RE technologies, where capex is the main component. As such, the sector is highly interlinked with the agricultural sector. The historic evolution of LCOE for biofuel production shows that there is a slight increasing trend in ethanol production. Biodiesel has a considerably higher LCOE, despite having a lower capex than ethanol plants. The technologies for advanced biofuels are very much still on the verge of commercialisation. Many technologies have already demonstrated their commercial benefits while some are still largely in R&D phase. The capex associated with advanced biofuels is presently high due to their infancy, and several processes still need to overcome technical barriers. Cost estimates still have very large ranges due to different assumptions on the production, harvesting and extraction processes. More funding is needed to bring these production processes to commercial scale, at which stage cost reductions will become more important. As with any new technologies and with more plants built and demonstrated, the capex is likely to reduce significantly, but the feedstock cost remains an important factor in addition to the cost reductions through technological development. The key to technoeconomic success is linked to feedstock availability, technological flexibility to use multiple feedstocks and process integration.

5 Social, economic and environmental impacts

Public R&D funding for RE technologies is justified by several social, economic and environmental impacts. In this section we evaluate a range of indicators that provide insight into these impacts: installed capacity, annual generation, industry turnover, imports/exports, jobs and share of energy consumption.

A direct link between these indicators and R&D funding is hard to establish, as the impact of R&D funding is confluent with numerous other factors that drive or prevent deployment. Still, the indicators presented in this section are relevant indicators to assess the evolution of the biofuels sector over time.

5.1 Installed capacity

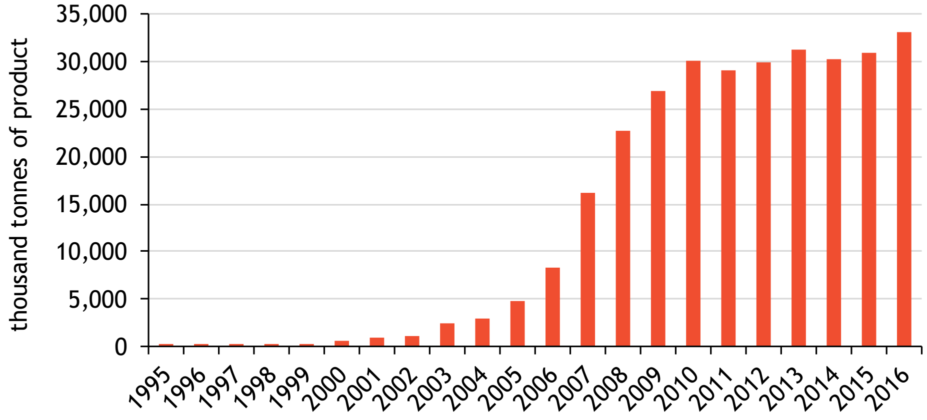
As installed capacities for RE technologies provide (near) carbon free energy that prevents the need for fossil fuel-based energy, they contribute to reducing greenhouse gas emissions and can be considered a measure of the environmental impacts. Installed capacity refers to the maximum installed generation capacity. This is expressed in MWe for electricity and MWth for heat production.

Production capacity for biofuels quickly increased between 2002 and 2009, rising from 1.1 million tonnes of product to over 30 million tonnes in 2010. After 2010, capacity continued to grow, albeit at a slower pace. These installed capacities basically refer to first generation biofuels. There have been quite successful technological advancements in the second generation biofuels, however the installed capacities are still small (estimated at 0.15 Mtoe per year in 2017)[11] and only very gradually increasing. The majority can be found in the Netherlands (glycerine to methanol and pyrolysis), followed by Italy, Finland and Denmark (lignocellulosic ethanol). Third generation biofuels largely concern the use of algae to produce biofuels and chemicals. While, the potential of algae as a sustainable feedstock is visible, technological advancements are still required to improve the economics of the processes.

Germany was one of the few MS who had production capacity in 1995, together with Austria and Czech Republic. Their primary production capacity was small, namely 161 thousand tonnes. By 2000, this capacity had grown to 507 thousand tonnes, and Spain installed capacity for 118 tonnes. By 2010, 23 MS had capacity to produce biofuels. The largest producers were the same as today: Germany, Spain, France, Italy and the Netherlands. They now have 68 % of the total EU installed capacity. Interestingly, except for France and Italy, these MS are not the largest R&D funders in the sector. Germany currently has a capacity of nearly 9 million tonnes of biofuel product per year, which is 25 % of total EU capacity.

[11] European Commission, 2017, Research and Innovation perspective of the mid - and long-term Potential for Advanced Biofuels in Europe

Figure 5.1 Installed capacity of biofuels primary production plants in the EU



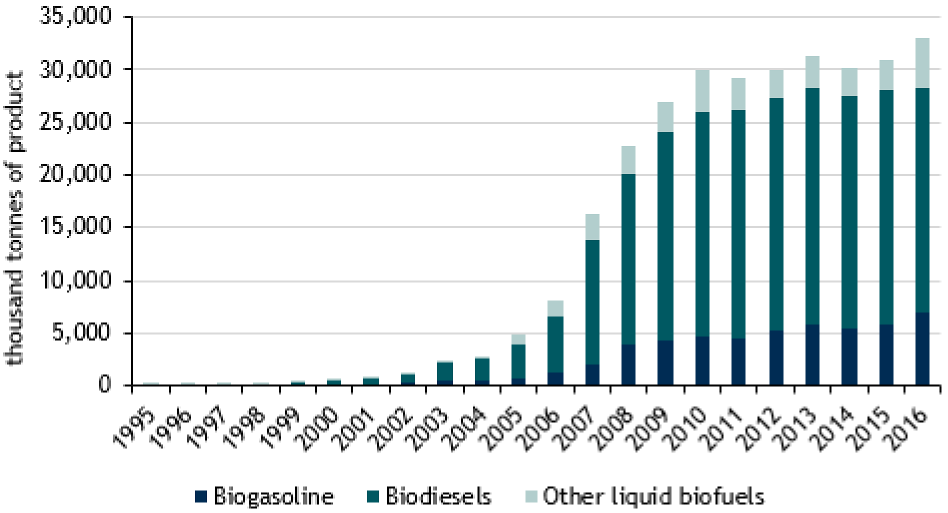
Source: Eurostat (2018)
Notes: The aggregate 'biofuel production capacity' refers to the production capacity, at the end of the year, in terms of tonnes of products per year. Includes 'Liquid biofuels' as defined by Eurostat: production for energy purposes of finished products only, not the total volume of liquids into which liquid biofuels may have been blended. It is the sum of biogasoline (Code 5546), biodiesels (5547), bio jet kerosene (5549) and other liquid biofuels (5548).

Figure 5.2 shows the capacity per product type. The capacity of biodiesel[12] production grew the most, totalling over 21 million tonnes since 2010. This is followed by biogasoline[13] capacity, which started to take off in 2003 and has grown to 6.9 million tonnes in 2016. Most MS are only able to produce biodiesels and biogasoline, but seven MS can also produce other liquid fuels[14], which reached a production of 4.8 million tonnes in 2016. The majority of this production takes place in Germany. Since production started in 2003, its capacity has been between 44 % and 87 % of total EU other liquid fuels.

Interestingly, the fourth largest R&D funder Denmark is one of the four MS that do not have production capacity for biodiesels and it is one of the ten MS that do not have capacity for biogasoline. In fact, it does not have capacity for any biofuels at all. Sweden, the second largest R&D funder, only started producing biofuels in 2012. This can be explained by the fact that the productions costs of the main biofuels crops (FAME, which is rapeseed based, and ethanol, which is cereal based) are higher in Nordic countries due to climate. The research targets production of advanced biofuels. Presently, investments to industrial scale plants are rare (none of NER300 liquid biofuels projects have been realised).

[12] In Eurostat statistics, biodiesel includes biodiesel (a methyl-ester produced from vegetable or animal oil, of diesel quality), biodimethylether (dimethylether produced from biomass), Fischer Tropsch (Fischer Tropsch produced from biomass), cold pressed bio-oil (oil produced from oil seed through mechanical processing only) and all other liquid biofuels which are added to, blended with Gas/diesel oil. Biodiesels is the sum of pure biodiesels (Code 5547R) and blended biodiesels (Code 5547O).
[13] In Eurostat statistics, biogasoline includes bioethanol (ethanol produced from biomass and/or the biodegradable fraction of waste), biomethanol (methanol produced from biomass and/or the biodegradable fraction of waste), bioETBE (ethyl-tertio-butyl-ether produced on the basis of bioethanol, and bioMTBE (methyl-tertio-butyl-ether produced on the basis of biomethanol. (The percentage by volume of bioETBE that is calculated as biofuel is 47 %, the percentage by volume of bioMTBE that is calculated as biofuel is 36 %.)
[14] In Eurostat, this category includes liquid biofuels, used directly as fuel, not included in the definitions of biogasoline, biodiesel or bio jet kerosene and liquid biofuels consumption that cannot be reported under the right category because of missing information.

Figure 5.2 Share of installed capacity of biofuels primary production plants in the EU by sub-technology



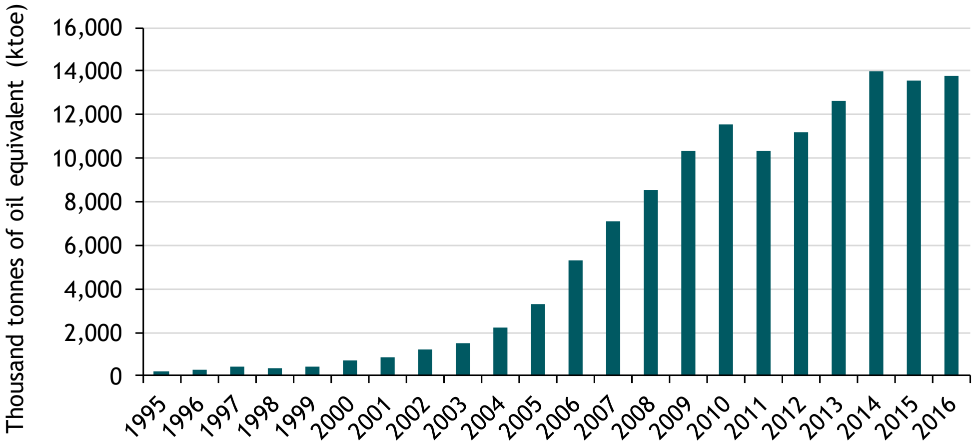
Source: Eurostat (2018)

5.2 Annual generation

While installed capacity is a commonly used indicator to measure the progress in deploying RE technologies, it can be somewhat misleading due to differences in capacity factors. Annual generation includes the effects of these differences and is therefore a valuable indicator to complement the statistics on installed capacities. Annual generation of biofuels is measured in thousand tonnes of oil equivalent (ktoe) produced.

Annual production of biofuels has increased from 223 ktoe in 1995 to over 13 Mtoe in 2016. Most growth occurred between 2003 and 2010 (see Figure 5.3).

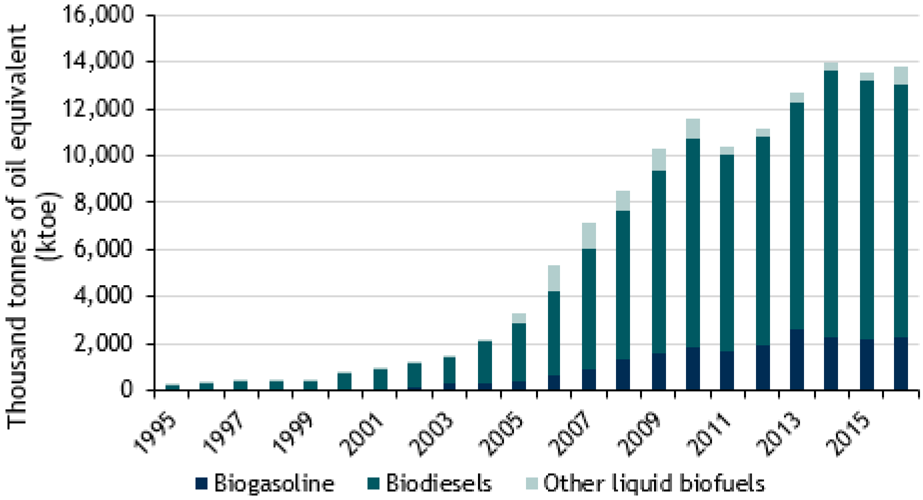
Figure 5.3 Annual primary energy production of biofuels in the EU



Source: Eurostat (2018)

Figure 5.4 shows the primary energy production of biofuels per sub-technology. By 2016, the EU produced 10.7 Mtoe of biodiesel, 2.3 Mtoe of biogasoline, and 756 ktoe of other liquid fuels.

Figure 5.4 Detail of annual primary energy production of biofuels in the EU per sub-technology



Source: Eurostat (2018)

Project spotlight: EMPYRO

The FP7 EMPYRO project lasted from 2009 until 2013. The project demonstrated a first of its kind poly-generation demo plant in Hengelo (NL). The project, coordinated by B.T.G Biomass Technology group BV, demonstrated the use of wood to produce steam, pyrolysis oil and electricity. The process uses fast pyrolysis technology to convert wood chips at high temperature in a very short residence time into vapours that are condensed to produce pyrolysis oil, other products being some non-condensable gases and char, which are used to produce process steam and for drying the biomass. The construction of the plant was started in February 2014 and took almost a year to complete. The plant started operation in March 2015 and has since then until October 2017 produced almost 20 million litres of pyrolysis oil. Fortunately, the plant has an off take long-term agreement with milk powder production facility Friesland Campina, which consumes almost all the pyrolysis oil produced. The use of pyrolysis oil based on estimation will save almost 15 % carbon emissions and will increase the energy efficiency of the plant by 20 % compared to other Friesland Campina facilities. Beside pyrolysis oil, the plant also produces electricity, which is self-utilised, and steam, which is used at the nearby AkzoNobel salt production facility, reducing the CO_2 emissions by almost 6 000 tonnes. The success of the Empyro project has paved the way for new pyrolysis oil installations and the technological advancements provide investors with greater confidence.

5.3 Share of energy consumption

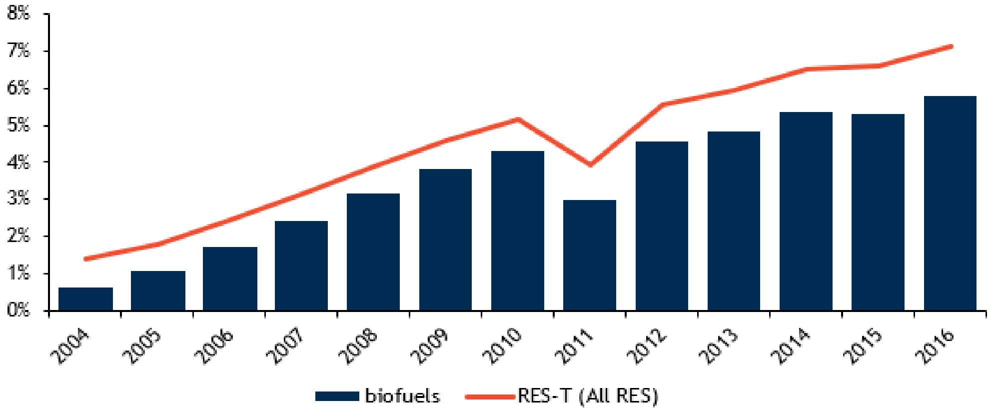
Share of energy consumption refers to the participation of biofuels energy in the gross final energy consumed in each market sector (electricity, heating and cooling, and transport). This indicator allows us to analyse the participation of the biofuels sector in the overall target of increasing the share of energy from renewable energy sources (RES) in the EU's gross final energy consumption.

Biofuels is the main RE technology consumed in transport. In 2016, it accounted for more than 80 % of the energy from renewable sources consumed in transport. The share of biofuels in transport in the EU has been increasing steadily from 0.6 % in 2004, to almost 6 % in 2016 (see Figure 5.5). This relates mostly to first generation biofuels, as the share of advanced biofuels is still very small.

The main consumers of biofuels in transport are Germany, France, Spain, Italy and the UK. However, the main contributors to the EU renewable energy consumption in transport (RES-T) are Germany, France, Italy, the UK and Sweden. Even though Spain is one of the main consumers of biofuels in transport, it is not one of the main contributors to the RES-T target, because the main biofuels consumed in this MS are classified as non-compliant (i.e. they were produced from cereal, starch-rich crops, sugars and oil crops, and from crops grown as main crops primarily for energy purposes on agricultural land). Spanish consumption of non-compliant biofuels in transport in the period 2004 to 2016 was the highest of all MS, with an average of 56 % of the total biofuels consumed being non-compliant.

In the overall EU consumption of compliant biofuels in transport[15], Germany heads the ranking with 28 % of the EU consumption, followed by France (20 %), Italy (9 %), UK (9 %), and Sweden (6 %).

Figure 5.5 Share of biofuels use in transport in the EU



Source: Eurostat (2018)
Notes: The share of biofuels used in transport includes biofuels and bioenergy. The methodology used for this indicator is based on the SHARES Tool Manual methodology[16].The calculation of the shares of biofuels use in transport, as well as the RES-T was done using a multiplier (2x for compliant biofuels) and cap limit of 0.07 % of non-compliant biofuels. 'Compliant' refers to energy from biofuels and gaseous biomass that was not produced from cereal, starch-rich crops, sugars and oil crops, and from crops grown as main crops primarily for energy purposes on agricultural land. A 7 % cap limit is applied to the share of non-compliant biofuels in the final consumption of energy in transport in the EU. For renewable electricity used in transport modes road transport and rail transport the multipliers 5x and 2.5x are applied respectively. The multipliers and cap limit are applied to numerator and denominator.

Regulations have been the main drivers for change in the markets. For example, Germany reduced the subsidies on biodiesel and as a result the biodiesel production slowed down. The EU imposed taxes on the ethanol import, which also almost eliminated developments in that area. The most prominent factors that affect the biofuels market are:

- feedstock limitations;
- the feedstock debate (Food, fuel, land use);
- the expense of the technology (see Chapter 4);
- NGOs working against bio-based feedstocks;
- public reaction against deforestation;
- changing policies;
- oil prices (a sharp decrease in the oil prices in 2009 could explain the share too).

[15] Greece was not considered in this calculation, since there was no detail for the consumption of compliant biofuels in transport in the SHARES detailed reports.
[16] Eurostat, 2016, See http://ec.europa.eu/eurostat/documents/38154/4956088/SHARES-2016-manual.pdf/77089cf0-bcee-49b9-aaa9-4fec390b44ca

5.4 Industry turnover

Industry turnover is the total amount invoiced from the market sales of goods and/or services supplied to third parties by all sellers in the biofuels sector. Following the definition in EurObserv'ER, it focuses on the main economic activities of the supply chain including fuel production, installation of equipment and operation and maintenance (O&M), as well as the production and trading of manufacturing equipment. A growing turnover indicates a growing market. Similar to the solid biomass sector, the approach used for biofuels also covers biomass supply activities (i.e. in the agricultural, farming and forestry sectors).

This indicator reflects the observations with the first generation biofuels since advanced biofuels have very limited installed capacity and hence a negligible contribution to the industry turnover. Over the period 2008 to 2016, estimates of industry turnover for biofuels have fluctuated between EUR 11.5 to EUR 15.1 billion. The turnover is partially dependent on the agricultural sector's ability to produce biofuels, which can fluctuate between years due to weather changes. For instance, several countries were affected by droughts, which decreased harvests. The highest turnover was reached in 2010, after which it decreased back to 2008 levels. The peak in 2010 can be attributed mostly to Poland and Spain, two of the five MS with the largest industry turnover. Their turnover reached EUR 2.5 and 1.4 billion respectively, after which it decreased again.

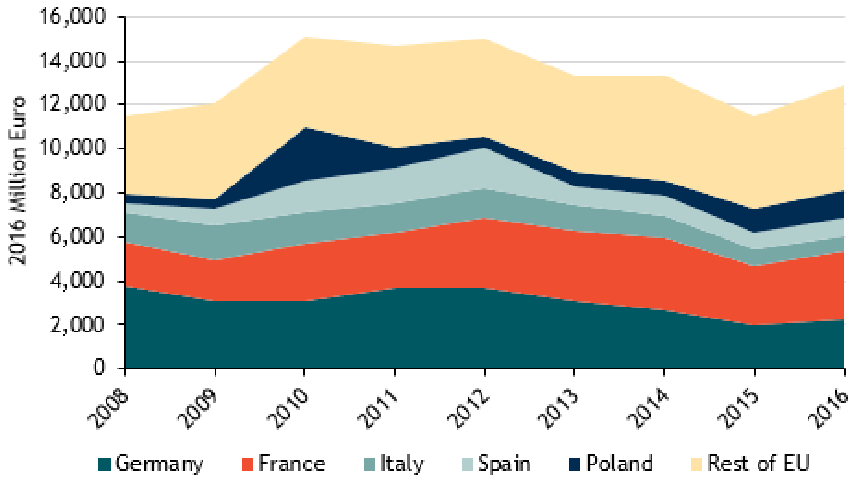
Although Germany has the largest capacity and generation, France has the largest industry turnover, which reached EUR 3.1 billion in 2016 (24 % of the total EU turnover). This can be explained by the larger share of activities in the agricultural sector that contribute to the industry turnover, which is also apparent in Poland's higher ranking in terms of industry turnover. Furthermore, France was the leading biodiesel consumer at 2.3 Mtoe and had one of the highest incorporation rates[17] of biofuel in transport sector in 2012.

In 2009, Spain's production rates quadrupled, which has been attributed to tax exemptions. It houses industry leaders such as Infinita Renovables and Entaban, but these had to close some of their plants due to financial troubles. 2014 saw the legal enforcement of the incorporation rate for biofuels in transport, which prompted the rise of consumption of biofuel.

Sweden had the highest EU incorporation rate (7.8 %) in 2012 and this rose to 19 % in 2016. Further ambitions to have 100 % clean vehicles by 2030 should stimulate market development in the future.

17 The term 'incorporation rates of biofuels' refers to the percentage of biofuels that are incorporated into conventional fuels in the transport sector. This term is associated with the EU specifications set for the incorporation of biofuels in the Fuel Quality Directive 2009/30/EC. According to this directive, biodiesel can be incorporated with conventional diesel at a rate of 7 %, while bioethanol can be incorporated with conventional petrol in 10 % blending.

Figure 5.6 Biofuels industry turnover in the EU



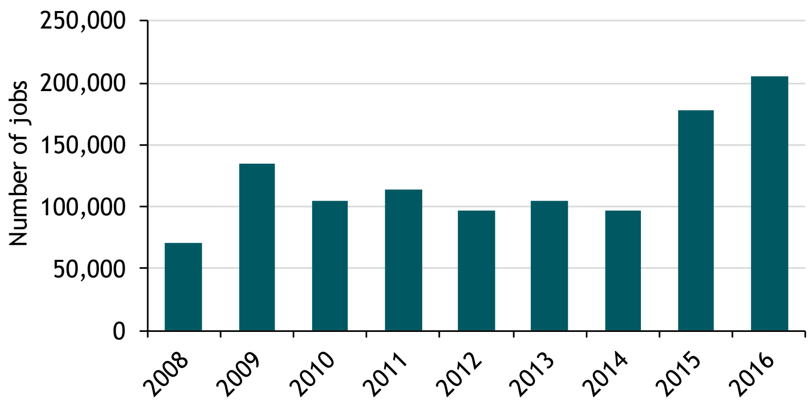
Source: EurObserv'ER reports 2010-2017
Notes: Data is missing for Croatia for the years 2008-2011.

5.5 Jobs

Employment is an important indicator to understand the socio-economic impact of RE technology deployment. Linking jobs to R&D funding is difficult due to the number of confounding factors, but it is possible to make a connection between RE deployment and jobs. Different methods exist for estimating employment figures. A consistent time-series was only available for 2008-2016. Like for the solid biomass sector, the approach used for biofuels also covers biomass supply activities (i.e. in the agricultural sector).

The number of jobs for biofuels in the EU rose from an estimated 70 900 in 2008 to over 205 100 in 2016 (see Figure 5.7). The leading countries in terms of employment are not necessarily the largest biofuel consumers such as France and Germany, but more notably Member States with a large share of agricultural areas such as Romania, Hungary, Lithuania and Poland. Since 2015, the 13 New Member States account for more than half of the total number of jobs in the biofuels sector. Biomass harvesting creates a lot of jobs compared to biorefineries.

Figure 5.7 Evolution of EU jobs in biofuels



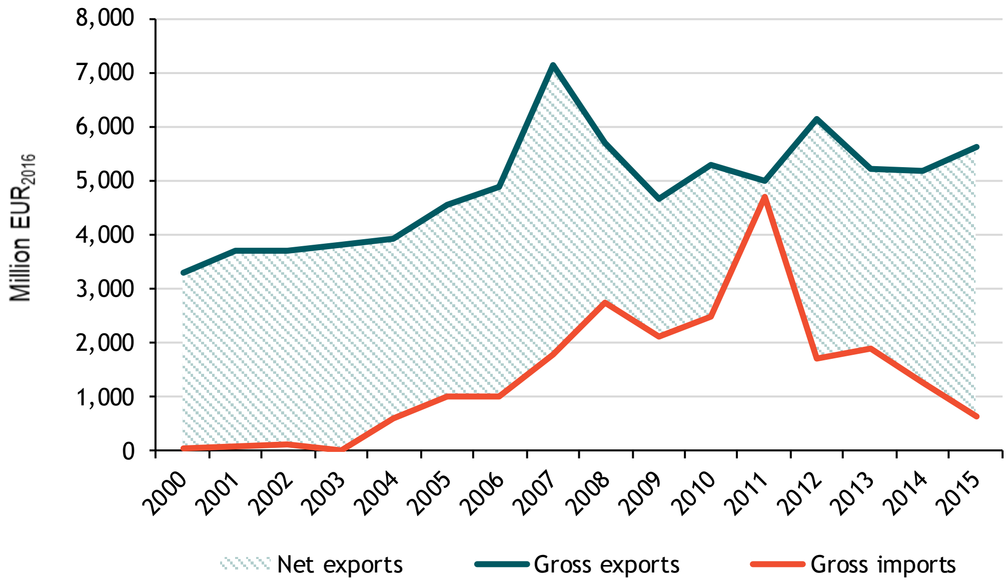
Source: EurObserv'ER (2010-2017)
Note: Data from Croatia is missing for years 2008-2011. Accounts for direct and indirect jobs in biofuels in the EU MS.

5.6 Imports/exports

International trade can provide a measure of the market uptake of biofuels technologies and development of the biofuels sector itself. It allows us to examine the extent of the external market for these goods, with increasing exports leading to increased growth of the domestic sector. Similarly, increased activity in the sector will lead to an increase in demand for intermediate goods used in the manufacture of renewable energy technologies, a proportion of which may be imported. Increasing imports of these intermediate goods also provide an indication of the growth within the technology sectors.

The EU is an exporter of biofuels components. Figure 5.8 shows that import and export of the biofuels sector have strong fluctuations over the years, but the trade balance is always positive.[18] The gross exports of the 2000-2015 period was 3.5 times the gross imports, indicating that the industry has a competitive position in the global market.

Figure 5.8 Trade balance for biofuels components in the EU

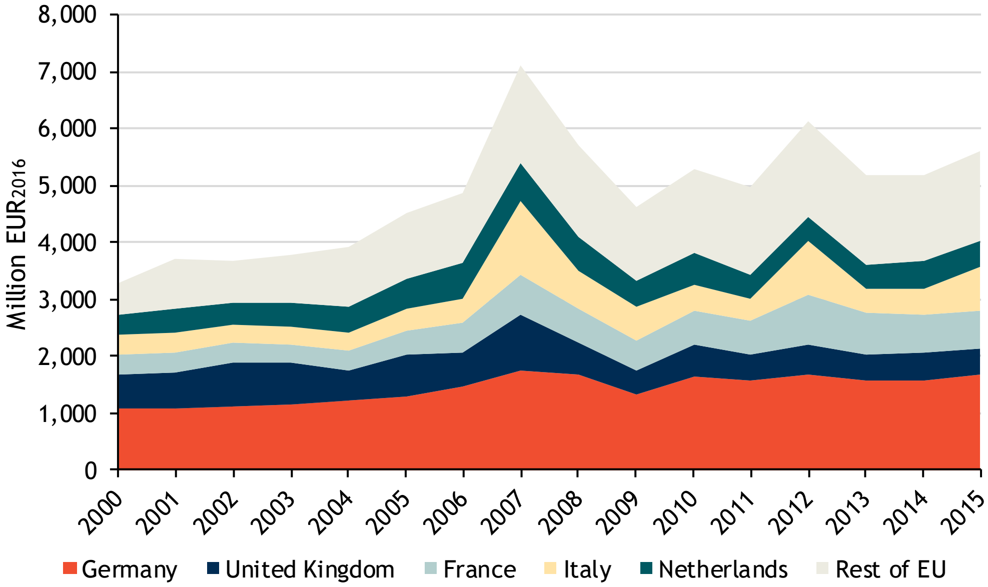


Source: Based on Comext (2018), Lako, P (2008), Eurostat (2018), Wind, I (2009), and Jha, V (2009)
Note: Data for 1999 and 2016 was 0 for all countries so it was excluded[19]. Trade data includes the imports and exports of the biofuels, and of the technology components to produce them. Feedstock trade is not accounted for. For an explanation of the methodology used, see Annex C.

Most EU exports to the rest of the world originate from Germany (see Figure 5.9). The other main exporters include the United Kingdom, France, Italy, and the Netherlands.

[18] The fluctuations are partly a consequence of the methodology chosen as the exact timings of the purchases are not known and an assumption needs to be made to allocate trade volumes related to new installed capacities to periods of time. In our methodology these trade volumes are allocated to the year in which the capacity was registered. In the absence of continuous capacity additions over the years, this leads to a spike in certain years.
[19] Due to statistical imbalances leading to a negative figure for component 382490 - Other chemical products and preparations of the chemical or allied industries (including those consisting of mixtures of natural products), not elsewhere specified or included: other, the value of Gross imports in 2003 was set to 0, instead of (-68.5 million EUR). The data for this component was taken directly from Comext (2018), assuming 100 % of the imports are used by the biofuels sector.

Figure 5.9 Total value of exports of Biofuels components from the EU (extra EU28 trade)



Source: Based on Comext (2018), Lako, P (2008), Eurostat (2018), Wind, I (2009), and Jha, V (2009).
Note: Data for 1999 and 2016 was 0 for all countries so it was excluded. For an explanation of the methodology used, see Annex C.

5.7 Conclusions

Capacity and production of biofuels has increased strongly between 1995-2016. It is now the biggest source of renewable energy in the transport sector. The share of biofuels use in transport has risen from less than 1 % in 2004 to over 6 % today. The largest biofuel producers are also the largest EU R&D recipients (except for Spain), which facilitates efforts to develop and implement new technologies and biofuel projects.

As the sector is interlinked with agricultural produce, many jobs were created in the Member States with a large share of agricultural areas such as Romania and Hungary. Estimates of jobs show that more than half of the 200 000 direct and indirect jobs in the biofuels sector are located in the 13 new MS, which have potentially the most growth potential for employment. Industry turnover and biofuel plants however are mostly located in the MS which receive significant R&D funding from EU and domestic budgets, such as Germany, France, Italy and the Netherlands.

Second generation biofuels offer sustainable use of land, biomass and contributes significantly to the GHG reduction. However, the technologies utilizing second generation feedstocks are still at the research and/or demonstration stage, and therefore have limited social, economic and environmental impacts at the moment.

The sector is very sensitive to changing policies and harvests of agricultural products, which have affected the market. R&D efforts should go hand in hand with supporting policies for the uptake of biofuels to achieve the greatest social, economic and environmental impacts.

6 Conclusions

The European Commission has played a pivotal role in the development of the biofuels sector in the EU. The biofuels sector received a considerable amount of R&D funding from the EU and MS and EU policies have driven a fast increase in the use of biofuels in the EU Member States. In response to the critical discussion about deriving 'first' generation biofuels from edible products, the focus of R&D has been on developing production technologies for advanced biofuels. Thus far, advanced biofuels are mainly driven by R&D funding, although regulation also plays a role here; the EU 2030 climate and energy policy framework, including the new Renewable Energy Directive (RED-2) and LULUCF (Land Use, Land Use Change and Forestry) policies, are creating new markets for advanced biofuels.

Funding under the FPs has contributed to many publications, patents and other research outputs, such as the development of new and improved technologies or products, knowledge transfer, and public-private knowledge development, which in turn all contribute to the development of the biofuels sector. It has grasped opportunities for innovation across the entire spectrum of biofuels, contributing to the advancement of TRLs for cellulosic ethanol, which is now close to commercialisation, algae technology, which is at the early demonstration scale, pyrolysis oil, which has been successfully demonstrated, and aviation biofuels, which now have small pilot projects and larger research projects have started under H2020. Research on other biofuels and more general projects have also provided support to the sector, such as biorefinery integration and coordination projects.

Aided by EU legislation and R&D funding, interest in biofuels grew in MS, and a substantial market has been created in the EU. First generation biofuels are now the biggest source of renewable energy in the transport sector. The largest biofuel producers are also the largest EU R&D recipients (except for Spain), which facilitates efforts to develop and implement new technologies and biofuel projects. The sector is very sensitive to changing policies and harvests of agricultural products, which have affected the market. R&D efforts should therefore go hand in hand with supporting policies for the uptake of biofuels to achieve the greatest social, economic and environmental impacts.

Second generation biofuels are entering the market as well, but their impact is still very modest. Due to their infancy the capex, opex and LCOE are still high, but is expected to decrease as more plants will be built and demonstrated. Continued technological advancement can bring these and other advanced biofuels to the market, offering sustainable use of land, biomass and a significant reduction of GHG emissions.

The EU holds some of the leading research institutes, manufacturers and project developers in the sector, which is characterised by its wide array of technologies and specialisations. Interest in biofuel technologies is strong in the United States and rising in other countries, such as India, China and Brazil. Continued EU R&D funding, combined with enabling regulation, can propel the momentum that Europe currently has in the sector.

Annex 7A - Case studies

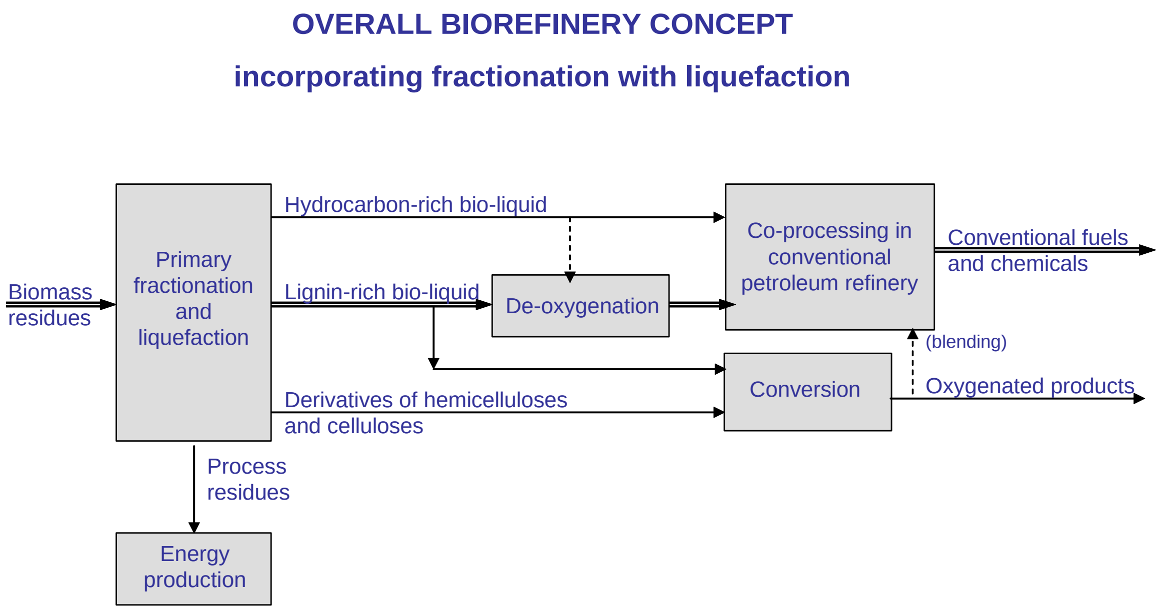
BIOCOUP

Author:	Muhammad Saad Qureshi	**Approver:**	Anja Oasmaa
Project title:	Co-processing of Upgraded Bio-liquids in Standard Refinery Units (BIOCOUP)		
Lead partner:	VTT- Technical Research Center of Finland		
Project location:	Finland		
Technology area/s:	Biofuels		
Start and end date:	May 2006 to April 2011		
Project cost:	EUR 12 859 901	**EC funding:**	EUR 7 599 971
Other funding sources:	Private investments from VTT		
Quantifiable outputs and impacts:	38 scientific journal articles 45 presentations at scientific conferences over 100 communications outside the consortium 4 patent applications 4 intensive training sessions were organised ASTM testing method needs were identified and a mandate was sent to CEN in 2011		
Further information:	The project website is no longer active Principle scientist VTT, Dr. Anja Oasmaa, Tietotie 4A 02150 Espoo, Finland, T +35 (0)8 40 59 32 834 Eanja.oasmaa@vtt.fi		

Project description

Depleting fossil based resources and global energy crisis together with increasing population and therefore pollution has motivated energy research to excel in renewable energy resources which are technically and environmentally sustainable. Co-processing of Upgraded Bio-liquids in Standard Refinery Units (BIOCOUP) project is aimed at identifying necessary steps to effectively co-feed biomass feedstock to standard oil refinery. The project also explored ways in which biomass could be transformed into chemicals and energy. The innovation involved the integration of biomass feedstock procurement from the industries involved in energy, pulp and paper and food business and consequently converting the upgraded biomass in existing conventional refineries. The availability of biomass is abundant ranging from timber industries, pulp and paper manufacturing to fermentation processes. Specifically, this includes agricultural residues, woody residues, black liquor (a side product from pulp and paper industry) and also organics from municipal solid waste. These sources of biomass can be efficiently liquefied into bio-liquids and with appropriate application of technologies can be upgraded to chemicals, low grade (non-refined) ready to co-feed crude and/or high-quality fuels ready for use in industrial settings. A schematic integration approach is presented in Figure A1.

Figure A1 Biocoup integration approach



The project derived from the European strategy on biofuels which is the maximisation of the European biomass resources to produce biofuels as an alternative to imported fossil fuels. The project helps to achieve GHG reduction, security of energy supply, cost-effective and sustainable methods, production of green products, etc. To enhance the competitiveness of the European energy, petrochemical and chemical industry sector, a diverse consortium of European universities, research institutes and private companies were assembled to cover the entire value chain of the co-feeding process and biomass to chemicals and energy.

Outputs and impacts

The project resulted in over 35 scientific journal publications, 45 scientific conference presentations, over 100 communications outside the consortium, and 4 patents. In particular, the patent on integrated biomass pyrolysis for flexible bio based feedstock into bio-oil was an important outcome from the BIOCOUP project. Key technical achievements of the project included:

- successful elucidation of the co-refining concept of bio-oil in standard refinery with laboratory-scale FCC or continuous hydro-processing units;
- the possibility to continuously upgrade pyrolysis oil at relatively mild conditions using a novel catalyst that renders the upgraded pyrolysis oil with improved properties;
- several different biomass to chemical platforms utilising novel catalysts were explored.

A large network of academic and research institute, universities and private companies targeted their expertise for the project's common goal. Efforts to standardise the pyrolysis oil quality indicators is one of the important key milestone of the project, which in a broader perspective will continue to serve the needs for the wider adaptability of bio-oil in industrial and commercial settings.

A detailed techno-economic study encompassing the different value chains revealed possible scenarios in which bio-oil co-feeding in conventional refineries could be efficiently achieved. The project directly contributed to the development of biofuel sector in European countries by exploring opportunities for local European biomass feedstock. The oil refining industry as a result of this project has gained interesting insights about the commercial benefits of bio-oil co-feeding. If the co-feeding concept is adapted, it will reduce the reliance on fossil-based fuels and reduce the emissions caused by wide use of mineral oil.

Outlook and commercial application of the outputs

The project has closed, but the creditability of its results is well known and its data is still used by the partners and other scientists continue to make requests for access to it. It was an extremely important project for development of co-feed applications and combined fuels and chemicals production.

The role of EU funding

The Integrated project (IP), lasting 5 years, was funded under Framework Programme 6 2004-ENERGY-3 (FP6-SUSTDEV) call. This call has been replaced by EU Horizon 2020 funding scheme. The funding from EU was substantial and almost 60 % of the total funding of the project. The EU-funding greatly leveraged the private funding needed to achieve the set goals of the project. Besides the monetary benefits from the EU-funding the publicity, networking possibilities and new strategic partners were of great value. EU-funded projects have direct visibility for the strategy makers and allow them to actively follow and collaborate on the findings of the project. One way of achieving this, was the annual progress reporting and presenting the preliminary results in conferences, which actively involved stakeholders in the value chain.

Full project participant list

Organisation	Country	Type
VTT- Technical Research Center of Finland	Finland	Research Institute
B.T.G Biomass Technology Group BV	The Netherlands	Private Company
Universiteit Twente	The Netherlands	Academic Institute
Shell Global Solutions International B.V	The Netherlands	Private Company
Center National De la Recherche Scientifique	France	Research Institute
Arkema SA	France	Private Company
Uhde Hochdrucjtechnik Gmbh	Germany	Private Company
Metabolic Explorer	France	Private Company
Inventia AB	Sweden	Private Company
Rijksuniversiteit Gronigen	The Netherlands	Academic Institute
Bundesforschungssantalt Fuer Forst - Und Holzwirtschaft	Germany	Research Institute
Kemijski Institut Ljubljana Solvenija	Slovenia	Research Institute
Alma Consulting Group SAS	France	Private Company
Albemarle Catalysts B.V	The Netherlands	Private Company
Chimar Hellas SA	Greece	Private Company
Technische Universiteit Eindhoven	The Netherlands	Academic Institute
Johann Heinrich Von Thunen Institut	Germany	Research Institute
Aalto Korkekoulusäätiö	Finland	Academic Institute
Boreskov Institute of Catalysis, Serbian Branch of Russian Academy of Sciences	Russia	Research Institute

BioDME

Author:	Muhammad Saad Qureshi	**Approver:**	Dr. Olov Öhrman
Project title:	Production of DME from Biomass and Utilisation as Fuel for Transport and for Industrial Use (BioDME)		
Lead partner:	Volvo Powertrain Corporation, Gothenburg, Sweden		
Project location:	Sweden		
Technology area/s:	Biofuels		
Start and end dates:	September 2001 to December 2012		
Project cost:	EUR 28 258 244.40	**EC funding:**	EUR 8 199 969.92
Other funding sources:	Private investments from Swedish Energy Agency		
Quantifiable outputs and impacts:	Demonstration of a BioDME plant (4tons/day), DME standardisation as a fuel, Development of a fuel injection systems. Field test on 10 Volvo HD trucks. Several presentations in scientific conferences.		
Further information:	Project website Prof. Research Manager, Dr. Olov Öhrman, RISE Research Institutes of Sweden, Division Bioeconomy - Energy Technology Center, T: +46 (0)70 619 23 91 (mobile) +46 (0)10 516 61 74 (landline) Box 726, SE-941 28 Piteå, Sweden, E: olov.ohrman@ri.se www.ri.se		

Project description

The project is called Production of DME from Biomass and Utilisation as Fuel for Transport and for Industrial Use (BioDME). DME (Dimethyl Ether) is a nontoxic gas in normal conditions but liquefies at about 6 bars and has similar properties as LPG. It has many applications such as a propellant, in power generation, fuel for heating and cooking or as a transportation fuel. DME can be produced from natural gas, coal or biomass. BioDME was co-ordinated by Volvo powertrain corporation and was funded jointly by European commission and Swedish Energy Agency. The project had had two main goals:

1. to operate a test fleet of heavy duty (HD) trucks run on biomass DME as a substitute for diesel fuel;
2. to produce DME from renewable sources known as BioDME.

Conventional diesel derived from fossil fuels has a very long history of development, which has enabled its application to wide variety of fuel-powered engines. Despite its good properties, one cannot negate the harmful effect on the environment of diesel fuel in the form of its GHG emissions. Thus, a constant search of a diesel substitute is a subject of parallel research.

Black liquor is an energy intensive by product of pulping process. It is produced in huge quantities worldwide and is traditionally used as a low-grade burning fuel. Under the BioDME concept, this black liquor is gasified into syngas and subsequently to DME biomass is used as a substitute for black liquor in to the CHP plant.

The project work was distributed between 7 partners:

- Volvo (Sweden) acted as the coordinator of the project and was responsible for the complete development of testing DME on Volvo HD trucks;
- Chemrec (Sweden) responsible for plant design, erection and production of BioDME;
- Delphi (UK) participated in the development of fuel injection system together with Volvo;
- Energy technology centre (Sweden) provided laboratory support;
- Haldor Topsøe (Denmark) provided process technology and operational support;
- Total (France) participated in the development of on fuel additive and lubricant;
- Preem (Sweden) had the task to explore the DME distribution in filling stations;

The direct beneficiaries of the project outcomes were the companies involved in the project. The project also contributed directly towards Sweden's renewable energy agenda. The project also contributed to the European goal of developing clean and renewable energy alternatives.

Outputs and impacts

The outputs included:

- **A BioDME demonstration plant** was constructed in Piteå, Sweden beside SmurfitKappa Kraftliner pulpmill with a production capacity of 4tons/day. The BioDME plant was essentially a combination of black liquor gasification to syngas and syngas conversion to DME. The plant cost EUR 22 million (excluding gasification) and was operated by 2 operators per shift. Almost 350 tonnes of DME was produced by the end of the project;
- **A DME ISO standardisation process** was initiated and several standards were developed to maintain fuel quality;
- **Fuel distribution** was critical component of the project. Four filling stations were used for DME distribution across Sweden;
- **A DME fuel injection system** was designed by Delphi suited to the fuel properties of DME;
- **Field tests** were performed on 10 different Volvo trucks. The trucks were used in several different settings for example in long haul Swedish mail, heavy load transport, etc. The tests accrued more than a million km.

The main impact was the successful demonstration of the use of BioDME, a sustainable biofuel from the by-product of a pulp mill. The standardisation of the DME as a fuel paved a way for acceptability in the community. Real technological advancement, addressing the associated challenges, was demonstrated by testing the fuel on a test fleet under real conditions. Problems were identified and rectified during the project which allowed the smooth uptake of the fuel. The EU funding played a vital role in supporting the project financially as well as providing adequate dissemination forums for the project result in the form of support for conferences, network meetings, etc.

Outlook and commercial application of the outputs

It is very likely that new EU regulations will encourage the use of biofuels in commercial applications. The results achieved in the BioDME project demonstrate an attractive use case. The efforts for standardisation of DME as a fuel will mobilise policy makers and relevant stakeholders to adapt BioDME as a potential biofuel. As a result of this project, black liquor to DME route is ready for full scale implementation.

To build a BioDME infrastructure in Swedish, at least 30 filling stations are needed, at an estimated investment of EUR 180 000 per filling station. The filling utilises existing LPG technology. The activities around BioDME development have been continued by Volvo truck corporation. It is expected that with investments in infrastructure and regulatory support, DME from biomass sources can prove a useful fuel source.

The role of EU funding

The project was supported under Framework Programme 7- Energy-2007-2-Tren (CP-Collective project), which is no longer operational and is superseded by Horizon 2020. Annual project reporting to update the Commission on the progress was an essential part of the project. Progress was disseminated through various conferences during the project. Local MS funding which was provided by the Swedish Energy Agency and 30 % of total project funding was provided by the Commission. Besides the financial support provided by the EU, collaboration with a large network of relevant companies was possible which was very helpful in publicizing the project objectives and outcomes. The project website, supported by the funding, also played a vital role in the dissemination of the project's concept and outcomes. The public outreach was also made possible by short project videos explaining the concept and information about the use of DME as a fuel.

Full project participant list

Organisation	Country	Type
Volvo Powertrain Corporation	Sweden	Private company
Chemrec AB - Former	Sweden	Private company
Haldor Topsøe AS	Denmark	Private company
Delphi Diesel System Ltd	United Kingdom	Private company
ETC-Energy Technology Center	Sweden	Private company
Total Marketing Services	France	Private company
Preem Petroleum AB	Sweden	Private company

EUROBIOREF

Author:	Muhammad Saad Qureshi	**Approver:**	Dr. Franck Dumeignil
Project title:	EUROpean Multilevel Integrated BIOREFinery Design for Sustainable Biomass Processing (EUROBIOREF)		
Lead partner:	CNRS, Center Nationale de la Recherche Scientifique, France		
Project location:	France		
Technology area/s:	Biofuels		
Start and end date:	January 2010 to February 2014		
Project cost:	EUR 36 648 416.26	**EC funding:**	EUR 23 073 794
Other funding sources:	Private investment		
Quantifiable outputs and impacts:	Biomass harvest (5 lignocelluosic plants, 10 oil crops), large test fields set, culture rotation strategies, biomass supply logistics model, chemical, thermochemical, biotech- conversion technologies development, Pilot plant in Norway (50 kg/h), -Jobs - almost 100 to 200 direct and up to 3 600 indirect, 33 patents filed, 60+ scientific papers published, project videos, 2 books, two-days conference, creation of one start-up company		
Further information:	Project website **Project Coordinator** Franck Dumeignil, Unité de Catalyse et Chimie du Solide - UMR CNRS 8181, Université de Lille, 59655 Villeneuve d'Ascq Cedex, France, Efranck.dumeignil@univ-lille.fr T +33(0)320 43 45 38 (landline) - +33(0)6 11 23 06 48 (mobile)		

Project Description

EUROpean Multilevel Integrated BIOREFinery Design for Sustainable Biomass Processing (EUROBIOREF) was a project based on the integration of biorefinery concepts. The project lasted 4 years and was coordinated by CNRS, France. The project was grant funded under the EU's Framework Programme 7. It encompassed the entire value chain of the biorefinery processes starting with sustainable biomass harvesting to fuels and chemicals processing.

The project aimed to explore the biorefinery value chain including, production and utilisation of sustainable biomass originating from high diversity in European regions, development of a sustainable high energy aviation biofuel, optimised production of chemicals, polymers and value-added products, improvements in biorefinery feedstock flexibility, optimisation in production time, reduction in energy needs and environmental footprints through a detailed life cycle analysis.

The flexible approach of this project enabled optimised use of sustainable biomass in European countries. The project aimed at integrating the efforts of a fragmented European biomass industry into the development of a techno-economical bio-refinery. The project further aimed at identifying the unexplored links in the biorefinery value chain, where simple integrations could make sense for the whole business. To that extent, the project identified, explored and optimised the harvest of suitable biomass feedstock, including oil crops and ligno-cellulosic materials that could be grown locally in European countries.

The project also explored the conversion of new and existing biomass into fuel and chemicals routes. The techno-economic challenges in each value chain were addressed. One of the most important parts of the project was the sustainability criteria. In every value chain, sustainability criteria were considered primarily before proposing the optimised solution. Besides many important indicators, the project also aimed to achieve a 30 % energy reduction and zero waste production, signifying the importance of sustainability in the biorefinery business.

The direct beneficiaries of the project were the stakeholders involved in the whole biorefinery value chains such as farmers, biorefinery owners, commodity chemicals manufacturers, fuel manufacturers and users of these products and services. The project was driven by sustainability goals from European governments and urgent need for an economical processes for the biorefinery business. The project involved 29 partners from 15 countries. The project had a highly diverse collaborative network of SME's, industries and academia joining forces from different parts of the biorefinery value chains

Outputs and impacts

During the project more than 300 dissemination activities were carried out with different stakeholders including, academics, citizens, industrials and students. At least 33 patents were filed out of which 10 were granted during the project. At least 29 scientific papers were published during the project and many were also published after project completion (over 60). The project resulted in 20 PhD theses and 5 master theses. Over 20 lectures were presented by the academic partners during university courses. A book was published on 'Biomass to Chemicals and Fuels' followed by a second aimed at students. Three professional training events were organised during the project. The project also organised a summer school in Italy on 'Utilization of Biomass for the Production of Fuels and Chemicals'. For active public engagement, activity reports, films, videos, leaflets, slideshow were made available in the project website. A two-days conference 'Tomorrow's Biorefineries in Europe' was organised in Brussels with other biofuels project funded under the same EU funding call with the support from EUBIA.

The main scientific outcomes were:

- **Biomass harvest**: 5 lignocellulosic plants and 10 oil crops were grown, large field tests in Poland and Madagascar, Culture rotation strategies between edible and non-edible crops were developed;
- **Logistics and transport**: Biomass supply logistics network model was developed;
- **Biomass to chemicals and polymers platforms**: biotech technologies were developed for platform molecules from glycerol and biomass hydrolysates;
- **Biomass to Fuel platform**: A new bio-based aviation fuel (42 Mj/kg) was developed through fermentation of biomass-derived hydrolysate to butanol and then by chemical reaction of the as-obtained butanol to 2-ethylhexanol which can be blended in jet fuel. 15 m^3 of the blends were designed and successfully tested in a jet reactor; five different diesel blending fuels were also tested for light duty road engines;
- **Piloting**: Pilot plant in Borregaard Norway (50 kg of dry lignocellulosic materials per hour) was constructed and plans developed for scaling it up.

Three major benefits to the society are:

- **sustainable bioeconomy:** EuroBioref contributed directly towards promoting plant biodiversity, reducing energy consumption and reducing waste to zero;
- **jobs:** Almost 100 to 200 direct while up to 3 600 indirect jobs created;
- **better quality of life:** Processes optimised with detailed LCA methods to design socio-economical bio-refining processes.

The EUROBIOREF project contributed considerably towards the integration of biorefineries. This was possible by addressing issues from the whole value chain. The project produced significant knowledge on European land use for sustainable biomass cultivation, biomass logistics, biomass-derived platform molecules conversion to fuels and chemicals. It significantly reduced the cost-intensive steps in the value chain guided by a detailed LCA analysis. The technological advancement brought by the project involved many direct and indirect jobs. The project in a broader scope contributed significantly in optimizing the biorefinery scenarios in European countries.

Outlook and commercial application of the outputs

The core of the project was the production of biorefining integration strategies, which contributed to the long-lasting impacts in domains corresponding to the whole value chain. Significant improvements in the chemical processes, which yielded several patents, brought forward the technological advancements. The patents produced during project are considerably valuable to business. At least one start-up resulted from the project called TEAMCAT (https://www.teamcat-solutions.com).

The role of EU Funding

The project was supported with EUR 23 million grant under the EU's Seventh Framework Programme. The funding programme was superseded by new programme called Horizon 2020. The overall cost of the project was almost EUR 36.6 million which makes the European funding in the project almost 62 % in total, leveraging funding from academic and private sources. (The progress reporting was a critical part of the project and EU Commission conducted an annual audit through 3rd party auditors. The project gained publicity from the EU-Cordis website. EU-funding also allowed the organisation of summer school, conference development and filing of patents.

Full project participant list

Organisation	Country	Type
CNRS, Centre National de la Recherche Scientifique	France	Research Institute
ARKEMA	France	Private company
BORREGAARD Industries. Ltd.	Norway	Utility company
NOVOZYMES A/S	Denmark	Private company
CRES, Center for Renewable Energy Sources	Greece	Research Institute
HALDOR TOPSØE A/S	Denmark	Private company
CERTH, Centre for Research & Technology Hellas	Greece	Research Institute
PDC, Process Design Center BV,	The Netherlands	Private company
QUANTIS	Switzerland	Private company
EUBIA, European Biomass Industry Association	Belgium	Association

Organisation	Country	Type
DTI, Danish Technological Institute, Centre for Renewable Energy and Transport	Denmark	Research Institute
Technische Universität Dortmund	Germany	University
MERCK KGaA	Germany	Private company
FEUP Faculdade de Engenharia da Universidade do Porto	Portugal	University
RWTH Aachen	Germany	University
CIRCC, University of Bari	Italy	University
WSK 'PZL-Rzeszow' S.A	Poland	Private company
OBRPR, Ośrodek Badawczo-Rozwojowy Przemysłu Rafineryjnego Spółka Akcyjna	Poland	Research Institute
SINTEF Materials and Chemistry	Norway	Research Institute
SOABE, Société Agricole de Befandriana-Sud & Partners Sarl	Madagascar	Private company
UMICORE AG & Co KG,	Germany	Private company
Nykomb Synergetics AB	Sweden	Private company
Alma Consulting Group SAS	France	Private company
Ruse Chemicals AD, Bulgaria – demerger from Orgachim AD	Bulgaria	Private company
Imperial College of Science	United Kingdom	University
Novance	France	
University of Warmia and Mazury in Olsztyn	Poland	University
Technische Universität Hamburg - Hamburg	Germany	University
BKW Biokraftwerke Fürstenwalde GmbH	Germany	Private company

Annex 7B - Literature

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Annex 7C - Methodological note on imports and exports

The value of the following components were assessed for biofuels:

Table C.0.1 HS6 product codes relevant to the biofuel sector

HS6 code	Brief product description
220710	Undenatured ethyl alcohol
220720	Ethyl alcohol and other spirits
380210	Activated carbon
382490	Other chemical products and preparations of the chemical or allied industries (including those consisting of mixtures of natural products), not elsewhere specified or included: other
840681	Steam turbines and other vapour turbines, of an output exceeding 40 MW
840682	Steam turbines and other vapour turbines, of an output not exceeding 40 W
841280	Other engines and motors
841182	Other gas turbines, of a power exceeding 5 000 kW
841620	Other furnace burners, including combination burners
841931	Dryers: for agricultural products
841940	Distilling or rectifying plant
847920	Machinery for the extraction or preparation of animal or fixed vegetable fats or oils
850161	AC generators (alternators): of an output not exceeding 75 kVA (kilovolt ampere)
850162	AC generators (alternators): of an output exceeding 75 kVA but less than or equal to 375 kVA
850163	AC generators (alternators): of an output exceeding 375 kVA but less than or equal to 750 kVA
850164	AC generators (alternators): of an output exceeding 750 kVA

Source: Comext database and Jha (2009)

Annex 7D- List of EU-funded projects

Table D.1 Research projects focused on biofuel technologies only

Acronym	Rcn	Title	EC Funding	Programme	Topic
2G-CSAFE	101302	Combustion of Sustainable Alternative Fuels for Engines used in aeronautics and automotives	2623543	FP7	ERC-AG-PE8
2NDVEGOIL	90327	Demonstration of 2nd Generation Vegetable Oil Fuels in Advanced Engines	2431309	FP7	ENERGY-2007-3.6-01
4REFINERY	209939	Scenarios for integration of bio-liquids in existing REFINERY processes	5864850	H2020	LCE-08-2016-2017
Accordion Bioreactor	207132	An innovative high capacity Accordion bioreactor technology for high performance and low cost microalgae production	49157	H2020	SMEInst-08-2016-2017
ACETOGENS	210552	Acetogenic bacteria: from basic physiology via gene regulation to application in industrial biotechnology	2455019	H2020	ERC-2016-ADG
AFFORHD	60064	Alternative fuel for heavy duty (AFFORHD)	2334999	FP5-EESD	1.1.4.-6.
ALGFUEL	94675	Biodiesel production from microalgae	161623	FP7-PEOPLE	FP7-PEOPLE-2009-IEF
ALL-GAS	103638	Industrial scale demonstration of sustainable algae cultures for biofuel production	7462498	FP7	ENERGY.2010.3.4-1
Ambition	206587	Advanced biofuel production with energy system integration	2494986	H2020	LCE-33-2016
ANAMIX	89992	A two year exchange programme on ANAerobic MIXed cultures to study and improve biological generation of chemicals and energy carriers from organic residues generated by agro-industrial activities	75594	FP7-PEOPLE	FP7-PEOPLE-IRSES-2008
APEX	196387	Advanced Process Economics through Oxidoreductases	1545429	H2020	BIOTEC-5a-2014
AQUAFUELS	93226	Alage and aquatic biomass for a sustainable production of 2nd generation biofuels	808877	FP7	ENERGY.2009.3.2.1
AQUATERRE	88211	Integrated European Network for biomass and waste reutilisation for Bioproducts	864997	FP7	KBBE-2007-3-1-08
ARTFUL	208958	Structure-activity relationships of an emerging family of fungal lytic polysaccharide monooxygenases	170157	H2020	MSCA-IF-2016
BABETHANOL	91093	New feedstock and innovative transformation process for a more sustainable development and production of lignocellulosic ethanol	3503029	FP7	ENERGY.2008.3.2.1
BABET-REAL5	199585	New technology and strategy for a large and sustainable deployment of second generation biofuel in rural areas	5573644	H2020	LCE-11-2015
BABILAFUENTE BIOETHA	86921	Project for the production of 200 million litres of Bioethanol en Babilafuente (salamanca) from cereals and lignocellulose	5206290	FP5-EESD	N/A
BEAL	200790	Bioenergetics in microalgae : regulation modes of mitochondrial respiration, photosynthesis, and fermentative pathways, and their interactions in secondary algae	1837625	H2020	ERC-CoG-2015
BECOOL	210282	Brazil-EU Cooperation for Development of Advanced Lignocellulosic Biofuels	4915617	H2020	LCE-22-2016
BEST	85625	BioEthanol for sustainable transport	9472068	N/A	SUSTDEV-1.1.5

Acronym	Rcn	Title	EC Funding	Programme	Topic
BEST	89706	Application of biofuel by-products to the soil: implications for Carbon Sequestration and GHG Emissions	177948	FP7-PEOPLE	PEOPLE-2007-2-1.IEF
BFSJ	197830	Production of fully synthetic paraffinic jet fuel from wood and other biomass	27874551	FP7	ENERGY.2013.3.2.1
BIOALGAESORB	95350	Enabling European SMEs to remediate wastes, reduce GHG emissions and produce biofuels via microalgae cultivation	3066653	FP7	SME-2
BioAOPBDies	98888	Intimate coupling of biological advanced oxidation processes for environmental de-pollution and biodiesel production	170919	FP7-PEOPLE	FP7-PEOPLE-2010-IEF
BIOBOOST	101509	Biomass based energy intermediates boosting biofuel production	5205891	FP7	ENERGY.2011.3.7-1
BIOCARD	75527	Global Process To Improve Cynara cardunculus Exploitation for Energy Applications.	3025042	N/A	SUSTDEV-1.2.5
BIOCAT	60068	Catalyst development for catalytic biomass flash pyrolysis producing promissing liquid bio-fuels (BIOCAT)	1694051	FP5-EESD	1.1.4.-6.
BIOCOUP	78776	Co-processing of upgraded bio-liquids in standard refinery units	8998430	N/A	SUSTDEV-1.2.5
BIODINA	86916	Sustainable community through the production of 30000Tm/year of bio-diesel starting from sunflower, rapeseed and palm biomass	2960021	FP5-EESD	N/A
BIODME	90341	Production of DME from biomass and utilisation as fuel for transport and for industrial use	9152160	FP7	ENERGY-2007-3.2-05
BIO-ELECTRICITY	67558	Efficient and clean production of electricity from biomass via pyrolyses oil and hydrogen utilizing fuel cells - target action g (BIO-ELECTRICITY)	2056466	FP5-EESD	1.1.4.-5.
BIO-ETOH	87870	Energy and cost reductions in production of fuel ethanol from biomass through membrane technology	2113857	N/A	SUSTDEV-1.1.5
BIOFAT	100477	BIOfuel From Algae Technologies	8162319	FP7	ENERGY.2010.3.4-1
BIOFUEL	95838	Biofuels from Solid Wastes	101333	FP7-PEOPLE	FP7-PEOPLE-2009-IRSES
BIOFUELSTP	91982	European Biofuels Technology Platform Secretariat	511766	FP7	ENERGY.2009.3.7.1
BIOFUELTP	80092	Biofuels Technology Platform Secretariat	580590	N/A	SUSTDEV-1.2.5
Bio-Green-IC-Engine	109236	Novel multizone thermodynamic model and specialised software for rapid optimisation of working process strategies and design parameters of Internal Combustion Engines run on advanced biofuels	301907	FP7-PEOPLE	FP7-PEOPLE-2012-IIF
BioLEAP	105215	Biotechnological optimization of light use efficiency in algae photobioreactors	1286605	FP7	ERC-SG-LS9
BIOLIQUIDS-CHP	90302	Engine and turbine combustion of bioliquids for combined heat and power production	1770835	FP7	ENERGY.2008.2.2.1
BIOLYFE	94482	Second generation BIOethanol process: demonstration scale for the step of Lignocellulosic hYdrolysis and FErmentation	9309892	FP7	ENERGY.2008.3.2.2
BIOMAP	92894	Development of Time-enabled Mapping and Dissemination Tool for Biofuels Projects	601346	FP7	ENERGY-2007-3.7-04
BioMates	205818	Reliable Bio-based Refinery Intermediates	5923316	H2020	LCE-08-2016-2017
BioMIC-FUEL	204518	Bio-inspired photonics for enhanced microalgal photosynthesis in biofuels	247610	H2020	MSCA-IF-2015-GF
BIORECYGAS	199500	Farming high value algae with industrial gas emissions	50125	H2020	SC5-20-2015-1

Acronym	Rcn	Title	EC Funding	Programme	Topic
BIOREF-INTEG	88269	Development of advanced BIOREFinery schemes to be INTEGrated into existing industrial fuel producing complexes	1110632	FP7	ENERGY-2007-3.3-03
BIOREFLY	197828	"2,000 TON/Y INDUSTRIAL SCALE DEMONSTRATION BIOREFINERY ON LIGNIN-BASED AVIATION FUEL"	13802357	FP7	ENERGY.2013.3.2.1
BIOREMA	94472	Reference Materials for Biofuel Specifications	699677	FP7	ENERGY-2007-3.7-03
BIOSKOH	204326	BIOSKOH's Innovation Stepping Stones for a novel European Second Generation BioEconomy	21568194	H2020	BBI.VC1.F1
BIOSYNERGY	81303	Biomass for the market competitive and environmentally friendly synthesis of bio-products together with the production of secondary enERGY carriers through the biorefinery approach	7118644	N/A	SUSTDEV-1.2.5
BIOTOP	86248	Biofuels Assessment on Technical Opportunities and Research Needs for Latin America	1101123	FP7	ENERGY-2007-3.2-07
BITES	86573	Biofuels technologies european showcase	651763	N/A	SUSTDEV-1;SUSTDEV-1.1.8
BRISK II	210188	Biofuels Research Infrastructure for Sharing Knowledge II	9800004	H2020	INFRAIA-01-2016-2017
ButaNexT	193725	Next Generation Bio-butanol	4610913	H2020	LCE-11-2014
BUTYROL	109750	Development of Platform Technology for Butanol Production using Biodiesel Industry Derived Glycerol Waste	231861	FP7-PEOPLE	FP7-PEOPLE-2012-IIF
C2B	207693	Carbon 2 Butanol, a breakthrough technology in eco-innovation that cuts GHG emissions byconverting industrial waste gases into chemicals and biofuel.	49157	H2020	SMEInst-09-2016-2017
CAB-CEP	85643	Co-ordination action biofuel cities European partnership	3005570	N/A	SUSTDEV-1.1.5
CANEBIOFUEL	90103	Conversion of Sugar Cane Biomass into Ethanol	1836771	FP7	ENERGY.2008.3.2.1
CASCATBEL	110687	CAScade deoxygenation process using tailored nanoCATalysts for the production of BiofuELs from lignocellullosic biomass	6418134	FP7	NMP.2013.1.1-1
CellulosomePlus	110786	Boosting Lignocellulose Biomass Deconstruction with Designer Cellulosomes for Industrial Applications	4028362	FP7	NMP.2013.1.1-2
COMBIO	67932	A new competitive liquid biofuel for heating (COMBIO)	1633238	FP5-EESD	1.1.4.-5.
COMETHA	185362	80,000 TON/Y PRECOMMERCIAL INDUSTRIAL SCALE DEMONSTRATION PLANT ON SECOND GENERATION LIGNOCELLULOSIC ETHANOL	17942956	FP7	ENERGY.2012.3.2.3
COMSYN	209938	Compact Gasification and Synthesis process for Transport Fuels	5010691	H2020	LCE-08-2016-2017
DegradePlant	98715	Directed evolution and semi-rational engineering of plant cell wall-degrading enzymes	210066	FP7-PEOPLE	FP7-PEOPLE-2010-IEF
DEMA	106280	Direct Ethanol from MicroAlgae	5062563	FP7	ENERGY.2012.3.2.1
DESYRE	82578	Designed yeast for renewable bioethanol production	182161	N/A	MOBILITY-2.1
DIBANET	91952	The Production of Sustainable Diesel-Miscible-Biofuels from the Residues and Wastes of Europe and Latin America	4127343	FP7	ENERGY.2008.3.2.1
DISCO	88398	Targeted DISCOvery of novel cellulases and hemicellulases and their reaction mechanisms for hydrolysis of lignocellulosic biomass	3332565	FP7	KBBE-2007-3-2-01

Acronym	Rcn	Title	EC Funding	Programme	Topic
EBTP-SABS	110099	European Biofuels Technology Platform – Support for Advanced Biofuels Stakeholders	500242	FP7	ENERGY.2013.3.7.2
ECOCAT	209838	Improving the economic feasibility of the biorefinery through catalysis engineering: enhancing the catalyst performance and optimizing valuable product yields	180360	H2020	MSCA-IF-2016
ECODIESEL	90993	High effiency biodiesel plant with minimum ghg emissions for improved fame production from various raw materials	5548877	FP7	ENERGY-2007-3.1-02
ECOFUEL	96908	EU-China Cooperation for Liquid Fuels from Biomass Pyrolysis	668406	FP7-PEOPLE	FP7-PEOPLE-2009-IRSES
ECO-LOGIC GREEN FARM	198392	Design of an agricultural greenhouse for intensive growing of microalgae in fresh / sea water with a syngas production plant and organic farming of chickens and pigs outdoors.	2494370	H2020	SFS-08-2015
ELECTROENZEQUEST	108449	BioElectrochemical system for Enzyme catalyzed CO2 sEquestration for the recovery of commercially viable carbonated water and methanol	178388	FP7-PEOPLE	FP7-PEOPLE-2012-IIF
ELOXY	204839	Eliminating Oxygen Requirements in Yeasts	2498150	H2020	ERC-ADG-2015
EMPYRO	94486	Polygeneration through pyrolysis: Simultaneous production of fuel oil, process steam, electricity and organic acids	5470535	FP7	ENERGY.2008.8.2.1
ENERFISH	90328	Integrated Renewable Energy Solutions for Seafood Processing Stations	3286747	FP7	ENERGY-2007-8.2-01
ENERGYPOPLAR	88261	Enhancing Poplar Traits for Energy Applications	3334722	FP7	KBBE-2007-3-1-02
ESBCO2	104523	Electrosynthesis of biofuels from gaseous carbon dioxide catalyzed by microbes: A novel approach/quest of microbe-electrode interactions	187894	FP7-PEOPLE	FP7-PEOPLE-2011-IOF
ETOILE	94371	BIOETHANOL PRODUCTION VIA LIGNOCELLULOSIC FERMENTATION OF OLIVE OIL RESIDUES	987853	FP7	SME-1
EUROBIOREF	93922	EUROpean multilevel integrated BIOREFinery design for sustainable biomass processing	24979998	FP7	ENERGY.2009.3.3.1
EUROPE'S METAGENOME	96761	Probing Europe's Undiscovered Genome: A Metagenomics Approach to Find Unique Enzymes for the Biofuel and Bioprocessing Industries	108261	FP7-PEOPLE	FP7-PEOPLE-2009-RG
FALCON	206994	Fuel and chemicals from lignin through enzymatic and chemical conversion	6045068	H2020	BIOTEC-02-2016
FASTCARD	110686	FAST industrialisation by CAtalysts Research and Development	8253868	FP7	NMP.2013.1.1-1
FIBREETOH	94485	Bioethanol from paper fibres separated from solid waste, MSW	9364576	FP7	ENERGY.2008.3.2.2
FLEDGED	205918	FLExible Dimethyl ether production from biomass Gasification with sorption-enhancED processes	5306455	H2020	LCE-08-2016-2017
FUEL4ME	106424	FUture European League 4 Microalgal Energy	4046465	FP7	ENERGY.2012.3.2.1
FUEL-PATH	89112	Exploiting the saccharification potential of pathogenic microorganisms to improve biofuel production from plants	2320416	FP7	ERC-AG-LS9
GAS2ALCO	90623	NOVEL EFFICIENT CATALYSTS FOR BIO-SYNGAS CONVERSION TO C2-C4 ALCOHOLS	49733	FP7-PEOPLE	PEOPLE-2007-2-2.ERG
GREEN-OIL	100223	Development of bio-oil dewatering and fractionation processes and testing of upgraded bio-oil as engine fuel and feedstock for the production of lubricants	2002741	FP7	SME-2011-1
Heat-To-Fuel	211646	Biorefinery combining HTL and FT to convert wet and solid organic, industrial wastes into 2nd generation biofuels with highest efficiency	5797519	H2020	LCE-08-2016-2017

Acronym	Rcn	Title	EC Funding	Programme	Topic
HYPE	88489	High efficiency consolidated bioprocess technology for lignocellulose ethanol	4088289	FP7	ENERGY-2007-3.2-02
i-CaD	192403	Innovative Catalyst Design for Large-Scale, Sustainable Processes	2004676	FP7	ERC-CG-2013-PE8
INTESUSAL	100473	Demonstration of integrated and sustainable enclosed raceway and photobioreactor microalgae cultivation with biodiesel production and validation	5250340	FP7	ENERGY.2010.3.4-1
ITAKA	106229	Initiative Towards sustAinable Kerosene for Aviation	9594376	FP7	ENERGY.2012.3.2.2
JATROPT	94718	Jatropha curcas Applied and Technological Research on Plant Traits	3243227	FP7	KBBE-2009-3-1-02
KACELLE	94489	Demonstrating Industrial Scale Second Generation Bioethanol Production - KAlundborg CELLulosic Ethanol plant	10056014	FP7	ENERGY.2008.3.2.2
LED	94481	Lignocellulosic Ethanol Demonstration	9345900	FP7	ENERGY.2008.3.2.2
LIGNOFLAG	204324	Commercial flagship plant for bioethanol production involving a bio-based value chain built on lignocellulosic feedstock	24321553	H2020	BBI.VC1.F1
MABFUEL	90637	Marine Algae as Biomass for Biofuels	1581323	FP7-PEOPLE	FP7-PEOPLE-IAPP-2008
MICROFUEL	107623	Mobile Microwave Pyrolysis Plant turns Biomass into Fuel Locally	2520750	FP7	SME-2
MICROGRASS	107794	Release of sugars from lignocellulosic biomass by microwave plasma	1146118	FP7	SME-1
MOMIMIC	208745	Multi-layered biomimetics of lytic polysaccharide monooxygenases	158088	H2020	MSCA-IF-2016
NEMO	90531	Novel high-performance enzymes and micro-organisms for conversion of lignocellulosic biomass to bioethanol	6518295	FP7	KBBE-2007-3-2-06
NEXT GEN BIOFUEL	92546	PRODUCING NEXT GENERATION BIOFUELS THROUGH THE FISCHER-TROPSCH PROCESS UTILIZING CLEAN BIOMASS DERIVING FROM THE PRE-TREATMENT OF AGRICULTURAL BIOMASS AND WASTE	49733	FP7-PEOPLE	FP7-PEOPLE-ERG-2008
NILE	75087	New Improvements for Ligno-cellulosic Ethanol	9095948	N/A	SUSTDEV-1.2.5
NOVACAM	109118	NOVel cheap and Abundant Materials for catalytic biomass conversion	1800854	FP7	NMP.2013.4.1-1
Operation SWAT	100969	High algal recovery using a Salsnes Water to Algae Treatment (SWAT) filter technology	1113574	FP7	SME-2011-1
OPTFUEL	90314	Optimized Fuels for sustainable transport in Europe	7868764	FP7	ENERGY-2007-3.2-05
PAcMEN	205589	Predictive and Accelerated Metabolic Engineering Network	3994076	H2020	MSCA-ITN-2016
Photofuel	193744	Biocatalytic solar fuels for sustainable mobility in Europe	6013247	H2020	LCE-11-2014
PROETHANOL2G	96238	Integration of Biology and Engineering into an Economical and Energy-Efficient 2G Bioethanol Biorefinery	1060961	FP7	ENERGY.2009.3.2.3
PYROCHEM	195365	Biopolymers 13C tracking during fast pyrolysis of biomass-A 2-level mechanistic investigation	183913	H2020	MSCA-IF-2014-EF
PYROHEAT	54167	Pyrolysis oil for heat generation: verification of a second generation pyrolysis process ('PYROHEAT')	1330030	FP5-EESD	1.1.4.-5.
RENEW	73982	Renewable fuels for advanced powertrains (RENEW)	10170519	N/A	SUSTDEV-1.2.5
Residue2Heat	199298	Renewable residential heating with fast pyrolysis bio-oil	5465728	H2020	LCE-02-2015

Acronym	Rcn	Title	EC Funding	Programme	Topic
SiCCatalysis	104398	Porous Silicon Carbide as a support for Co metal nanoparticles in Fischer–Tropsch synthesis	169112	FP7-PEOPLE	FP7-PEOPLE-2012-IRSES
SIZE	198617	Size matters: scaling principles for the prediction of the ecological footprint of biofuels	1674582	H2020	ERC-CoG-2014
SOLARIS	211761	Solaris energy tobacco for the creation of a European sustainable biojet fuel value chain	1096345	H2020	SMEInst-07-2016-2017
Solaris	198555	Solaris Energy Tobacco	50125	H2020	SC5-20-2015-1
STEELANOL	195267	Production of sustainable, advanced bio-ethANOL through an innovative gas-fermentation process using exhaust gases emitted in the STEEL industry	10217997	H2020	LCE-12-2014
SUNLIBB	95909	Sustainable Liquid Biofuels from Biomass Biorefining	3697554	FP7	ENERGY.2009.3.2.3
SUNLIQUID	185363	sunliquid® large scale demonstration plant for the production of cellulosic ethanol	23055194	FP7	ENERGY.2012.3.2.3
SUPRA-BIO	94178	Sustainable products from economic processing of biomass in highly integrated biorefineries	13335808	FP7	ENERGY.2009.3.3.1
SUSFUELCAT	106702	Sustainable fuel production by aqueous phase reforming – understanding catalysis and hydrothermal stability of carbon supported noble metals	3543415	FP7	NMP.2012.1.1-1
SUSTOIL	87800	Developing advanced Biorefinery schemes for integration into existing oil production/transesterification plants	1107412	FP7	ENERGY-2007-3.3-03
SWEETFUEL	89368	Sweet Sorghum : an alternative energy crop	3280118	FP7	KBBE-2008-3-1-02
SYNTOBU	109739	Biological production of butanol from syngas	100784	FP7-PEOPLE	FP7-PEOPLE-2013-CIG
TASAB	206310	TOWARDS A SUSTAINABLE ALGAL BIOREFINERY	180360	H2020	MSCA-IF-2015-EF
TCPBRCBDP	94856	Tandem catalysis for the production of biofuel related chemicals from biomass derived polyols	197004	FP7-PEOPLE	FP7-PEOPLE-2009-IIF
TCR	205272	Feasibility Assessment on Thermal Catalytical Reforming	50000	H2020	SMEInst-03-2016-2017
THERMCP	205231	Construction of microcompartments in thermophilic Geobacillus thermoglucosidasius as nano-bioreactors for advanced biofuels production at high temperature	195455	H2020	MSCA-IF-2015-EF
THERMONET	87175	Network cluster on thermal biomass conversion implementation	1044392	FP5-EESD	N/A
Torero	209957	TORrefying wood with Ethanol as a Renewable Output: large-scale demonstration	11279394	H2020	LCE-19-2016-2017
TO-SYN-FUEL	209765	The Demonstration of Waste Biomass to Synthetic Fuels and Green Hydrogen	12043890	H2020	LCE-19-2016-2017
VAALBIO	84428	Valorization of alcohols issued from biomass	92556	N/A	MOBILITY-4.2
VALOR-PLUS	111059	Valorisation of biorefinery by-products leading to closed loop systems with improved economic and environmental performance	7471890	FP7	KBBE.2013.3.4-01
VASCULAR GENE MAPS	107837	Gene expression profiling of plant vascular tissue in model and crop species	395500	FP7-PEOPLE	FP7-PEOPLE-2012-IOF
WASTE2FUELS	200420	Sustainable production of next generation biofuels from waste streams	5989743	H2020	LCE-11-2015
N/A	54758	Large bioethanol / etbe integrated project in china and italy	419328	FP5-EESD	1.1.4.-6.

Table D.2 Research projects focused on biofuel technologies in combination with other RES:

Acronym	Rcn	Title	EC Funding	Programme	Topic
BIOGO-FOR-PRODUCTION	110962	Catalytic Partial Oxidation of Bio Gas and Reforming of Pyrolysis Oil (Bio Oil) for an Autothermal Synthesis Gas Production and Conversion into Fuels	9108153	FP7	NMP.2013.1.1-1
BIOTROLL	67151	Integrated biological treatment and agricultural reuse of olive mill effluents with the concurrent recovery of energy sources	1954799	FP5-LIFE QUALITY	1.1.1.-5.
CO-PRODUCTION BIOFUE	67138	Integrated biomass utilisation for production of biofuels target action h and j (CO-PRODUCTION BIOFUELS)	8290814	FP5-EESD	1.1.4.-6.
ENANAMMIC-BIOF	92496	Engineering Anaerobic Mixed Microbial Communities for Biofuels Production	48717,6	FP7-PEOPLE	PEOPLE-2007-2-2.ERG
FLEXFUEL	87887	Demonstration of a flixible plant processing organic waste, manure and/or energycrops to bio-ethanol and biogas for transport	4628085	N/A	SUSTDEV-1.1.5
GLYFINERY	85764	Sustainable and integrated production of liquid biofuels, bioenergy and green chemicals from glycerol in biorefineries	4190818	FP7	ENERGY-2007-3.3-02
MacroFuels	199672	Developing the next generation Macro-Algae based biofuels for transportation via advanced bio-refinery processes	5999893	H2020	LCE-11-2015
NOE-BIOENERGY	73983	Overcoming Barriers to Bioenergy (NOE-BIOENERGY)	9890245	N/A	SUSTDEV-1.2.5
PREMIA	87881	R&D, demonstration and incentive programmes effectiveness to facilitate and secure market introduction of alternative motor fuels	1236281	N/A	SUSTDEV-1.1.5
PYROCHAR	110941	PYROlysis based process to convert small WWTP sewage sludge into useful bioCHAR	1148939	FP7	SME-2013-1
SOLENALGAE	199416	IMPROVING PHOTOSYNTHETIC SOLAR ENERGY CONVERSION IN MICROALGAL CULTURES FOR THE PRODUCTION OF BIOFUELS AND HIGH VALUE PRODUCTS	1441875	H2020	ERC-StG-2015
N/A	71003	Clean and Efficient Energy from Waste and Biomass	0	N/A	2.3.2

Source: CORDIS (2018)
Notes: Some projects have missing data in CORDIS. The title of the projects and the other available data was included in the database of the study for completeness.

Annex 8

Technology Sector Report Hydropower

(Deliverable D2.8)

Authors:
Onne Hoogland (Trinomics)
Elske Veenstra (Trinomics)
Perla C. Torres Vega (Trinomics)
Simon Morris (Ricardo Energy & Environment)

Trinomics

1 Introduction

This report is one in a series of eight technology reports for the study *Impacts of EU actions supporting the development of renewable energy (RE) technologies*, prepared for the European Commission. The report has two objectives: 1) describing how EU research and development (R&D) funding for the hydro-power technologies has impacted the hydro-power sector in the EU, and 2) describing more broadly the development of the hydro-power sector to which the EU R&D funding has contributed. It is based on a compilation of data from several databases, a questionnaire sent to coordinators of EU-funded R&D projects, interviews, case studies and literature research. The methodology applied for this study is documented in a separate deliverable.[1] Where relevant, limitations and assumptions are mentioned throughout this report.

Hydropower technologies refer, in our study, to technologies that harness the energy stored in falling or fast running water for the purpose of generating electricity. The potential energy of water is converted into kinetic energy which in turn is converted into mechanical energy as the water passes through a turbine. This turbine drives an electricity generator. There are several types of hydropower plants. The main ones are hydropower dams, which contain an element of water storage. The others are run-of-river hydro plants which harness the energy of water flowing through rivers and involve little or no water storage. There is also a range of hydro turbine types – the suitability of which depends on the physical characteristics of a given hydro installation, in particular the flow through the turbine and the head (m^3/s), the 'drop' of the water, and the distance the water falls before it enters the turbine.

Hydro is the EU's first RE technology: the long history of development means hydro was established as a mainstream electricity source over 100 years ago. As a consequence, in 1995, EU hydro capacity was already 106 GWe, rising by 21 % over the following 20 years to 129 GWe, providing the biggest share of all EU renewable electricity production throughout the period. The hydro development that has taken place can be characterised by three trends:

- large installations using dams to store significant volumes of water (e.g. Sonna in Norway (270 MWe), Glendoe in the United Kingdom (100 MWe), and Blanca in Slovenia (42.5 MWe));
- a large number of small installations, usually run of river, so without a dam;
- refurbishment of older hydro schemes to increase capacity and output.

There are over 500 hydro schemes with a dam in Europe of over 100 MWe in capacity. Of these, fewer than 20 have been completed since 2000. In the energy and climate roadmaps, the expansion of hydro in the EU is expected to be limited. There is however an increasing number of smaller sites, with many more smaller sites available for development. The overall installed capacity of small hydropower in Europe (including non-EU countries) was over 18 GWe in 2016, while the potential capacity is estimated at 39 GWe.[2] This has shaped the scope of the projects that have received R&D funding.

Over the same period, understanding of the water environment has increased, as has regulation to protect the water environment. This has shaped the sector to some degree, as the environmental

[1] Trinomics (2018) - Study on impacts of EU actions supporting the development of renewable energy technologies – Literature review and methodology (Deliverables D1.1 and D1.2)
[2] UNIDO (2016), World Small Hydropower Development Report 2016. http://www.smallhydroworld.org/fileadmin/user_upload/pdf/WSHPDR-2016-ES-FPP-2.pdf

impact of impoundment of large bodies of water is better understood and the regulations governing extraction of water has increased. There are fewer sites now available for schemes using dams and there are more restrictions on run of river schemes. More research is needed for the development of technologies that can take these environmental concerns into account.

Given the maturity of the hydro sector, R&D has included topics that help address barriers to new market segments or offer further improvements to the established technologies. Examples include:

- new designs of turbines for low head sites such as weirs or on the surface of rivers;
- cost-effective methods to reduce the environmental impacts of hydro schemes;
- methods to improve or maintain the efficiency of hydro turbines, for example by use of coatings for impellers.

2 Historical R&D funding

2.1 EU R&D funding

The European Commission has supported research and development in hydropower technologies for more than 30 years. It receives a relatively small part of the R&D funding for RE technologies, which can be ascribed to the fact that the technology is more developed compared to other RE technologies (and that the potential for new sites is seen as rather limited). During FP5-7 and H2020, EUR 24 million was provided to 21 projects. Another EUR 7 million was provided to projects that focused on a combination of hydro and other RE technologies, of which 2 were combined with wind and one with hydro (see Table 2.1 and see Annex D for a full list of projects).

Table 2.1 EU funding per framework programme (1998 to mid-March 2018, 2016 million euros[3])

	Hydropower		Hydropower and other RES	
Framework programme	EU funding	Number of projects	EU funding	Number of projects
FP5	4.91	8	5.11	2
FP6	4.15	4	-	0
FP7	12.09	5	1.82	1
H2020[4]	3.06	4	-	0
Total EU funding	24.22	21	6.93	3

Source: CORDIS (2018)

2.1.1 *Top recipients*

Table 2.2 shows the top recipients of R&D funding from FP7 and H2020 and highlights the diversity of organisations that have received R&D funding, which include research institutes, universities and manufacturing companies. Table 2.3 shows that most FP7 and H2020 funding was allocated to parties in Switzerland, followed by Germany and Ireland. It is the only RE technology that has allocated most funding to a non-EU country.[5] Most of this funding was allocated to Andritz Hydro AG and Ecole Polytechnique Federale de Lausanne, the top first and third recipients of EU funding for hydro.[6]

Table 2.2 Top 10 recipients of EU funding by organisation (in 2016 euros)

Rank	Organisation	Type of organisation	Funding
1	Andritz Hydro AG	Supplier, Research & Development	2 433 140
2	DP Designpro Limited	Design	1 952 023
3	Ecole Polytechnique Federale de Lausanne	Research Institute	1 641 038
4	Universitaet Rostock	University	999 182
5	University of Southampton	Research University	865 592
6	National Technical University of Athens	University	641 658
7	Tecnoturbines S.L.	Manufacturer and Project Developer	626 631

[3] Historical values have been inflation adjusted to arrive at 2016 constant values. This has been done to show the values of budgets, prices and other monetary indicators without the impact of varying price levels over the years so that they can be compared over time more accurately.
[4] Funding from H2020 is still ongoing. The tables and graphs presenting EU R&D funding in this section include funding until mid-March 2018 (unless specified otherwise).
[5] Switzerland has participated in EU research programmes since 1988 and became a full associate partner in 2004. During the period from 15 September 2014 to 31 December 2016, the association of Switzerland to Horizon 2020 covered only a limited part of the Programme. As of 1 January 2017, Switzerland is associated to the whole of Horizon 2020 again. More information on the associate partners is available here: http://ec.europa.eu/research/participants/data/ref/h2020/grants_manual/hi/3cpart/h2020-hi-list-ac_en.pdf
[6] Andritz Hydro AG received part of the FP funding through its Austrian subsidiary, Andritz Hydro GmbH.

Rank	Organisation	Type of organisation	Funding
8	Technische Universitat Darmstadt	Research University	605 191
9	Universitat Politecnica de Catalunya	Engineering University	493 572
10	Sendekia Arquitectura e Ingenieria Sostenible Sl	Design & Manufacturing	435 041

Source: CORDIS (2018)
The source data covered H2020 funding and 75 % of FP7 funding. No data was available for recipients of FP5, FP6 and part of the FP7 funding. Projects under 'multiple RES technologies' are not included in this table.

Table 2.3 Top 10 recipients of EU funding by country (in 2016 euros)

Rank	Country	Funding
1	Switzerland	3 777 671
2	Germany	2 988 139
3	Ireland	1 952 023
4	Spain	1 555 245
5	France	1 374 335
6	United Kingdom	865 592
7	Portugal	820 759
8	Austria	653 081
9	Greece	641 658
10	Bulgaria	393 231

Source: CORDIS (2018)
The source data covered H2020 funding and 75 % of FP7 funding. No data was available for recipients of FP5, FP6 and part of the FP7 funding. Projects under 'multiple RES technologies' are not included in this table.

2.1.2 *Evolution of research topics*

As can be seen from Figure 2.1 and Figure 2.2, the largest proportion of EU funding has been for small hydropower (SHP), for which 15 projects received over EUR 15 million. Most funding went to the development of new small-scale hydro turbines and technology deployment (see Figure 2.3). Some of the projects focused on the improvement and optimisation of resource, material and deeper understanding of the operation through computational modelling, which was also the main topic for other hydro projects.[7]

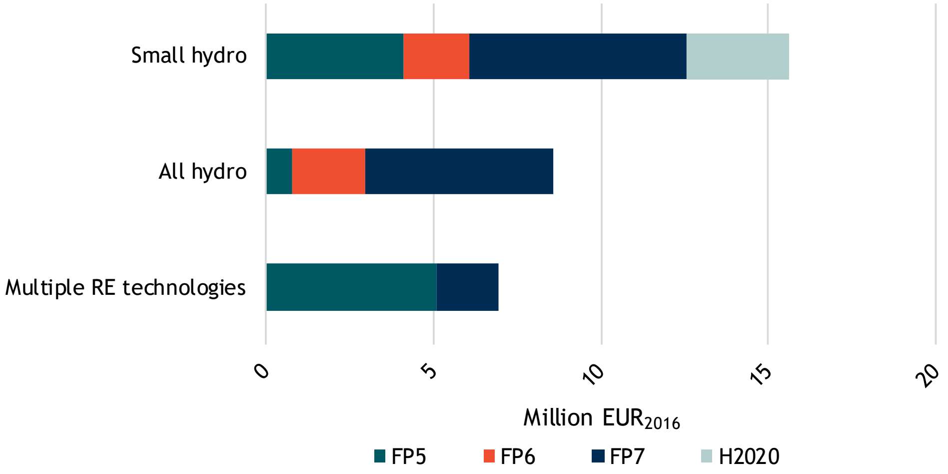
One of the impacts of EU funding has been its contribution to improving the operational performance of the existing installed capacity. Thanks to projects such as Hyperbole, current IET standards for the operation of turbines have been assessed through modelling. If these results are applied to operating schemes, this will enable them to increase their operating parameters and increase the electricity market services that can be delivered, potentially benefiting the wider renewables sector by facilitating increased penetration.

EU funding has helped to improve the systems and processes used for the design of existing hydropower technologies. Whilst there are less opportunities for new large sites within the EU, globally there is still a significant potential for large-scale hydropower. The industry led CAVISMONITOR project, and projects alike, have developed new modelling tools that can be used by original equipment manufacturers (OEMs) to improve the design of their turbines, increasing performance and reliability, ultimately making the turbines more competitive on the global market, potentially increasing exports from the EU.

[7] https://setis.ec.europa.eu/system/files/Technology_Information_Sheet_Hydropower.pdf

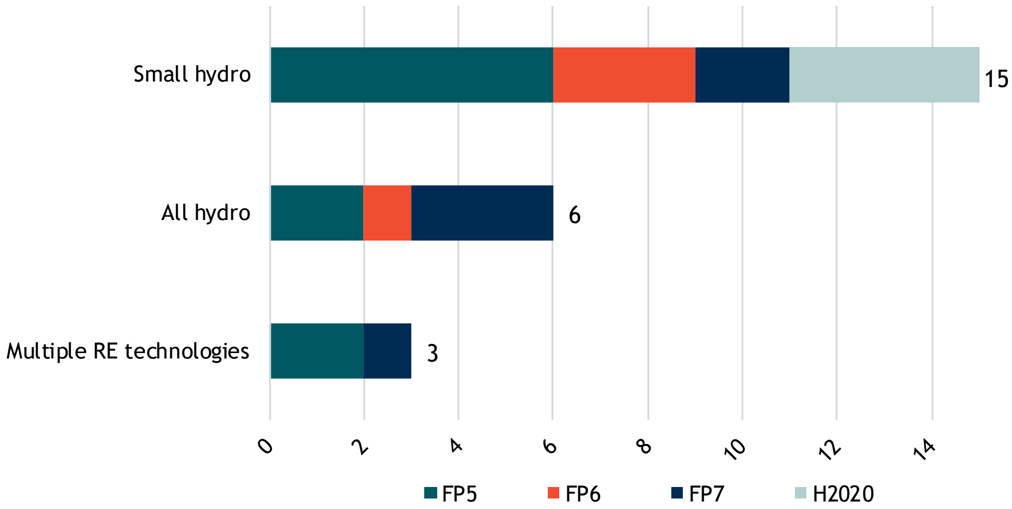
EU funding of new smaller scale hydropower technologies has the potential to open up new sites that may otherwise not have been technically or economically viable. There are a large number of sites for smaller schemes, primarily run of river, that new technologies such as those developed under the Hydrokinetic and River-Power projects will be suitable for.

Figure 2.1 EU funding per sub-technology/area (2016 million euro)



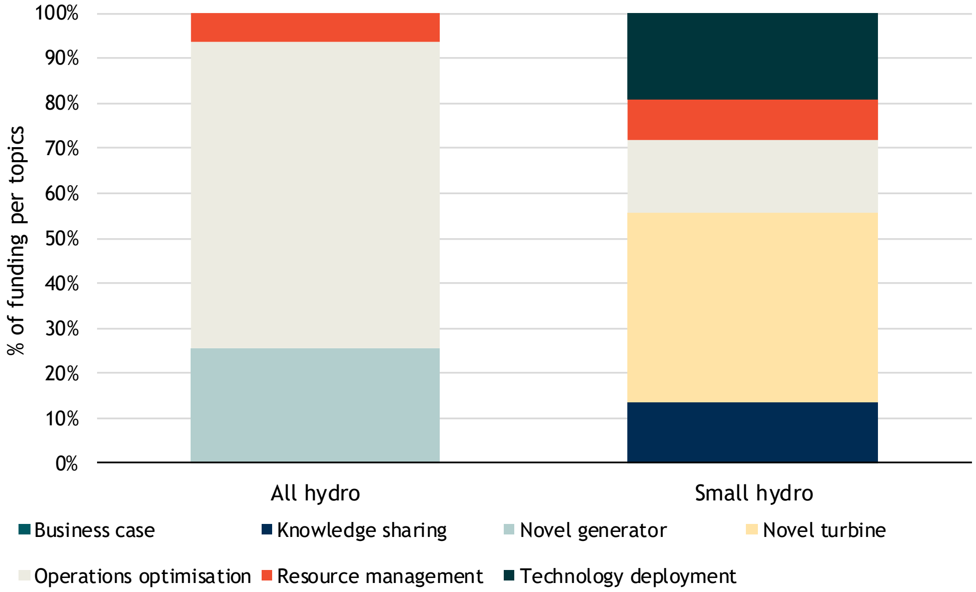
Source: CORDIS (2018)
The area 'multiple RE technologies' includes projects in which hydropower is one of multiple RE technologies

Figure 2.2 Number of projects per sub-technology/area



Source: CORDIS (2018)
The area 'multiple RE technologies' includes projects in which hydropower is one of multiple RE technologies

Figure 2.3 Research topics per sub-technology/area

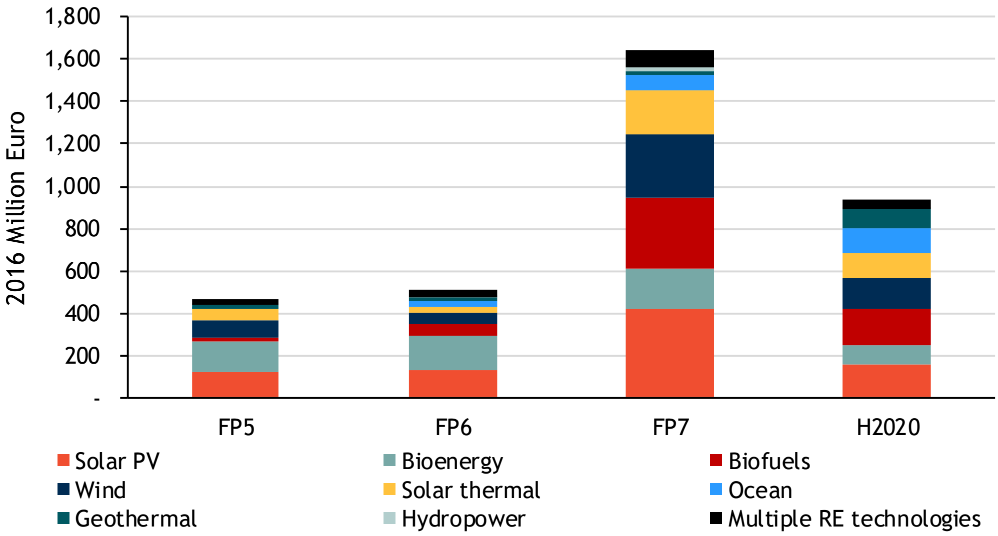


Source: CORDIS (2018)

2.1.3 Share of funding for each sector in proportion to the overall funding of all RE technologies

Being a mature technology, opportunities for technology improvements in hydropower are often related to manufacturing or project development processes and procedures, which are often part of internal business improvements that do not require grant funding. There are only a few new sites available in Europe for large dam projects, and environmental constraints place increasing restrictions on further developments, so a lot of global R&D in this technology takes place outside of Europe. Run of river technology is well developed and understood, so as previously highlighted, there is less requirement for R&D.

Figure 2.4 Share of funding for each technology sector in proportion to overall funding



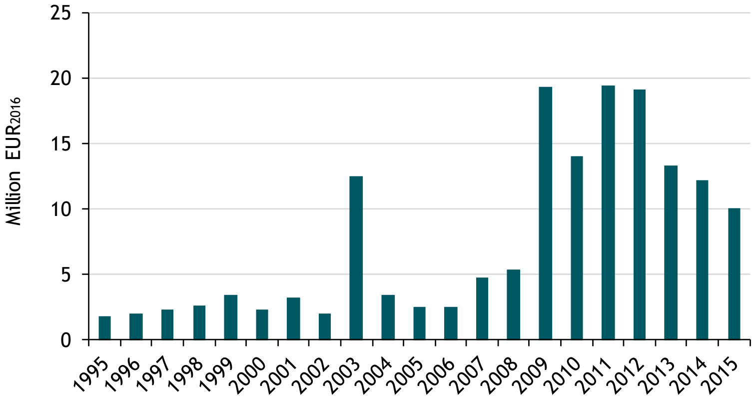
Source: CORDIS (2018)
The area 'multiple RE' includes projects of multiple RE technologies.

2.2 Member State R&D funding

2.2.1 Evolution over time

Annual R&D funding by Member States (MS) has fluctuated between EUR 2 million and EUR 17 million in the EU-15 (see Figure 2.5). Funding from 2008 onwards is considerably higher, which can be attributed to higher R&D budgets from Austria, Italy and Finland, as well as improved data availability from Poland. The peak in 2003 can be attributed to Finland, which provided an exceptionally large EUR 10.3 million for hydropower R&D that year.

Figure 2.5 Annual MS R&D funding in the EU for hydropower

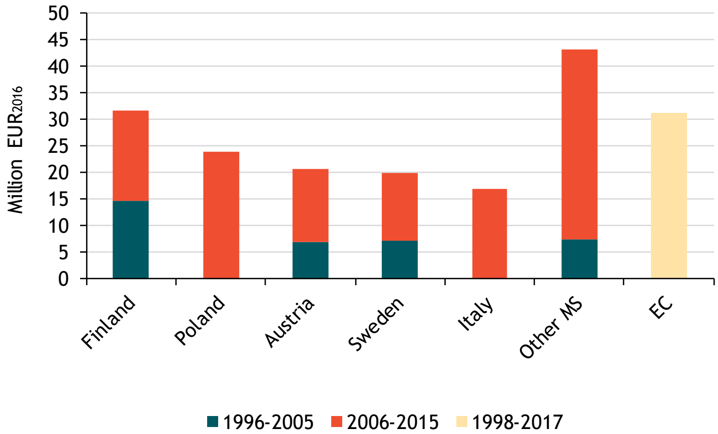


Source: Based on data from OECD/IEA (2018).
Note: Data for 20 EU countries was available in this source: The EU15 plus Czech Republic, Estonia, Hungary, Poland, Slovakia. Data for Italy was not available for 2010 and 2015, data for Poland was not available for years before 2008.

2.2.2 Largest Member State funders

The largest funders of R&D for hydropower technologies are Finland, Poland, Austria, Sweden and Italy (see Figure 2.6). These are countries within significant water resources and mountainous regions suitable for hydropower schemes. Together they have provided 72 % of total MS funding. Except for the UK, all MS provided significantly higher funding to hydropower technologies during the period 2005 to 2015 than 1995 to 2004.

Figure 2.6 Hydropower R&D budgets of the main Member States (1996-2015) and the EC (1998-2017)

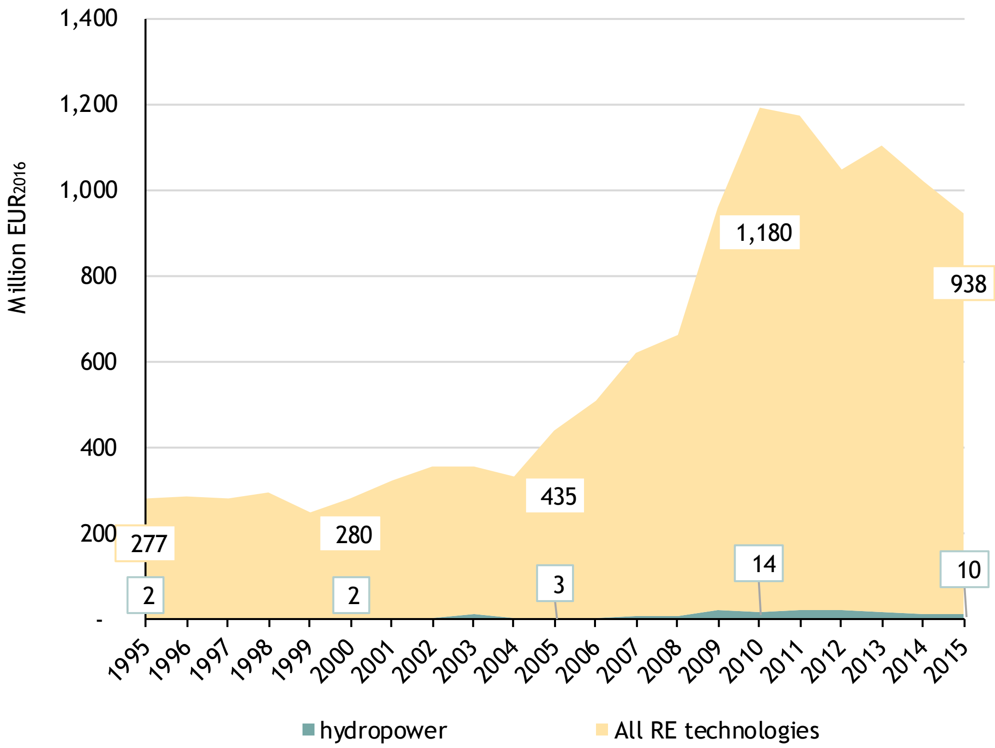


Source: OECD/IEA (2018), Eurostat (2018) and CORDIS (2018).
Note: National budgets for 2016 were excluded from the analysis because they are early estimates and lack reliability/coverage. EC funding includes projects in which hydropower is one of multiple RES technologies. Data for 20 EU countries was available in this source: The EU15 plus Czech Republic, Estonia, Hungary, Poland, Slovakia. Data for Italy was not available for 2010 and 2015, data for Poland was not available for years before 2008.
Time window of comparison between MS and EC funding is shifted 2 years due to data availability of MS budgets for the scope of analysis (FP5-H2020).

2.2.3 Comparison of total RE technology funding

Overall, MS R&D funding for hydro is very modest. Figure 2.7 shows that the share of R&D funding for RE technologies that is allocated to hydropower technologies is below 2 %, which is comparable to the share in EU R&D funding for RE technologies. This makes hydro the RE technology with the lowest MS R&D budgets in the period 1995 to 2015.

Figure 2.7 National R&D funding for hydropower and for all RE technologies



Source: Based on data from OECD/IEA (2018).
Note: Data for 20 EU countries was available in this source: The EU15 plus Czech Republic, Estonia, Hungary, Poland, Slovakia. Data for Italy was not available for 2015, for the Netherlands for 2004 and data for Poland was not available before 2009 for any RE technologies.

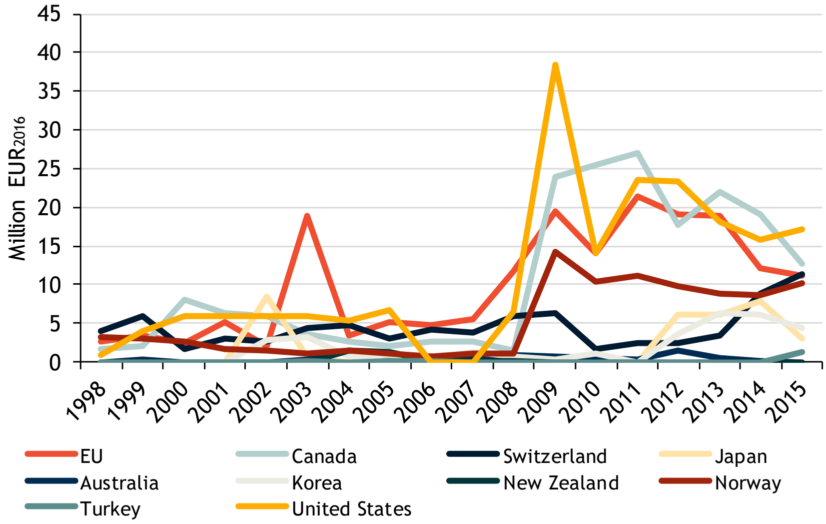
2.3 Private and international R&D funding

2.3.1 International public R&D funding

Average funding from the EU and MS for hydro has been EUR 8.9 million a year between 1995-2015 (see Figure 2.8). The United States of America (USA) provided EUR 10 million on average per year in the same period, making it the largest funder of hydropower R&D, followed by Canada with EUR 9.1 million a year. Other countries with significant funding are Norway (EUR 4.9 million on average) and Switzerland (EUR 4.5 million on average). Their R&D budgets are higher than those of EU MS. For most countries, this is only a small part of their R&D budget for RE technologies. Despite the potential for SHP and the features of hydropower as a dispatchable resource plus an option for storage, countries do not invest heavily in R&D for this technology.

This is different for China. Chinese R&D data are not available in the OECD/IEA database, but are much larger than any other country. The China Institute for Water Resources and Hydropower Research (IWHR) is the lead organizer of research projects in the water resources sector, signing research contracts of CNY 1.24 billion (EUR 169 million) in value in 2016. Between 2012 and 2016, the average annual contracted value was EUR 162 million.[8] There is clearly a lot more interest from the Chinese government in hydropower R&D than in other countries.

Figure 2.8 Comparison of international R&D funding for hydropower



Source: OECD/IEA (2018).
Note: EU covers EU and MS funding. National budgets for 2016 were excluded from the analysis because they are early estimates and lack reliability/coverage. Data covers 20 EU countries: the EU15 and Czech Republic, Estonia, Hungary, Poland, Slovakia and the European funding programmes FP5, FP6, FP7 and H2020. For countries outside the EU, national budgets were available for Australia, Canada, Japan, Korea, New Zealand, Norway, Switzerland, Turkey and the USA. Data for Italy was not available for 2010 and 2015, data for Poland was not available for years before 2008.

2.3.2 Private R&D funding

Hydropower is listed next to ocean energy as the RE technology with the lowest total R&D investments in 2016: both have a total investment of EUR 0.093 billion. Like public R&D funding, the interest in R&D activities for hydropower technologies seems low. Due to the low number, a further split between corporate and government R&D could not be determined from the Frankfurt School-UNEP Centre/BNEF study.

2.4 Conclusions

Hydropower receives relatively low R&D funding, because the technology is well established. In addition, opportunities for technology improvements are often part of internal business improvements that do not require grant funding. Nevertheless, EU funding has contributed to improving the design of existing hydropower technologies. EU funding of new smaller scale hydropower technologies has the potential to open up new sites that may otherwise not have been technically or economically viable. There are a large number of sites for smaller schemes, primarily run of river, that new technologies will be suitable for.

R&D funding mostly comes from countries with large mountainous areas, which are best suited for hydropower plants. Within the EU, Finland and Poland allocate the most R&D funding to hydro. Countries outside of the EU, such as the USA, Canada, Norway and Switzerland, provide more R&D funding. Parties based in Switzerland also receive the most EU R&D funding.

[8] China Institute for Water Resources and Hydropower Research (IWHR) (2016) Annual Report 2016. http://www.iwhr.com/IWHR-English/rootfiles/2018/06/05/1522721836172933-1522721836174257.pdf

3 Research effectiveness

R&D projects can lead to patents, publications, spin-offs and several other, less concrete but potentially important direct outputs such as standardisation and knowledge exchange. Such impacts are the most direct impacts of R&D funding and therefore provide the cleanest view on the effectiveness of research budgets spent. In this section we discuss patents and publications and the relation to R&D funding for the hydropower sector.

3.1 Patents

Patents are a commonly used indicator to measure the output of R&D funding as data is readily available, in a standardised form, and a direct measurement of the output of R&D funding. However, some limitations have to be taken into account, such as the fact that filing a patent is not an objective of all research projects and that the economic value of patents differs strongly. It is also becoming more common for companies to not file patents, to ensure secrecy of their innovations.

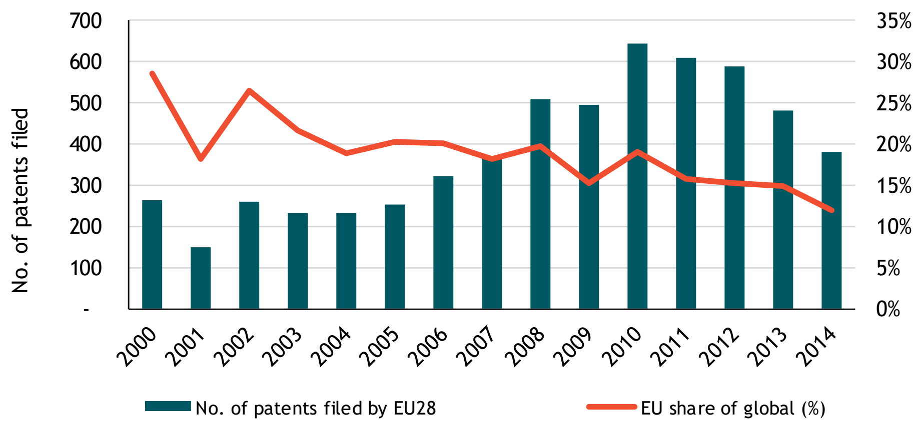
3.1.1 Evolution over time

Figure 3.1 shows the profile of patents filed for hydropower technologies in the EU. As most research is focused on optimisation, not many new patents follow from R&D on hydropower. The EU's share of global patents has been relatively stable, around 20 %. In recent years this has decreased, as other countries have started to file more patents while the EU has filed fewer patents. The main driver behind this is the continuing global expansion in hydro. For example, China accounts for 26 % of the global installed capacity in 2015, compared to 8.4 % in the USA, 7.6 % in Brazil and 6.5 % in Canada.[9] The most likely future market for hydro is expected to be in Asia, with an estimated unutilised potential of 7 195 TWh/year, and more room for large-scale hydro.

In the EU, most patents were filed in Germany (29 % of EU total), followed by the United Kingdom (17 %), France and Spain (9 % each). Interestingly, these are not the countries with the largest R&D budgets in the EU. The top 5 funders only filed 16 % of the total EU patents. They are however some of the countries that received the most EU R&D funding. They are also the main exporters of hydropower components in the EU (see section 5.6).

[9] https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Hydropower_2016.pdf

Figure 3.1 Evolution of hydropower patents filed by EU countries



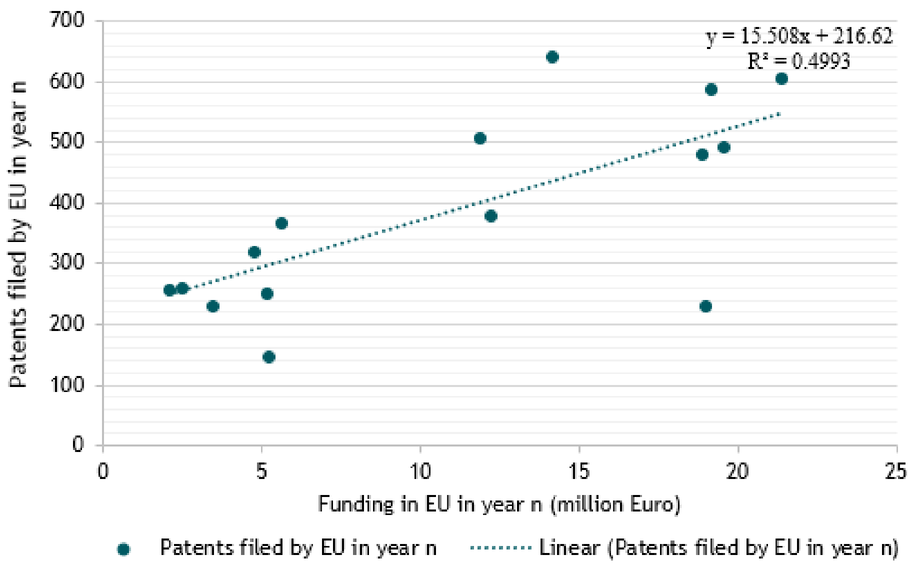
Source: IRENA INSPIRE (2017)

3.1.2 Effectiveness of R&D funding in producing new patents

In theory, higher R&D budgets in a region are expected to lead to an increase in the number of patents filed from that region. The extent to which this relation exists in the hydropower sector provides insight into the objectives of the research (is it targeted at technology development, so more likely to result to a patent application?) and the effectiveness of the research (was it successful in developing the technology so resulting in a patent application?).

Figure 3.2 shows that there is no clear correlation between the total amount of patents filed and the amount of EU R&D funding (MS + EU combined). It again shows that most research in the hydropower sector is not focused on new technologies, but on improvements of existing technologies. This is in line with the findings for other RE sectors and underlines that patent applications are generally not a primary objective of a research project.

Figure 3.2 Effectiveness of R&D funding in producing new patents



Notes: We tested a delay of 0, 1, 2, 3, 4 and 5 years for the patents filed from year 2000-2014. 2015 data of patents was excluded because the source (IRENA) mentioned it is common to have delays of 3 years from a patent application and the year is reflected in the database. The correlation went up when 2015 data was excluded. A delay of 0 years between funding year and patents filed showed the highest correlation (R^2 = 0.4993).

3.1.3 Contribution of EU funding

Albeit not the main focus of research, EU funding has contributed to the creation of patents in several research projects. An example is given in the box below.

Project spotlight: HYDROGENIE

The FP6-funded project HYDROGENIE aimed to develop and field test a compact High Temperature Superconductors (HTS) hydropower generator with reduced investment costs, lowered environmental impacts, and strongly improved performance to reduce the price per kWh by 10 %. The focus of the project was the use of superconducting technology in rotating machinery. The research led to a patent on the support structure for superconducting coils, and another patent on glass fibre struts that support the outer parts that give mechanical strength to the assembly. Three other patents came from this: one on composite cryostat walls, one on pumping rotating vessels, and another one on how to form superconducting coil formers. The project also published articles, some of which were cited by other articles, and tested the technology in a lab. The proof in the lab was sufficient to demonstrate that the technology would have worked in the generator, with the caveat that there would need to be further development of the rotating coupling.

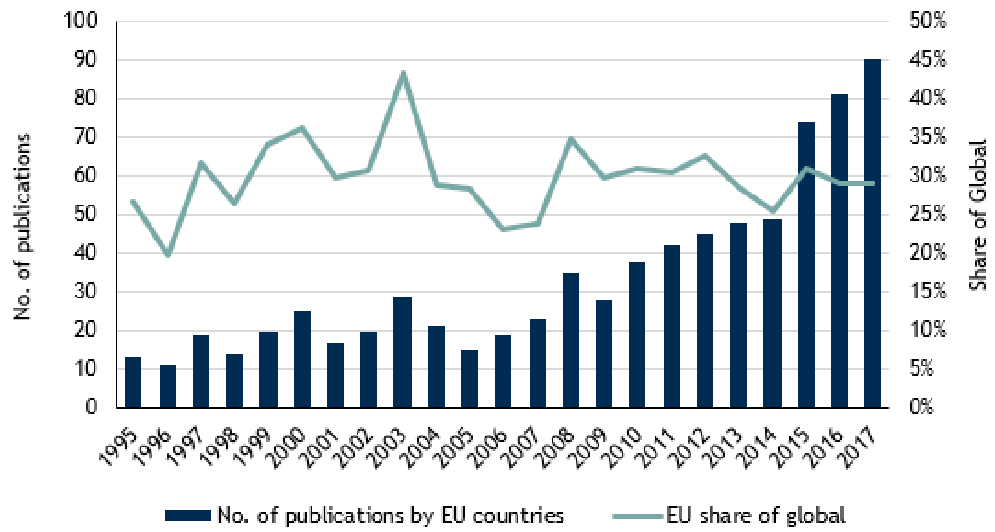
3.2 Publications

Publications of research papers are a useful indicator to measure the output of R&D funding. Publications have a close relation with public R&D funding, allowing us to differentiate the effect of public R&D funding from private R&D funding. Publications are categorised by country on the basis of the address of the author. If it has authors from different regions, the publication is counted for both regions.

3.2.1 Evolution over time

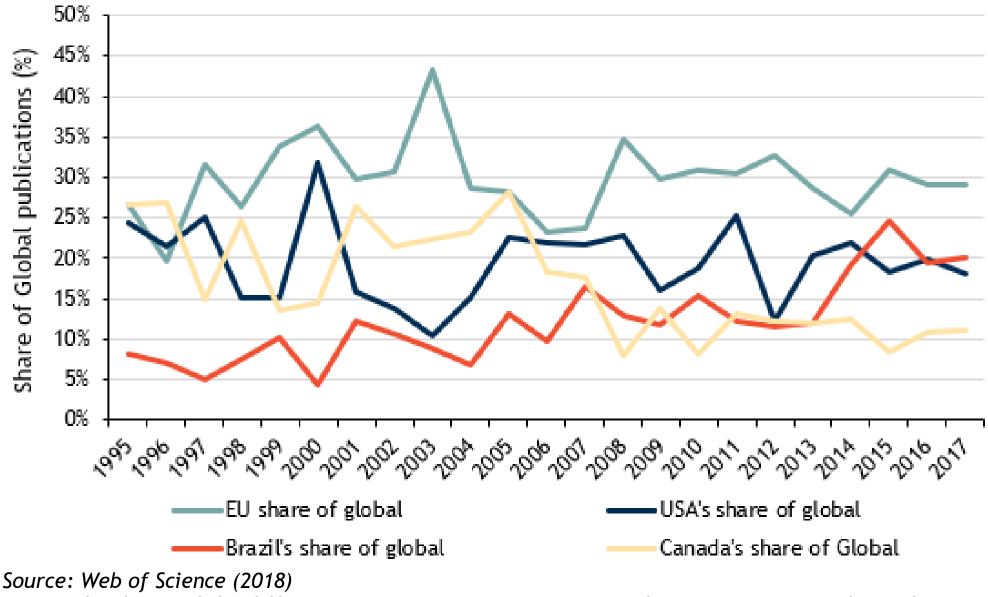
Figure 3.3 shows the number of publications related to the hydropower sector that had an EU-based author, and the share of global publications that were (co-)authored by the EU. EU-based authors were involved in around 30 % of the global hydropower publications between 1995 and 2017, maintaining its global leadership during this period. Besides the EU, the largest numbers of publications had authors from the USA, Brazil and Canada (see Figure 3.4). Brazil has steadily increased its number of publications reaching 20 % of global publications in 2017, making it the second largest country contributing to hydropower publications in that year. Brazil has the third largest installed capacity of hydropower in the world, and a large unutilised potential. It has also eased restrictions on hydro in the Amazon and other rivers, which may explain the increasing interest in R&D. Conversely, Canada shows a decreasing trend over the years. In 1995 it started at 27 % of global publications, which was reduced to 11 % in 2017. Meanwhile the EU share remained constant between 20 % and 35 %, with a peak in 2003 when it co-authored 43 % of all publications. In the EU, France has authored the most publications (155), followed by the UK (144), Italy (94), and Spain (75). These MS are also some of the MS with the most patents filed (see section 3.1) and some of the main exporters of hydropower components (see section 5.6).

Figure 3.3 Evolution of hydropower publications by EU countries



Source: Web of Science (2018)
Notes: keywords used are: 'hydroelectric' title, topics and abstract of articles between 1995-2017, and refining the search to include only the articles listed under the following Research Areas: Environmental Sciences Ecology, Engineering, Water Resources, Energy Fuels, Geology, and Science Technology Other Topics. The share of global refers only to those publications with an address listed. 2 % of the global publications had no address listed in that period of time. One article can have multiple authors (therefore, also multiple countries). The count is the number of articles in which at least one author listed an EU MS as their address.*

Figure 3.4 Comparison of the share of hydropower global publications between key countries



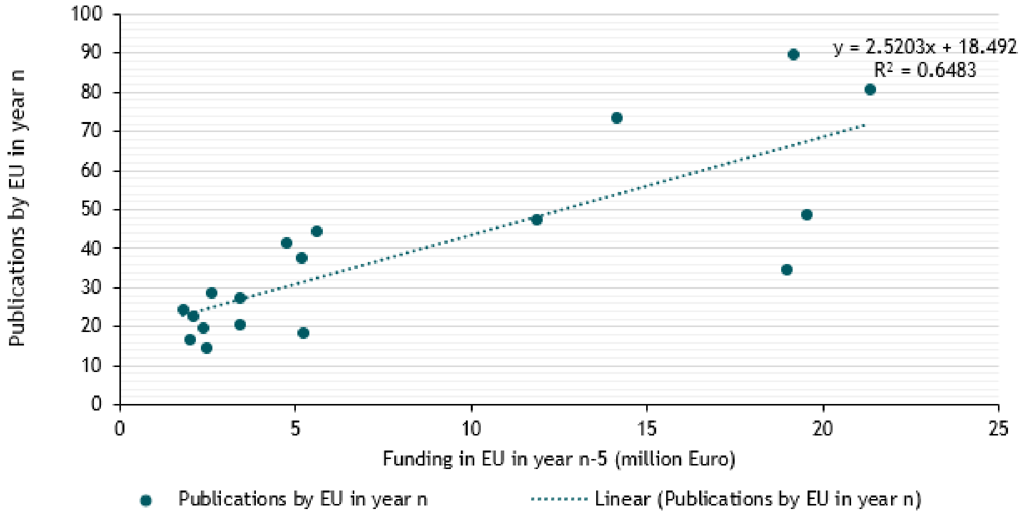
Source: Web of Science (2018)
Notes: The shares of the different countries/regions are not cumulative since one article can have multiple authors (therefore, also multiple countries).

3.2.2 Effectiveness of R&D funding in producing publications

In theory, higher R&D budgets in a region are expected to lead to an increase in the number of publications from that region. The extent to which this relation exists in the hydropower sector provides insight into the objectives of the research (does it aim for a publication?) and the effectiveness of the research (is it successful in realising a publication?).

As shown by Figure 3.5, the correlation between the total number of EU publications and the amount of EU R&D funding (MS + EU combined) is closer than with the number of patents. This is in line with the findings for other RE sectors and underlines that publishing is often one of the primary objectives of a research project. The correlation was the highest when taking into account a time lag of five years.

Figure 3.5 Effectiveness of R&D funding in producing publications



Notes: We tested the publication effectiveness of R&D funding for the period 1995-2017. Funding in EU includes EU funding and MS funding. We tested different delays (0,1,2,3,4 and 5 years) to evaluate which one had the highest correlation. After two years of delay, for each year of delay, the sample size was reduced by one number (e.g. with 0, 1 and 2 years of delay the sample size was 21 years, with 3 delay the sample size was 20 years)
With 2 years of delay (n-2), the R^2 is the lowest of all the ones tested (0.3263). The highest R^2 was found using 5 years of delay (0.6483).

3.2.3 Contribution of EU funding

At least 7 % of EU publications (36 in total) benefitted from EU funding sources between 2008-2017. Not all publications report their sources of funding, therefore it is likely that the actual figure is higher. The EU funding sources used are not always specified and thus may include funding from other instruments than the Framework Programmes for research and technological development.

Table 3.1 shows the top 10 EU organisations that have authored the most hydropower publications. France, which authored the most publications from the EU, has a prominent place in the top 10, supplying the entire top 5 and another institution placed 7th. The majority are universities and research institutes, with the exception being Electricite de France (EDF). Interestingly, none of these organisations are in the top 10 recipients of EU funding (see Table 2.2), although Table 2.3 does show that France has been the fifth largest recipient of EU funding. Also outside of France, most of the top EU organisations that write publications are not in the top EU funding recipients. Only the National Technical University of Athens received a lot of funding under FP7/H2020, making it the sixth largest recipient of EU funding. This can be explained by the large role of FP participants outside of academia, such as manufacturers and project developers, who are less prone to write scientific publications as part of their research outputs. As hydro is a mature technology, more funding is directed to optimisation and process development, and less to fundamental research which would lead more easily to scientific publications.

In addition, Swiss organisations are not included in Table 3.1 as they are not part of the EU, but Switzerland is the top recipient of EU funding for hydroelectric R&D. Swiss authors wrote 79 publications. The top university that received EU funding was the Ecole Polytechnique Federale de Lausanne (ranking 3rd), which authored at least 13 publications. The Federal Institute of Technology in

Zurich (ETHZ) wrote 18 publications, the most of all Swiss organisations. This is more than the National Technical University of Athens and the Polytechnic University of Madrid, which rank 9 and 10 in the top EU organisations contributing to publications. Authors based in Norway wrote 41 publications, of which the Norwegian University of Science and Technology (NTNU), the Norwegian Institute for Nature Research, and SINTEF each contributed to 7.

Table 3.1 Top organisations in the EU contributing to hydropower publications

Rank	Institutions	Country	No. Publications	EU funding rank
1	Centre National de la Recherche Scientifique CNRS	France	71	*30+*
2	Institut de Recherche pour le Developpement LRD	France	35	*30+*
3	Universite de Toulouse	France	24	*30+*
4	Universite Toulouse IIII Paul Sabatier	France	24	*30+*
5	Electricite de France EDF	France	22	*30+*
6	Uppsala University	Sweden	20	*30+*
7	Universite Federale Toulouse Midi Pyrenees Comue	France	16	*30+*
8	Universidade de Lisboa	Portugal	15	*30+*
9	National Technical University of Athens	Greece	14	6
10	Polytechnic University of Madrid	Spain	14	*30+*

Source: Web of Science (2018)
Notes: keywords used are: 'hydroelectr' title, topics and abstract of articles between 1995-2017, and refining the search to include only the articles listed under the following Research Areas: Environmental Sciences Ecology, Engineering, Water Resources, Energy Fuels, Geology, and Science Technology Other Topics. The count is the number of articles in which at least one author listed the European organisation as their address.*

3.3 Start-ups and spin-offs

The creation of start-ups and spin-offs is another potential impact of research projects, which can function as an important link between the research and the development of a European industry. Start-ups and spin-offs are not reported consistently, however. Therefore, questionnaire results are used to provide insight into these impacts.

One interviewee mentioned how EU R&D funding related to a start-up in the HydroKinetic 25 project. The leading company, GKinetic, was not a spin-off from EU R&D funding, however EU funding enabled them to license their technology to a grant recipient, DP DesignPro. It also enabled them to develop the technology further and deploy a demonstration of the technology in France.

3.4 Other research outputs

As mentioned in chapter 2, the bulk of R&D funding went to the improvement and optimisation of resource and material, which has contributed to improved operational performance of existing plants. For instance, the Hyperbole project assessed current IET standards and improved operating schemes. The Cavismonitor project, amongst others, also developed new modelling tools that can improve hydro plants' design, performance and reliability. Some projects, such as FP7 HYLOW (see project spotlight below), focused specifically on small hydropower (SHP), and developed and tested an innovative design that could make new locations available for SHP that were previously not viable technically or economically. H2020 Hydrokinetic and River-Power are more recent examples that focus on this.

EU funding has also contributed to other research outputs, such as knowledge sharing tools on financing, environmental impacts and the water energy nexus, amongst other topics. An example is RESTOR HYDRO (see project spotlight below). The projects enabled the sharing of knowledge and made it publicly available to the sector.

The projects also improved international collaboration between industry, academia, government and communities. For academics, the structure of EU projects enforced them to work in a more structured way. It also directly contributed to education on the hydropower sector. Industry partners such as Alstom and Voith have applied the knowledge they gained through the projects in their machines and development. Not only did the EU funding contribute to new knowledge, it also accelerated developments that would otherwise have happened at a much slower pace.

Project spotlight: RESTOR HYDRO

The RESTOR hydro project (Renewable Energy Sources Transforming Our Regions – Hydro) aimed at assessing the state of SHP and refurbishment potential in the whole EU region. It created a 'Guidebook on Cooperatives', documenting a reproducible business model combining three critical elements: 1) Local investment via a community shares based cooperative, 2) twinning with Structural Funds and 3) providing projects that are large enough to be bankable by financial institutions. The project also developed methodology guidelines and a database 'RESTOR Hydro Mills Map' for identification and refurbishment of (running and dormant) SHP project sites. The project identified 28 SHP restoration projects, for which cooperatives were formed. These cooperatives were assisted by the RESTOR hydro partners in applying for permits. As such, the research project gave the tools to site owners, investors, municipalities, and others to implement and refurbish hydropower generating sites.

Project spotlight: HYLOW

The FP7-funded project HYLOW aimed to develop an innovative hydrostatic pressure turbine to exploit SHP with very low head or pressure differences below 2.5 m and hydraulic power ratings of 50 kW to 1 000 kW. This novel hydraulic machine utilises differential hydrostatic pressures; with theory and initial model tests indicating high theoretical efficiencies for low head differences. It rotates at slow speeds and operates under atmospheric pressure with a continuous bed, thus minimising negative impact on fish and allowing for unhindered sediment and fish passage. Through this innovative design, it is hoped that unused potential in rivers (600 MW to 1 000 MW in the UK and more than 500 MW in Germany) can be economically and ecologically exploited.

The results of this work were used for the design of two field installations of 5 kW and 10 kW power rating and 1.20 m head difference. Both field installations were built and tested; a 5 kW grid connected machine installed on the River Lohr, Germany, and a 10 kW stand-alone installation at a river weir on the River Iskar, Bulgaria. A series of public workshops to disseminate the project findings have been carried out and the results of the model tests and full scale prototype were presented at several conferences. On the other hand a low head tubular propeller was developed and the use of a Pump as turbine (PAT). The outcome of the design is being investigated as part of two feasibility studies, with the potential of being installed in most of existing water distribution systems. Likewise, further necessary development work on a new R&D project was applied for by partners that have been involved in the development work to allow for further investigation of the social, economic and environmental impacts.

3.5 Conclusions

Hydro technology is a mature technology which has been in operation for 150 years. As a result, technological advancement in the field mostly focuses on optimisation of resource, material and deeper understanding of the operation through computational modelling. This could explain why the number of patents filed is limited. The contribution of EU funding to publications could be limited because of this reason as well: the top recipients of EU R&D funding are for a large part manufacturers and project developers, which are less prone to publishing scientific papers than academic institutions. Nevertheless, EU funding has contributed to the creation of patents and publications in several research projects on hydropower. French research institutions and universities have published the most articles on hydro technology in the EU. France is the fifth largest recipient of EU R&D funding. It also has the most installed capacity. Both factors likely contribute to the presence of knowledge in the country. EU funding also enabled a company to develop and demonstrate their technology in France.

Other impacts of EU funding relate to the improvement and optimisation of existing plants, which directly impacts the hydropower market, and the development of new SHP technologies and designs that enable the exploitation of new sites. Additionally, EU funding created knowledge sharing tools, contributed to education, and enabled industry partners to use the gained knowledge in their machines and development..

4 Technology development

One of the core objectives of R&D funding on RE technologies is to contribute to the development of the technology to make it cost competitive and allow for increased uptake of the technology. The impacts on technology development can be assessed technologically, or from an economic point of view, looking at the costs, performance and competitiveness of the technology. This section focuses on key indicators that assess technology development from an economic point of view: capital expenditure (capex), operational expenditure (opex) and Levelised Cost of Energy (LCOE).

4.1 Capex

Capex (capital expenditure) refers to the initial investment costs of hydropower projects. Cost-reducing innovations can contribute to a downward trend in capex, which in turn can make the sector more cost competitive and allow for increased uptake of the technology. One of the main limitations of this indicator is that capex is highly location- and technology-specific and will therefore vary between projects.

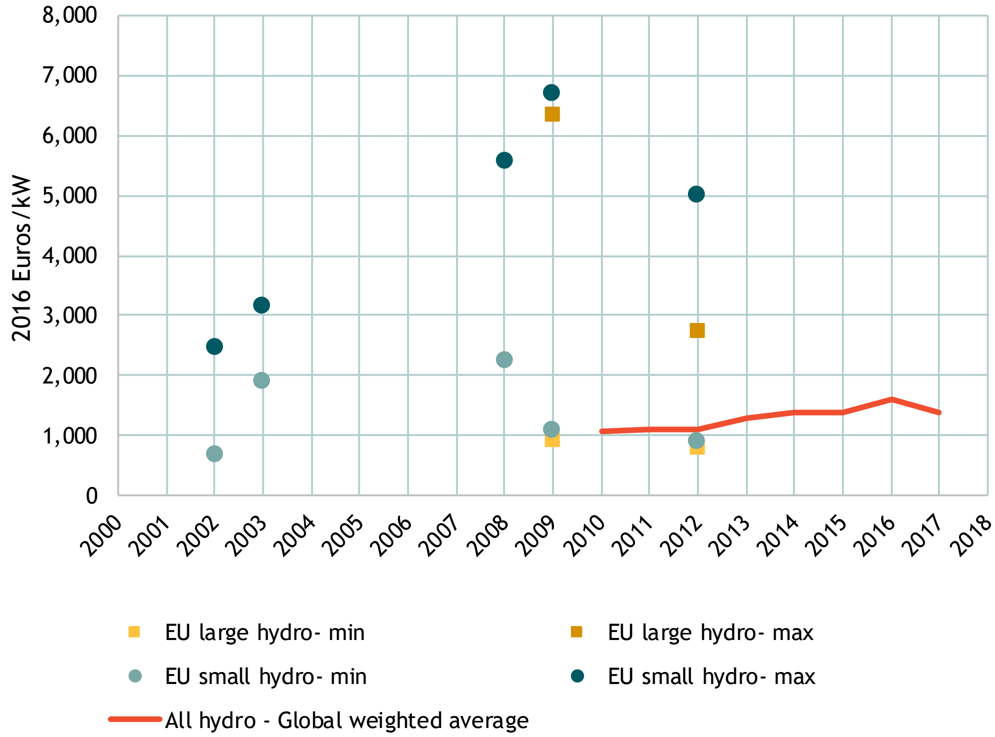
The main costs that contribute to the total capex of a hydropower project are civil construction costs, generator and turbine costs, and environmental management system costs. As these costs are for items that are not specifically for the hydro sector, such as civils costs, it is possible that innovations from the funding of R&D in other sectors have an impact on the cost of hydro schemes.

Capturing energy for a hydropower project requires civil works to control the body of water, whether with a dam, or a penstock (the pipework used in a run-of-river scheme). This has a significant contribution to the total costs for any hydropower project. The construction costs depend on the site and the installed technology. The flow and drop of the water influence the technology type that will be constructed. If the site has a high head (i.e. the drop that the water falls before passing through the turbine, which can range from 1 m to over 100 m), a longer penstock needs to be built. A Kaplan turbine is typically used for low to medium heads of 2 m to 40 m, with medium to high flows (3 m^3/s to 30 m^3/s). For sites with a high head of more than 25 m and low flows (0.01 m^3/s to 1.5 m^3/s), a Pelton turbine is more suitable. The more recent Archimedes screw technology is applicable to sites with a low head and a low flow. These technologies all come with different capex. Hydropower projects with a dam again have different civil construction requirements, leading to a different capex.

In addition to the head and flow of the water, the mountainous locations in which hydropower projects are most often found have specific locational construction requirements, which make civil costs very site-dependent as well.

The technology for hydropower goes back to the 1900s. There is little room for technological improvements that would cut the capex further. In fact, values from IRENA show an increasing trend for capex, starting at EUR 1 058/kW in 2010, and reaching its peak in 2016 with EUR 1 608/kW (see Figure 4.1). The general capex values combine all hydro schemes of different capacities, which can skew the results slightly. There is a strong correlation between the turbine cost and the capacity of the installation, with lower capacity schemes generally having a higher cost in EUR/kW than higher capacity schemes. As there are fewer larger sites being developed, an increasing trend in EUR/kW is to be expected in turbine costs. As generator costs in the EU have not increased significantly in the last 5 years, it is likely that other costs related to the construction have increased. Industrial players confirm that civil costs for hydro have gone up and explain this by the changing policy context for hydro projects. Contractors often use market pricing methods to match their charges to the available project budget. In countries where there is a feed-in tariff, the capex often reflects variations on the feed in tariff. Scheme design has also gone up in expense, because of administrative hurdles since the advent of feed-in tariffs. Additionally, environmental hurdles have been introduced by legislation around flora and fauna and the cost of grid connections. These factors have played a role in the increasing capex.

Figure 4.1 Evolution of hydropower capex for electricity generation



Source: IRENA (2018), Ecofys et al (2011), SETIS (n.d.), ESHA (2004, 2008) and SHERPA (2008),
Notes: The minimum and maximum values of small hydro refer to the lower and higher values in the capex estimates for hydropower projects of capacity lower than 10 MW, while for large hydro the same applies but for projects of capacity larger than 10 MW.
For global weighted average of electricity generation, data was taken from IRENA database. IRENA's data is the 'Global weighted average' based on their database with ~15 000 real projects.

Figure 4.1 also shows the minimum and maximum values of capex given in literature for large and small hydro plants in the EU. These can be significantly higher than the global weighted average given by IRENA. Table 4.1 below shows these capex figures in more detail. For large hydro, capex range between EUR 819/kW and EUR 6 355/kW. Small hydro projects show similar ranges, between EUR 687 and EUR 6 686/kW. The wide ranges show that the capex for hydropower is highly location- and technology-specific.

Table 4.1 Capex of large and small hydropower projects in the EU

Sub-technology	Year	EUR_{2016}/kW	Source
EU large hydro	2009	939 - 6 355	Ecofys et al (2011)
	2012	819 - 2 762	SETIS (n.d.)
EU small hydro	2002	687 - 2 472	ESHA (2004)
	2003	1 892 - 3 153	ESHA (2008)
	2008	2 232 - 5 581	SHERPA (2008
	2009	1 078 - 6 686	Ecofys et al (2011)
	2012	895 - 5 013	SETIS (n.d.)

Project spotlight: CAVISMONITOR

The FP-funded project CAVISMONITOR developed a system for the visualisation of cavitation monitoring and implemented this in a pump in the lab. Cavitation causes down-time of plants, which has cost implications. The monitoring system enables plant operators to estimate the amount of degradation of the turbine over time, so that maintenance work can be scheduled at convenient times and unexpected down-time avoided. The project directly contributed to changes in the physical design of turbines and the procedure of designing the turbines. Less time is now needed for the design, which influences the cost of the development of the turbine. Thus, the project has contributed to the cost developments of capex and opex for hydropower. The two publications that were published under this project were well received by the scientific community, with both cited by more than 140 other papers. Seven research projects have built upon the outcomes of this project, of which four were EU-funded (one is funded by FP7, one by the ESC and two by the European Space Agency).

Project spotlight: HYDRO LOW HEAD

The HYDRO LOW HEAD project received a grant of EUR 1 million through the Horizon 2020 programme to develop a low head (less than 10 m head pressure) micro-turbine solution that works in variable speed to produce as much energy as possible under variable conditions, which occurs frequently in rivers, channels, spillways, irrigation systems, treatment plants, etc. The installation time is between 1 and 2 months, reducing civil works by 35 %. The pay back for the final clients is between 2 and 4 years, depending on the power and working times. The team received press interest and exhibited at an international trade fair as well as winning several international awards. *Information retrieved from public websites, including: EC, 2018, Community Research and Development Information Service*

4.2 Opex

Opex (operational expenditure) includes fixed and variable costs for operation and maintenance (O&M) of the plants. Similar to capex, cost-reducing innovations can contribute to a downward trend in opex, which in turn can make the sector more cost competitive. Only global figures were available for the opex – the figures thus include opex of plants outside the EU.

Opex is often less location-specific than capex in hydropower as a lot of the generation and performance is monitored remotely. Larger generators require less manual intervention and the fixed operating costs of hydro schemes are low in relation to the capital costs. There are regular maintenance requirements (weekly or monthly) on smaller schemes which for remote sites may be high.

Variable operating costs such as repairs and refurbishment can be high, as they might require refurbishment of penstocks and tailraces (where the water flows back into the water course after passing through the generator) or repairs to civils which can be expensive to implement in more remote areas. Some EU-funded R&D projects have looked at ways of making efficiency gains in turbine design, such as the Cavismonitor project, which will potentially reduce maintenance requirements. These are marginal gains as the technology is very mature.

In general, operating costs for larger capacity projects are generally lower as calculated by EUR/kWh than for smaller capacity installations. Depending on the technology and scale, the opex ranges from 0.26 EURct/kWh to 2.4 EURct/kWh.

Project spotlight: HYBRILA
The HYBRILA project was part-funded by FP5 and focused around an Irish local authority, Kerry County Council (KCC), that wished to reduce its electricity bill. KCC wanted to investigate having its demand met by a green electricity supplier generating electricity from an 8.6 MW hybrid system of hydro, wind and biomass. KCC wanted to reduce its annual electricity bill by 5 % and the supplier (who was also the generator) wanted to ensure that this could be done in a manner that was more financially rewarding than the current alternative (i.e. seeking a contract under the Alternative Energy Requirement Scheme (AER)). The hydro system is a 250 kW hydropower plant linked to an auxiliary water supply. A computer model was produced for a comparison between existing and proposed trading arrangements to evaluate potential benefits. *Information retrieved from public websites, including: EC, 2018, Community Research and Development Information Service*

4.3 LCOE

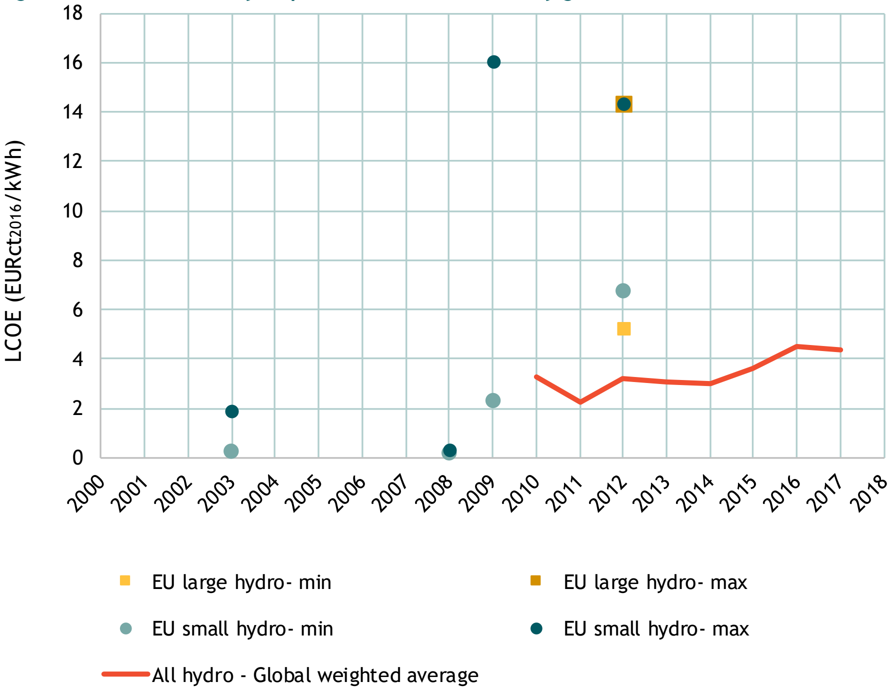
The Levelised Cost of Energy (LCOE) is an indicator to compare the project costs of different energy generation technologies.[10] Similar to capex and opex, cost-reducing innovations can contribute to a downward trend in LCOE, which in turn can make the technology more cost competitive. While LCOE is a relatively comprehensive measure of the technology's costs, it does not include all the costs for delivering energy, such as ancillary services and transmission and distribution costs.

The LCOE for conventional hydro is estimated between 0.9 and 17.2 EURct/kWh. For small hydro (less than 15 MW) this can be higher, ranging from 1.5 to 19.5 EURct/kWh. The spread in LCOE is likely to be due to the range of different capacities across the data. The larger capacity schemes will have a lower LCOE.

From IRENA's data, we see an increase of LCOE between 2012 and 2016 (see Figure 4.2). This may reflect an increase in the number of small capacity generators, which will have a higher capital cost as above. Figure 4.2 also shows the minimum and maximum values of LCOE given in literature for large and small hydro plants in the EU. These can be significantly higher than the global weighted average given by IRENA. Table 4.2 shows these LCOE figures in more detail. Also here, no reduction in LCOE is visible, which can relate to the growing number of small hydro plants in the EU, and the increasing costs relating to new legislation (see Section 4.1).

[10] There are different ways of calculating the LCOE; the method applied here is explained in the methodology document.

Figure 4.2 Evolution of hydropower LCOE for electricity generation



Source: IRENA (2018), Ecofys et al (2011), SETIS (n.d.), ESHA (2008) and SHERPA (2008),
Notes: The minimum and maximum values of small hydro refer to the lower and higher values in the LCOE estimates for hydropower projects of capacity lower than 10 MW, while for large hydro the same applies but for projects of capacity larger than 10 MW. LCOE from IRENA was taken directly from the database and converted to EUR_{2016}.

Table 4.2 LCOE of large and small hydropower projects in the EU

Sub-technology	Year	$EURct_{2016}$/kWh	Source
EU large hydro	2012	5.22 - 14.32	SETIS (n.d.)
EU small hydro	2003	0.25 - 1.83	ESHA (2008)
	2008	0.17 - 0.28	SHERPA (2008
	2009	2.25 - 16.02	Ecofys et al (2011)
	2012	6.75 - 14.32	SETIS (n.d.)

4.4 Conclusions

Efficiency gains are reported on some sites where turbines/dams are replaced, however because hydropower is a mature technology, there is little room for further technological improvements. R&D is mostly focused on improving manufacturing costs or costs on the control side. The capex and LCOE of hydropower seems to have increased in recent years, although cost trends are difficult to determine due to the highly location- and technology-specific cost characteristics of hydro plants. The increasing costs are likely not due to technological developments, but due to a changing policy context, and a growing share of SHP projects, which are inherently less cost-efficient than the conventional large-scale dams.

5 Social, economic and environmental impacts

Public R&D funding for RE technologies can lead to several social, economic and environmental impacts. In this section, we evaluate a range of indicators that provide insight into these impacts: installed capacity, annual generation, industry turnover, imports/exports, jobs and share of energy consumption.

A direct link between these indicators and R&D funding is hard to establish, as the impact of R&D funding is confluent with numerous other factors that drive or prevent deployment. Still, the indicators presented in this section are relevant indicators to assess the evolution of the hydropower sector over time.

5.1 Installed capacity

As installed capacities for RE technologies provide (near) carbon free energy that prevents the need for fossil fuel-based energy, they contribute to reducing greenhouse gas emissions and can be considered a measure of the environmental impacts. Installed capacity refers to the maximum installed generation capacity. This is expressed in MWe for electricity.

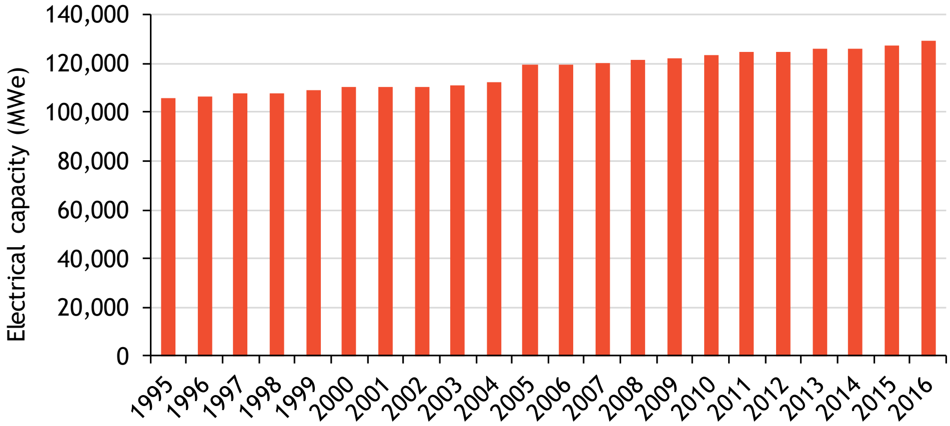
Installed capacity of hydro has steadily increased from 106 GWe in 1995 to 129 GWe in 2016. Historically, it was the largest source of RE in the EU, but since 2014 there has been more installed wind capacity. Installed capacity of solar PV is also catching up quickly, standing at 100 GWe in 2016, which could mean that hydropower capacity will become the third largest source in the future in terms of installed capacity. In terms of generation, hydropower still generates the most renewable electricity of all RE technologies (see section 5.2).

A study of SHP potential has found that over 82 % of economically feasible potential has already been exploited across many of the Member States.[11] In addition, the implementation of directives such as the EU Water Framework Directive[12] is seen to impact on the development of future suitable sites due to the increased requirements on environmental standards for water.[13] As a result, future growth of the sector is likely to be impacted.

The MS that added the most capacity between 1995 and 2016 are Spain, Portugal and Italy. After France, Italy and Spain have the most installed capacity (18.3 GWe and 16.7 GWe respectively), and thus a strong domestic market (see section 5.4). Italy is one of the largest MS funders, while Spain and Portugal rank among the top 10 recipients of EU funding. While France houses the top 5 organisations in the EU that contribute to publications on hydropower technologies, Portugal and Spain also have a presence in the top 10.

[11] European Small Hydropower Association ESHA (2008) State of the Art of Small Hydropower in EU-25, https://hub.globalccsinstitute.com/sites/default/files/publications/138218/State-art-small-hydropower-EU-25.pdf; UNIDO (2016), World Small Hydropower Development Report 2016. http://www.smallhydroworld.org/fileadmin/user_upload/pdf/WSHPDR-2016-ES-FPP-2.pdf
[12] http://ec.europa.eu/environment/water/water-framework/index_en.html
[13] SETIS (n.d.) Hydropower. European Commission, https://setis.ec.europa.eu/system/files/Technology_Information_Sheet_Hydropower.pdf

Figure 5.1 Installed capacity of hydropower plants in the EU



Source: Eurostat (2018)

Europe has a long history of SHP development, which has enabled the region to have the highest rate of installed capacity. The overall installed capacity of SHP in Europe (including non-EU countries) was 18 684 MW in 2016, while the potential capacity is estimated at 38 943 MW.[14] This includes Norway, which has an installed capacity of 2 242 MW and an estimated potential capacity of 7 676 MW, which is 70 % of the potential in Northern Europe. Italy has the second largest potential capacity of 7 073 MW, of which 3 173 MW is used. Many European countries with significant SHP capacity, such as Germany, Switzerland, Sweden and Spain, have already utilised all SHP potential. Western Europe reached the world's highest SHP development rate at 85 %, and only has considerable potential left in Austria and France. In the EU, the five MS with the highest installed capacity, together with Germany, also house the most installed capacity for SHP.[15]

5.2 Annual generation

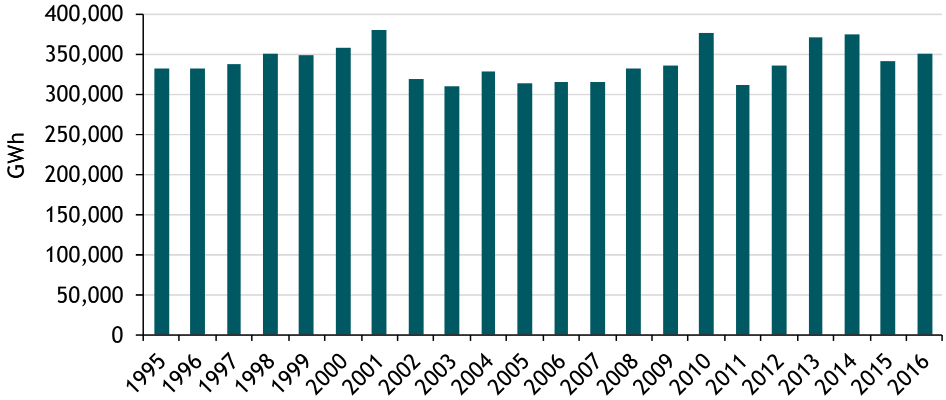
While installed capacity is a commonly used indicator to measure the progress in deploying RE technologies, it can be somewhat misleading due to differences in capacity factors. Annual generation includes the effects of these differences and is therefore a valuable indicator to complement the statistics on installed capacities.

For hydropower, it is important to bear in mind that installed capacity and output are very distinct. Periods of low rainfall have a major impact on the electricity production, which can come to a complete standstill. This is often the case for smaller generators. Likewise, the water course for smaller generators may freeze in the winter. Thus, although installed capacity has risen over the years, annual generation of hydropowered electricity has fluctuated around 350 TWh per year. Generation has not increased over the years as installed capacity has increased. The majority of historic installations have been large reservoir hydropower plants. These have a more stable output/generation year-round due to the volume of water stored in the reservoir, making these less susceptible to variation in annual rainfall. Newer capacity installed tend to be smaller scale run-of-river installations which are very dependent on annual rainfall.

[14] UNIDO (2016), World Small Hydropower Development Report 2016. http://www.smallhydroworld.org/fileadmin/user_upload/pdf/WSHPDR-2016-ES-FPP-2.pdf
[15] SETIS (n.d.) Hydropower. European Commission, https://setis.ec.europa.eu/system/files/Technology_Information_Sheet_Hydropower.pdf; UNIDO (2016), World Small Hydropower Development Report 2016

Still, hydropower generates the most renewable electricity of all RE technologies in the EU. It is followed by wind (302 TWh in 2016) and solar PV (105 TWh in 2016). Hydropower is not only important for the quantity of electricity it generates, but also for the quality of electricity, as it is dispatchable (unlike wind and solar PV). The only other dispatchable RE technologies that generate electricity at a large scale are bioenergy and geothermal energy, which generated 175 TWh and 7 TWh in 2016 respectively – only half of what hydropower generates.

Figure 5.2 Annual electricity generation in the EU from hydropower



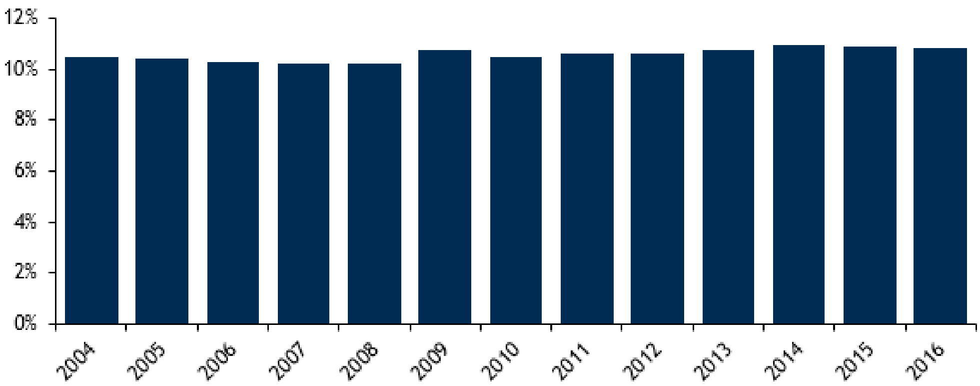
Source: Eurostat (2018)

5.3 Share of energy consumption

Share of energy consumption refers to the participation of hydropower in the gross final energy consumed in each market sector (electricity, heating and cooling, and transport). Also here, a direct link to R&D is difficult to establish, but this indicator allows us to analyse the participation of the hydropower sector in the overall target of increasing the share of energy from RE technologies in the EU's gross final energy consumption.

The share of gross final electricity consumption from hydropower in the EU is above 10 %. Just like the annual generation, this share has been more or less stable over the years. As other renewable energy sources (RES) are growing, the share of hydropower in renewable electricity consumption is decreasing. Whereas it was still 76 % of all renewable electricity in 2004, this has dropped to between 36 % and 40 % in 2014-2016.

Figure 5.3 Share of gross final electricity consumption from hydropower in the EU



Source: Eurostat (2018)

5.4 Industry turnover

Industry turnover is the total amount invoiced from the market sales of goods and/or services supplied to third parties by all sellers in the hydropower sector. Following the definition in EurObserv'ER, it focuses on the main economic activities of the supply chain including manufacturing, provision and installation of equipment, and operation and maintenance (O&M). It does not include the generation of electricity itself. Linking industry turnover to R&D funding is difficult due to the number of confounding factors, but it is possible to make a connection between RE deployment and turnover. A growing turnover indicates a growing market. EurObserv'ER only monitors turnover and jobs for SHP plants (less than 10 MW).

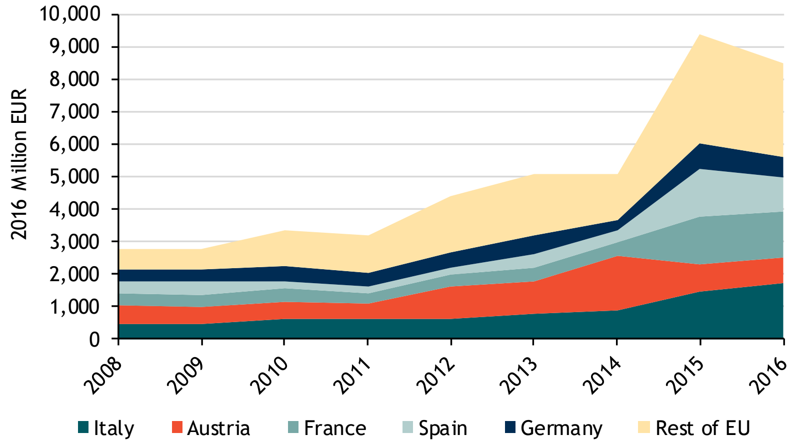
Estimations of industry turnover for SHP plants show a substantial increase over the years. Starting below EUR 3 billion in 2008, it is now estimated to be above EUR 8 billion. The MS with the largest turnover (Italy, Austria, France, Spain and Germany) are also the MS with the largest installed capacity of SHP plants.

About 360 small hydro companies are based in Italy, making it one of the most important markets for small hydro. Prime hydrological conditions and the largest untapped potential for small hydro in the EU encourage development, although the long and complicated authorisation and licensing process poses a challenge. Italy has a large number of small hydro plants and many technology and component suppliers in the country, which explain high turnover figures, which grew to an estimated EUR 1.7 billion in 2016, the highest in the EU. In addition, Italy has had an incentive scheme for RE generation since 1999 based on purchasing green certificates. As of January 2016, this incentive has been replaced by a feed-in tariff (FiT) scheme which is determined on the amount of generation.[16]

France, which also has a significant small hydro capacity and considerable potential for more, but most of the unutilised potential is in greenfield projects. The Water Framework Directive and environmental legislation has posed several challenges for the small hydro sector. France has had a fairly constant amount of installed capacity, without many new additions, therefore turnover was modest. In 2012, it introduced a programme to install 3 GW to small hydro capacity, but progress was slow due to the scarcity of new sites and constraints for installations. Industry picked up in 2015-2016, as the estimated turnover rose from EUR 430 million to over EUR 1.4 billion.

[16] McDermott Will & Emery (2015), Italy: Incentive Regimes for Renewable Energy Plants, available at: https://www.lexology.com/library/detail.aspx?g=7c389972-c16e-4347-909f-18e26c3a2ae2

Figure 5.4 Hydropower industry turnover in the EU



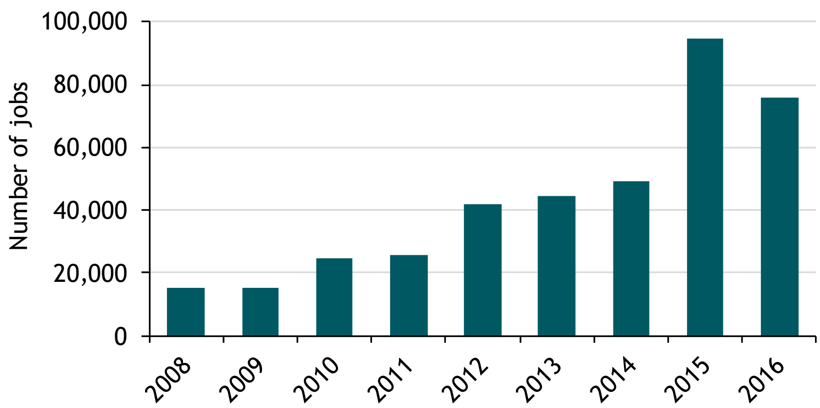
Source: EurObserv'ER reports 2010-2017.
Notes: The source covers only 'Small Hydro' (less than 10 MW) except for some MS where, in some years, small and large hydro are included: Austria and United Kingdom (years 2014-2015), Poland (2011-2012), Greece (2014) and Sweden (2011). Data is missing for Croatia on years 2008-2011, and for Portugal and United Kingdom on years 2008 and 2009. Figures do not include electricity generation.

5.5 Jobs

Employment is an important indicator to understand the socio-economic impact of RE technology deployment. Linking jobs to R&D funding is difficult due to the number of confounding factors, but it is possible to make a connection between RE deployment and jobs. Different methods exist for estimating employment figures. A consistent time-series was only available for 2008-2016. EurObserv'ER only monitors turnover and jobs for SHP plants (less than 10 MW).

The number of jobs for SHP in the EU rose from an estimated 15 000 in 2008 to over 75 000 in 2016. The five MS with the largest small hydro capacity (Italy, Spain, France, Austria and Germany) have about 60 % of the total EU jobs. Data on jobs in large hydropower are unavailable but are to some extent included in the number of jobs for SHP presented here, as some MS do not provide a distinction. The number of jobs for large hydropower that is not included in this figure is likely relatively small. IRENA estimates the total number of jobs in hydropower (both large and small) at 106 700 in 2015, which is 11 900 higher than the number of jobs in SHP reported by EurObserv'ER for that year.

Figure 5.5 Evolutions of jobs in hydropower



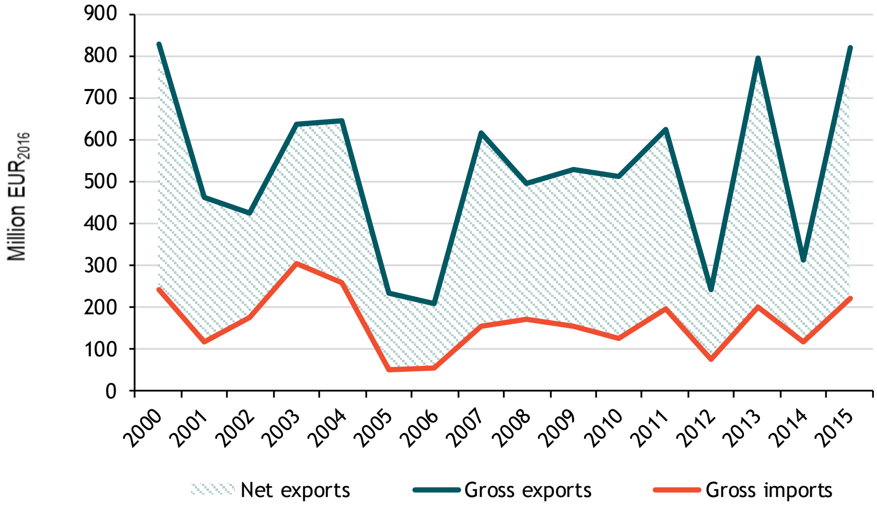
Source: years 2008-2016 EurObserv'ER (2010-2017)
Notes: The source covers only 'Small Hydro' (less than 10 MW) except for some MS where, in some years, small and large hydro are included: Austria and United Kingdom (years 2014-2015), Poland (2011-2012), Greece (2014) and Sweden (2011). Data is missing for Croatia on years 2008-2011, and United Kingdom on 2008.

5.6 Imports/exports

International trade can provide a measure of the market uptake of hydropower technologies and development of the hydropower sector itself. Linking trade to R&D funding is difficult due to the number of confounding factors, but it is possible to make a connection between RE deployment and imports/exports. It allows us to examine the extent of the external market for these goods, with increasing exports leading to increased growth of the domestic sector. Similarly, increased activity in the sector will lead to an increase in demand for intermediate goods used in the manufacture of RE technologies, a proportion of which may be imported. Increasing imports of these intermediate goods also provide an indication of the growth within the technology sectors.

The EU has the leading SHP sector in the world, exporting its technologies all over the world. Figure 5.6 shows that import and export of the hydro sector have strong fluctuations over the years, but the trade balance is always positive.[17] For the whole period 2000 to 2015, the total value of exports was 3.2 times the total value of imports, indicating that the EU hydropower industry has a competitive position in the global market.

Figure 5.6 Trade balance for hydropower components in the EU

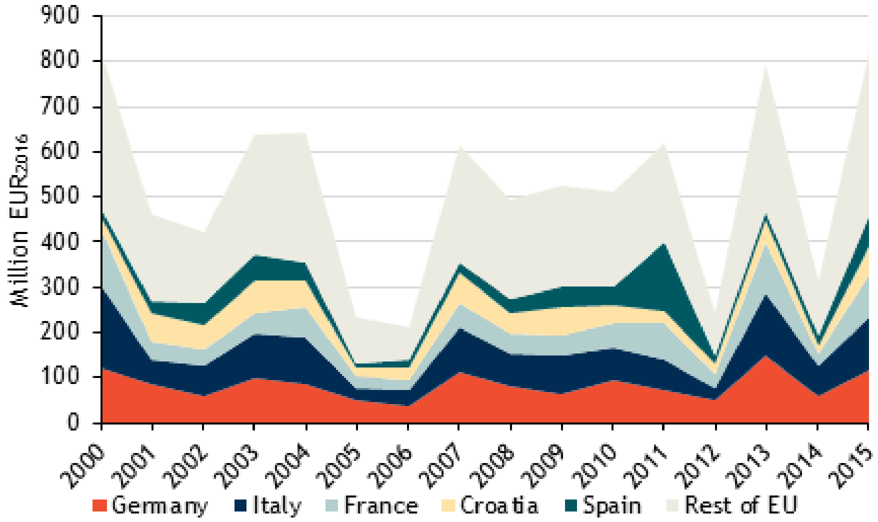


Source: Based on Comext (2018), Lako, P (2008), Eurostat (2018), Wind, I (2009), and Jha, V (2009). Data for 1999 and 2016 was 0 for all countries so it was excluded. For an explanation of the methodology used, see Annex C.

Most EU exports to the rest of the world originate from Germany (see Figure 5.7). Germany is the fifth MS with a large hydropower industry turnover in the EU. The other main exporters include Italy, France and Spain, consistent with the high industry turnover in these countries, but also Croatia. Apart from Croatia, these MS also have some of the most patents filed and publications in the EU. Austria, the MS with the second largest hydropower industry turnover, is not listed as a main exporter (extra-EU trade) because their main activity in trade was exports intra-EU.

17 The fluctuations are partly a consequence of the methodology chosen as the exact timings of the purchases are not known and an assumption needs to be made to allocate trade volumes related to new installed capacities to periods of time. In our methodology these trade volumes are allocated to the year in which the capacity was registered. In the absence of continuous capacity additions over the years, this leads to a spike in certain years.

Figure 5.7 Total value of exports of hydropower components from the EU (extra EU28 trade)



Source: Based on Comext (2018), Lako, P (2008), Eurostat (2018), Wind, I (2009), and Jha, V (2009).
Data for 1999 and 2016 was 0 for all countries so it was excluded.
For an explanation of the methodology used, see Annex C.

5.7 Conclusions

Historically, hydro was the largest source of RE in the EU. Now most potential has been utilised, which leaves less room for market growth compared to other RE sources. In addition, the implementation of new environmental legislation narrows the scope of future suitable sites due to the increased requirements on environmental standards for water. As a result, future growth of the sector is likely to be impacted. Industrial activities will mostly focus on SHP, which shows an increasing industry turnover and jobs creation and still has untapped potential. The EU plays a leading role in SHP, exporting its technologies all over the world.

6 Conclusions

Hydropower is the EU's first RE technology: the long history of development means hydropower was established as a mainstream electricity source over 100 years ago. As a consequence, in 1995, EU hydropower capacity was already 106 GWe, rising by 21 % over the following 20 years to 129 GWe. Although installed capacity of wind and solar PV are (close to) surpassing that of hydropower, hydropower plants still generate the most renewable electricity of all RE technologies: 350 TWh per year, which is 10 % of gross final electricity consumption in the EU. Both dammed hydro schemes and run of river schemes on the whole have higher capacity factors than a lot of onshore wind and solar PV projects. It has several other advantages over most other RE technologies, including a high level of reliability, low operating and maintenance costs, flexibility and large storage capacity, which can provide grid balancing services that can help system operators handle the variability of other RE technologies.

Hydropower receives relatively low R&D funding from the EU and MS, and the energy and climate roadmaps do not expect strong growth of the sector. Despite the potential for small hydropower (SHP) and the features of hydropower as a dispatchable resource plus an option for storage, the EU and MS do not invest heavily in R&D for this technology. This could be because the core technology (hydro turbines and civils infrastructure) is well established and opportunities for technology improvements are often part of internal business improvements that do not require grant funding. Norway and Switzerland have higher R&D budgets, but all national R&D funding is very low compared to China, which spent about EUR 160 million per year on hydropower technologies between 2012 and 2016.

Nevertheless, EU funding has contributed to improvements of existing technologies and the development of new technologies in the hydropower sector. Given the maturity of the hydropower sector, R&D has included topics that help address barriers to new market segments or offer further improvements to the established technologies. Between FP5 and H2020, EU R&D funding has supported three developments in the hydro sector: 1) improving the operational performance of existing installed capacity; 2) improving the design of existing technologies; and 3) development of new small hydropower (SHP) turbines and technology deployment.

The largest proportion of EU funding has been for small hydropower (SHP), where there is an estimated unutilised potential of 21 GWe in Europe (including non-EU countries). This has shaped the scope of the projects that have received R&D funding. Most of this funding went to the development of new small-scale turbines for low head sites such as weirs or on the river surface mounted technologies, and technology deployment. The funding of new SHP technologies has the potential to open up new sites that may otherwise not have been technically or economically viable. There are a large number of sites for smaller schemes, primarily run of river, that new technologies such as those developed under the Hydrokinetic and River-Power projects will be suitable for.

More generally, EU funding has contributed to knowledge development and knowledge sharing on investment opportunities, acquiring permits, and turbine design improvements, amongst other things. EU-funded projects have also led to the creation of patents and publications in areas where this is useful.

Being one of the biggest RE sources, growth of the hydropower sector has significant social, economic and environmental impacts. It provides 10 % of gross final electricity consumption in the EU, which was 37 % of all EU renewable electricity production in 2016, and creates substantial industry turnover and jobs. It also has a positive trade balance with the rest of the world. The EU holds a leading position and has significant exports to the rest of the world in both SHP technologies and large hydropower. Estimations of industry turnover for SHP plants show a substantial increase over the years, from less than EUR 3 billion in 2008 to over EUR 8 billion in 2016. The number of jobs for SHP in the EU rose from an estimated 15 000 to over 75 000 in the same period.

Sites with the best conditions for hydropower have mostly been utilised, especially in Western Europe. In addition, the implementation of new environmental legislation narrows the scope of suitable sites. However, hydropower continues to play a strong and important role in the renewable energy mix, and there are still further growth opportunities of SHP projects, in which the EU holds a leading position and has significant exports to the rest of the world. EU funding has contributed to the improvement of SHP technologies and designs in Europe, which enable the exploitation of sites that were previously not viable.

Annex 8A - Case studies

RESTOR Hydro

Author:	Katie Moran	**Approver:**	Mrs Gunvor Axelsson Gårdsjuridik, Project Manager
Project title:	RESTOR Hydro (Renewable Energy Sources Transforming Our Regions – Hydro)		
Lead partner:	Swedish Hydropower Association, Sweden		
Project location:	Sweden		
Technology area/s:	Hydropower		
Start and end date:	June 2012- June 2015		
Project cost:	EUR 2 581 853	**EC funding:**	EUR 1 936 389
Other funding sources:	Crowdfunding, grants and regional loans and partner organisations		
Quantifiable outputs and impacts:	Two publications (guidebook and methodology), 1 243 kW total installed capacity capability		
Further information:	Project website Project Manager – Mrs Gunvor Axelsson Gårdsjuridik, Project Manager, Environmental Lawyer/Reporter, Tråvad Tråvadsbro 2, 53492 Tråvad. T +46 0708727216. E gunvor@axelsson.info		

Project description

As populations expand and countries develop, there is a growing demand for energy across the globe. Use of fossil fuels has exacerbated greenhouse gas emissions and had a detrimental impact on the environment, initiating a shift to more sustainable sources of energy such as hydropower. Unrealised potential for small and micro hydropower generation exists in Europe's thousands of historic mills, water wheels, inoperative hydropower stations, weirs and other lateral structures in rivers. Repowering abandoned sites results in the generation of hydroelectric power for local use and for injection to the European electrical grid. This simultaneously leads to increasing electricity production from renewable sources, energy independence and grid stability. Besides enhancing energy supply security, the creation of local energy sources gives a boost to local economies, provides income sources and creates jobs.

The specific objectives of the RESTOR Hydro project were to:

- identify the overall benefit that can realistically be derived from restoration of historical hydropower sites in the EU-27 along with methodology guidelines for identification and refurbishment of RE, environmental, economic and social benefits;

- prepare a strong and supportable business model combining 1) local investment via community shares based cooperative, 2) twinning with Structural Funds and 3) providing projects that are large enough to be bankable by financial institutions;
- trigger investments in eight EU target countries proving the business model and its promotion in EU-27 to boost investment in RE and supply;
- Communicate the success of such initiatives and create an awareness campaign and encourage municipalities, site owners, investors and others to encourage new renewable power generating

RESTOR Hydro aims at assessing the state of SHP and refurbishment potential in the whole EU-27 region. Restoration programs have been implemented in eight selected target countries: Belgium, France, Greece, Italy, Lithuania, Poland, Slovenia, And Sweden. These programmes aim to supply electricity to local communities and the European grid on a sustainable and economically viable basis. It aimed to raise awareness of the benefits of SHP and demonstrate its attractiveness as a local investment, which brings revenue to local communities and contributes to energy independence, while preserving historical heritage and the environment. The RESTOR hydropower project involved 10 partners from the selected EU target countries outlined above and was coordinated by the Swedish Hydropower Association.

Outputs and impacts

The RESTOR Hydro project had several outputs:

1. More than 50 000 sites identified and described in the RESTOR Hydro Mills Map;
2. A Guidebook on Cooperatives was produced which centred around cooperatives and investments documenting a reproducible business model. This business model offers several advantages including; stimulating local investment in RE, increasing social acceptance of hydropower through community participation and generating economies of scale and reducing administrative difficulties;
3. The 'Small and Micro Hydropower Restoration Handbook – The All-inclusive Replicable Model' provided methodology guidelines for identification and refurbishment to provide RE, environmental, economic and social benefits. Both publications have been published in nine languages;
4. 28 dormant sites selected, and cooperatives formed with all information, investigations and legal background needed put forward in applications for permit(s). These sites have a total energy generation capacity of 1 243 kW.

Creating local energy provides income for local economies and creates jobs. For example, in Lithuania, some of the sites identified to be rehabilitated have developed into visitor centres which provides opportunity for local jobs and boosts tourism. This project has increased social acceptance through local community ownership, while highlighting the preservation of aesthetic and historic elements and improving environmental quality. It influenced the removal of non-technological barriers by reducing complexity and simplifying regulatory and administrative procedures and recommending improvements for micro hydropower.

In some areas, environmental and ecological constraints, such as the WFD (Water Framework Directive) have limited the opportunity for development of sites identified. In France, the ecological continuity policy reduced the number of potential sites by 70 % and increased the amount of procedures required to obtain a permit. Underdeveloped legislations and unstable economies have created uncertainty for investments and have hindered development. Public opposition to hydropower was also a key issue across Europe, preventing new development and refurbishment of old sites.

Outlook and commercial application of the outputs

The RESTOR Hydro project closed in June 2015. Since then, the initial sites identified have undergone continued exploration with the aim of developing them into power generating sites in the future. The RESTOR Hydro Map and guidance created as part of the project, including information on how to set up cooperatives and how and where to find funding, will enable each participating country to develop SHP potential at these sites and see further impacts as a result of this project. No further investment is considered necessary for this project, however, those who go on to restore the sites will require funding, but this project has provided the information and guidance on how to do this. An example of this is Moulins D'Oc, an association formed because of the RESTOR Hydro project, which aims to refurbish 3 mills in France to produce 200 kW of clean and renewable hydroelectricity.

The role of EU funding

The RESTOR Hydro programme was funded through Intelligent Energy Europe (IEE) which offered a helping hand to organisations willing to improve energy sustainability, with a view of reaching the EU 2020 targets. This stream of funding is now closed, although several projects funded under the programme are continuing. The EU's Horizon 2020 programme has taken over in supporting research, demonstration and market up-take of energy-efficient technologies.

Funding was made available through annual calls for proposals to support projects putting the concept of 'intelligent energy' in practice, with the majority supporting those that promote energy efficiency and RE. RESTOR Hydro was funded through the ALTENER funding stream which aimed at increasing the share of renewables in the production of electricity, heat and cooling, and to integrate them in the local energy systems. EU funding provided 75 % of the total project costs with the remaining provided through local investments and by project participants.

The RESTOR Hydro project also saw some non-monetary benefits owing to being in receipt of EU funding. For example, the project received wider publicity through articles in local newspapers, boosting public supports, and 'big hydro' organisations in some countries also voiced their backing. Being in receipt of EU funding provides a 'quality stamp' and thus gave the project a greater influence to attract potential partners and enhanced the network of resources available. Changes in the consortium, due to the replacement of a coordinator, meant there had to flexibility with the funding. This was managed very effectively, making it possible to finalise the project successfully.

Full project participant list

Organisation	Country	Type
Swedish Hydropower Association	Sweden	Trade Association
National Technical University of Athens	Greece	Academic Institute
Lithuanian Hydropower Association	Lithuania	Trade Association
WIRTSCHAFT UND INFRASTRUKTUR GMBH & CO PLANUNGS KG	Germany	Private Company
Association of Energy Producers from Renewable Energy Sources	Italy	Trade Association
Federation of Renewable and Alternative Energy	Belgium	Trade Association
NettoWatt	Belgium	Consortium
Polish Association for Small Hydropower Development	Poland	Trade Association
H.E.B. d.o.o., Ljubljana	Slovenia	Private Company
France Hydro Electricite	France	Trade Association

HYPERBOLE

Author:	Marcus Alexander	**Approver:**	Prof. François Avellan
Project title:	**HY**dropower stations **PER**formance and flexi**B**le **O**peration towards **L**ean integration of new renewable **E**nergies (HYPERBOLE)		
Lead partner:	École Polytechnique Fédérale de Lausanne		
Project location:	Switzerland		
Technology area/s:	Hydropower		
Start and end date:	September 2013 to February 2017		
Project cost:	EUR 6 294 644.40	**EC funding:**	EUR 4 325 542
Other funding sources:	In-kind contributions from industry		
Quantifiable outputs and impacts:	20 scientific publications and 2 doctoral theses (full list here), development of a product and a new IEC standard		
Further information:	Project website Project coordinator and scientific coordinator: Prof. François Avellan Institute of Mechanical Engineering - École Polytechnique Fédérale de Lausanne, Batiment CE 3316 Station 1, 1015 Lausanne, Switzerland T +41 216932524. E Francois.Avellan@epfl.ch		

Project description

The 20-20-20 strategic energy policy decided by the European Union and its accompanying Renewable Energy Directive is leading towards a dramatic electric energy system transition. The two major pillars of this transition are:

I. a massive penetration of renewable energies;
II. a broad deployment of energy efficiency initiatives and technologies.

For this goal, hydropower already plays an important role and will increasingly do so to *a)* contribute to RE production, and to *b)* provide for the highly dynamic energy storage requirements for system balancing that enable a widely distributed injection of solar and wind energy into the transmission and distribution systems through the provision of advanced system services.

The overarching objective of the HYPERBOLE project was to enhance hydropower plant value by extending machine operating ranges while also improving component long-term availability. More specifically, the project aimed to study the hydraulic, mechanical and electrical dynamics of several hydraulic machine configurations under an extended range of operations: from overload to significant part loading. A two-pronged modelling approach relied on numerical simulations as well as reduced-scale physical model tests. Upon suitable concurrence between simulations and reduced-scale physical models results, validation took place on a carefully selected physical hydropower plant properly equipped with monitoring systems. Finally, the benefits resulting from the extended control flexibility provided by a set of hydro units were demonstrated through extensive simulation of the operational conditions of an electric power network with a large variety of sources.

To address this ambitious research plan, a consortium was assembled featuring three leading electric equipment manufacturers of hydraulic turbines, storage pumps, reversible pump-turbines (Alstom[18], Andritz and Voith), an SME (Power Vision Engineering SARL), as well as world-renowned academic institutions (Ecole Polytechnique Federale De Lausanne, Universitat Politecnica De Catalunya, Inesc Tec, Universitaet Stuttgart and Haute Ecole Specialisee De Suisse Occidentale). Extensive tests on both experimental rigs and real power plants were performed to validate the obtained methodological and numerical results.

Outputs and impacts

The scope of the project was to develop a methodology to better understand the flow instabilities of the turbine when operation outside of operating parameters. Such flows induce additional unsteady mechanical loadings of the components of the machine and can lead to the reduction of their lifespan. A model was developed for this which was later field tested in British Columbia. The result of this project was the development of a model at TRL 5.

Alongside this, the project also developed a procedure to check the operating parameters of the turbine through an empirical approach. This involved performing modelling and testing of the turbine to IEC standard tests. The scope was then extended to investigate the behaviour of the machines (through modelling) beyond the operating conditions of the IEC standards. Following this procedure, they could correctly identify the instability of the turbine at various stages of flow. The outcome of this process was published in the IEC. In it expected that this methodology could lead to the revision of the scale-up relating to oscillating phenomena in the IEC 60193 standard for industrial model testing in the future. This would allow a significant proportion of currently installed hydro turbines to operate in a wider range of conditions than they can at present.

As a result of this work, the HYPERBOLE project contributed to the development of an optimisation algorithm for the identification of adequate strategies regarding the participation of reversible hydropower plants in the secondary reserve market, in complement to the participation in the tertiary reserve market. Thus, it will be possible for hydro pumping promoters to identify and obtain additional profits resulting from their participation in reserve markets because of the extended control flexibility and operation range provided by new hydro units.

The obtained results are of upmost importance in the further development of high-end hydro-mechanical equipment. The present configuration of the consortium and the collaboration between all the involved parties offer the European players a unique and unparalleled access to a completely new set of data and insights. The important knowledge and tools developed in the HYPERBOLE project represent a major competitive advantage for the European hydro equipment industry and allows the partners to sustain and extend their global market share. For instance, the numerical simulations of the dynamic mechanical behaviour of turbines in various operation modes developed and validated in the HYPERBOLE project will enable European manufacturers to design and engineer more robust hydraulic turbines capable of operating within an extended operating range. It will also enable the hydropower plant owners to define their strategy for optimizing components lifetime and productivity gains for their hydropower plants.

[18] ALSTOM Hydro is now part of GE Renewable Energy.

Furthermore, the methodology developed in the HYPERBOLE project for the prediction of hydropower plants stability will enable the hydropower plant owners to avoid operating conditions putting at risk the stability of the hydro-mechanical system and reducing the lifetime of the generating unit mechanical components.

Outlook and commercial application of the outputs

As a result of the new partnerships that were developed for this project, they are in the process of setting up a new project to propose to the commission for submission by the end of December 2018 as a H2020 project demonstrator. This will be a new partnership with utilities and TSO which so far has not happened yet. The project will be a demonstrator with the aim of applying this technology and methodology to a new power plant, which would take the model to TRL7.

There were no spin-offs directly from this project. However, a partner in the project was a spin-off of EPFL, Power Vision Engineering. Through the project Power Vision Engineering have extended their market reach and extended the number of employees from a team of 3 to having 5 people working for them.

The role of EU funding

This project was supported under FP7-ENERGY, topic ENERGY.2013.2.7.1 - Optimisation of water turbines for integration of renewables into the grid. The project was funded to the tune of EUR 4 325 542 and is now closed. EU funding amounted to 69 % of the total project cost, the rest of the contribution being from project partners.

Funding for this project enabled academic institutions and private companies (OEMs) to work together to carry out experimentation and real-world tests that will further increase the understanding of operation and control of hydropower systems. Having the involvement of the OEMs in the project has enabled a close partnership between research and industry. The next step is to include the other stakeholders, mainly the utilities and electricity operators (which will be done through a follow-on EU-funded project).

This project has provided the OEMs involved with more insight and tools to face competitors. It has further highlighted the need for more inertia and backup in the electricity system when considering the development of PV and wind in Europe. It sets out how and why hydropower paves the way to face this challenge.

Full project participant list

Organisation	Country	Type
Ecole Polytechnique Federale De Lausanne	Switzerland	Academic institute
ALSTOM Hydro France (ALSTOM is now part of GE Renewable Energy)	France	Private company
Andritz Hydro Gmbh	Austria	Private company
Andritz Hydro Ag	Switzerland	Private company
Voith Hydro Holding Gmbh & Co Kg	Germany	Private company
Power Vision Engineering Sarl	Switzerland	Private company
Universitat Politecnica De Catalunya	Spain	Academic institute

Organisation	Country	Type
Inesc Tec – Instituto De Engenharia de Sistemas E Computadores, Tecnologia E Ciencia	Portugal	Academic institute
Universitaet Stuttgart	Germany	Academic institute
Haute Ecole Specialisee De Suisse Occidentale	Switzerland	Academic institute

HydroKinetic-215

Author:	Simon Morris	**Approver:**	Roisin Mc Cormack
Project title:	Commercialisation of a viable and proven HydroKinetic Turbine that will harness the power of the world's rivers, canals and estuaries in a sustainable, innovative and cost-effective way (HydroKinetic-25)		
Lead partner:	DesignPro Ltd, Rathkeale Industrial Estate, V94 E5CO Rathkeale Limerick, Ireland		
Project location:	Ireland		
Technology area/s:	Hydropower		
Start and end date:	March 2016 to August 2016		
Project cost:	EUR 71 429	**EC funding:**	EUR 50 000
Other funding sources:	Private investment from DesignPro Ltd		
Quantifiable outputs and impacts:	1 spin-off (DesignPro Renewables) which subsequently led to: Development of a new product 2 patents[19] 1 Award (Champions of EU Research) 9 direct jobs[20]		
Further information:	Project website[21] Sales & Marketing Manager - Roisin Mc Cormack, Rathkeale Industrial Estate, Rathkeale, Co. Limerick, V94 E5C0, Ireland. T +353 (0)69 63842 Ext 326. E rmccormack@designproautomation.com		

Project description

Despite its large resource potential, hydrokinetic energy is still largely untapped with only 5 % exploited to date. Europe, as well as many countries around the world, is rich of small and medium-sized rivers and straits between islands. Existing technologies require very fast flow speeds and large deployment spaces to make turbine outputs viable. The main goal of HydroKinetic-25 project was to expand on a strategic business plan for commercializing an innovative hydro RE device specifically designed to cater to a niche, 'low-power', small-scale energy generation market. HydroKinetic-25 project had one SME participant - DesignPro Ltd who are based in Ireland and the project lasted for 6 months. The innovative hydro RE device is designed to harness low-carbon, reliable and affordable energy from river and estuarine environments. Unlike other established forms of hydropower, no height differential, or 'head' of water, is needed to generate adequate power from the flow of water. This avoids expensive and disruptive civil works. The project had 8 key tasks including: a market study, a geographical analysis, optimisation of the product, a distribution plan, assessment of risks and barriers, an overview of the proposed manufacturing process, an assessment of the economic viability of the project and continued work and research into regulatory and IP licensing issues. With a validated business plan and a project showing huge potential, DesignPro entered into a formal IP licence agreement with GKinetic gaining full rights to develop and commercialise devices up to 100 kW.

19 DesignPro' does not own these patents but have an IP licence agreement in place to be the sole exploiter of the concept and technology up to 100kw.
20 In addition, 15 employees from DesignPro Automation contribute and work on the project on a part-time basis.
21 Future information on the spinoff can be found at: http://designprorenewables.com/

Outputs and impacts

As a consequence of the project, DesignPro Renewables could substantially improve the proposed business plan for the development of the technology, identify the key risks and adapt its strategy for the commercialisation to mitigate against these. Significant progress was made on the optimisation of the product. Key risks within the business plan that were assessed included supply chain, distribution, manufacture, testing and the economic viability. The project team formulated their development plans for phase 2 and in November 2016 applied for EU Horizon 2020 (H2020) SME Instrument, Phase 2 funding. However, despite scoring well and receiving a seal of excellence, their first attempt was not successful. The project team re-applied in January 2017 and were successful in receiving funding for a EUR 2.7 million project. The phase 2 project included the establishment of a new spin off (DesignPro Renewables) and production, deployment and operation of two pilot devices (25 kW and 60 kW). DesignPro Renewables is dedicated to implementing the actions and deliverables of the phase 2 project and are now well underway to achieving the overall vision which is to generate viable, green energy from flowing water.

The 25 kW run-of-river hydrokinetic turbine has progressed from the design into the build phase in preparation for deployment. The device will be deployed at SEENEOH test site on the Garonne River in Bordeaux. The 25 kW device will remain at the facility for 12 months until being lifted out and relocated to a commercial deployment site. The phase 2 project has created nine full time jobs during the project development stage and it is estimated that 50 jobs will result from the commercial roll out.

New partnerships have formed as a direct result of phase 1 and 2. DesignPro Renewables, are working with several highly experienced suppliers and partners whose expertise and knowledge is instrumental to the success of their ambitious project. One such partner that they found great synergy with is Mitsubishi Electric. After a successful tendering process, Mitsubishi are now working with them on the PTO (power take off) system for the 25 kW turbine. Interest in the project has become worldwide and they are beginning to bring together a potential client database. Due to its small size and ease of deployment and maintenance, this RE device opens huge new market opportunities in terms of river energy generation where it previously was not possible. For example, they have identified new markets in Indonesia whose communities are often reliant on diesel generators.

There have been two patent applications made – one is about where flow is accelerated into turbines and the other is for the unique mechanical pitch control system. Both patents originated from G-Kinetic and DesignPro are licensing this IP for global use in applications up to 100 kW. In June 2017 DesignPro was one of only two Irish SME's acknowledged for reaching the pinnacle of European research, being awarded the status of a 'Champion of EU Research'.

Outlook and commercial application of the outputs

A new product – the DP60/25 will be ready to manufacture and will be commercially available by the end of 2019. DesignPro Renewables have invested in a Sales and Marketing division to help identify potential sales opportunities. They plan to take potential customers to Bordeaux (as the 25 kW machine will be there for 12 months) to secure orders. Successfully bringing this device to market would allow end users to generate predictable, zero carbon energy from the largely untapped resources of our tides, rivers, canals and estuaries. This could potentially be a large contributor to reducing the world's harmful carbon dioxide (CO_2) emissions, directly addressing the issue of global warming and the need to move to greener energy sources.

The role of EU funding

Phase 1 was funded under the H2020 EU Framework Programme for research and innovation under the call 'Stimulating the innovation potential of SMEs for a low carbon energy system'. They received 70 % funding from H2020. The remainder of the costs were met provided by Design Pro from company resources, and no additional private funding was required.

Overall, the funding proved invaluable in supporting the company to determine many critical aspects of the core business idea while also adding significant weight to the project and allowing for a much more focused approach moving into the next stages. The conditions associated with this funding included delivering a final project report and maintaining record of expenditure (though no mandatory audit was required).

The phase 2 project will run for a total of 27 months, ending September 2019. They secured 70 % funding for a EUR 2.7 million project from H2020 with the balance coming from DesignPro Ltd.

Full project participant list

Organisation	Country	Type
DesignPro Ltd	Ireland	Private Company

Cavismonitor

Author:	Katie Moran	Approver:	Prof. Marko Hočevar, University of Ljubljana
Project Title:	Cavitation monitoring in hydraulic machines with the aid of a computer aided visualization method (CAVISMONITOR)		
Lead Partner:	Turboinstitut (now Kolektor Turboinstitut d.o.o.), Rovsnikova 7, SI-1000 Ljubljana, Slovenia		
Project Location*:	Ljubljana, Slovenia		
Technology Area/s:	Hydroelectricity		
Start and End Date**:	2000 – 2003		
Project Cost:	€478,571	EC Funding:	€190,000
Other Funding Sources:	In-cash/in-kind contributions from industry		
Quantifiable Outputs and Impacts:	Multiple Publications, Cavitation Monitoring System product, numerous new partnerships as well as several new research projects leading from this project		
Further Information***:	Project website Project Manager – prof. Brane Širok, dr. Matej Novak, prof. Marko Hočevar, Project Manager, now: Faculty of Mechanical Engineering, Laboratory for Hydraulic Machines LVTS, Room 314, University of Ljubljana, Slovenia. T +386 1 4771 200 (ext. 314). E marko.hocevar@fs.uni-lj.si		

Project Description

The Cavismonitor project aimed to develop a system for visualisation of cavitation monitoring in hydraulic turbines. The scientific objectives were to gain new fundamental knowledge of physical phenomena of cavitation in hydraulic machines with the aid of a recent computer-aided visualisation method. The technical objectives involved the employment of this fundamental knowledge along with a new method of computer-aided visualisation to develop a new, direct method of cavitation detection and monitoring on vital parts of hydraulic machine and then increase turbine operating range due to exact definition of cavitation limits, which are continuously monitored. The project aimed to perform monitoring on a model hydraulic machine in a laboratory environment, as well as on a real hydroelectric power plant turbine prototype. The aim was to develop a monitoring system that would enable the operator/user of the generator to estimate the amount of erosion and degradation that would occur on the turbine over time.

Cavitation is the formation of vapour bubbles in the liquid flowing through any hydraulic turbine, it is the collapse of these bubbles that generates pressure waves which can ultimately cause damage to machinery, through cavitation erosion. Cavitation in hydraulic turbines causes unplanned maintenance and, therefore, down time of the generators, this has cost implications. If operators could better schedule preventative maintenance, they could schedule inspections and welding procedure at times that would not impact operations.

Turboinstitute, the project co-ordinator, directly benefitted from this project as they used the results from the monitoring to influence the procedure for, and physical design of, the turbines they sold. The main drivers for this project were the potential to reduce the costs of unplanned maintenance, but also reducing the cost of the design process. The Cavismonitor project involved; Darmstadt Univeristy of Technology - Germany, Institute of Hydropower Machines and Pumps – Vienna, Austria and Soske Elektrarne Nova Gorcia (SENG) – also based in Slovenia.

Outputs and Impacts

The main outputs of the project consisted of a publication titled 'Relationship between cavitation structures and cavitation damage', (M. Dular et al., 2004), which has been cited 162 times including in papers such as 'Material and velocity effects on cavitation erosion pitting', scientific journals such as the Journal of Fluids Engineering and in books e.g. Fluid Mechanics and Its Applications. Other impacts included increased knowledge and understanding of cavitation as well as the added benefit of collaboration and co-operation with other organisations.

The most important output of Cavismonitor project is establishing new research capabilities and knowledge, which later resulted in a series of research, innovation and industrial projects. Included in the Cavismonitor project among others was as a student M. Dular, now a professor at University of Ljubljana, recipient of 2018 European Research Council (ERC) grant with funding of approximately 2 million EUR for the CABUM project. The CABUM project explores the phenomenon of cavitation, where bubbles appear in a liquid when there is a sudden decrease in pressure, finally collapsing in a higher-pressure area. It is a process that until recently was considered undesirable, because it causes noise, vibration and erosion in water machines. In recent years, however, under specific conditions, it has been used for the cleaning of surfaces, improvement of chemical processes, waste water treatment, and elsewhere. The idea behind the CABUM project is based on the lessons learned from the multi-year cooperation with the business sector. Clearly, gaps in the knowledge of the physical background of cavitation have been shown, which limit the introduction of this technology into advanced industrial processes. The project will explore the dynamics of cavitation bubbles in the interaction with bacteria and viruses, which will open the door for energy efficient and environmentally friendly water purification in the future (A. Šarc et al., 2018).

Outlook and commercial application of the outputs

A Turboinstitute developed from the knowledge of Cavismonitor and a cavitation detection system, which was based on other indirect sensing methods. The Cavismonitor project provided knowledge about the relation between visual information and indirect variables like vibrations and acoustic emission. A cavitation monitoring system was developed from this. The system was sold to customers following the end of Cavismonitor project across countries of western Balkan region (ex. Yugoslavia).

In addition to the above mentioned CABUM ERC project, subsequent projects which have occurred as a result from Cavismonitor are still ongoing. These include four EU funded projects; ACCUSIM (FP-7), CRYOCAV (ESA), CATHEF (ESA) and CABUM (ERC). The recently completed ACCUSIM project (Accurate Simulations in Hydro-Machinery and Marine Propellers) aimed to develop reliable numerical tools and methods for detailed analysis of turbulent flows to facilitate the design of powerful hydro-machinery and marine propellers and strong emphasis was put on the ability to accurately predict cavitation regimes that can be expected in such machines.

The role of EU Funding

The Cavismonitor project was funded under FP5-EESD programme. The total cost of the project was EUR 478 571 with a EU contribution of EUR 190 000 (40%). Later FP5-EESD was later superseded by subsequent FP6, FP7 and H2020 projects.

The Cavismonitor project was co-funded by other sources. For project leader Turboinstitute, the required co-funding was provided by company own resources from revenue from sales of water turbines and other hydromechanical equipment. As such, private funding was used in project leader Turboinstitute case. For Turboinstitute, the Cavismonitor project enabled an overview of activities of other research groups and companies, within the consortium and wider through participation in conferences. Among this, the most important was relation among cavitation structures and cavitation erosion, which was within the Cavismonitor project researched by Darmstadt University of Technology, Germany.

The EU funding was essential for the project as it provided salaries and funding for material for research activities. EU funding also enabled cooperation among research groups within the project consortium and wider in EU. The Cavismonitor project offered also wider publicity and coverage for the already mentioned cavitation monitoring system, although it's impact was limited.

Full project participant list

Organisation	Country	Type
Turboinstitute, now Kolektor Turboinštitut d.o.o.	Slovenia	Private Company/ R&D
Darmstadt University of Technology	Germany	Academic Institute
Institut of Hydropower Machines and Pumps	Austria	Research Institute
Soške elektrarne Nova Gorica - SENG d.o.o.	Slovenia	Private Company

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Annex 8B - Literature

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Annex 8C - Methodological note on imports and exports

The value of the following components were assessed for hydropower:

Table C.1 HS6 product codes relevant to hydropower sector

HS6 code	Brief product description
382450	Non-refractory mortars and concretes
681091	Prefabricated structural components
841011	Hydraulic turbines of a power not exceeding 1 000 kW
841012	Hydraulic turbines of a power exceeding 1 000 kW but less than or equal to 10 000 kW
841013	Hydraulic turbines of a power exceeding 10 000 kW
841090	Hydraulic turbines: parts, including regulators
850161	AC generators (alternators): of an output not exceeding 75 kVA (kilovolt ampere)
850162	AC generators (alternators): of an output exceeding 75 kVA but less than or equal to 375 kVA
850163	AC generators (alternators): of an output exceeding 375 kVA but less than or equal to 750 kVA
850164	AC generators (alternators): of an output exceeding 750 kVA
850421	Liquid dielectric transformers: having a power handling capacity not exceeding 650 kVA
850422	Liquid dielectric transformers: having a power handling capacity of between 650 kVA and 10 000 kVA
850423	Liquid dielectric transformers: having a power handling capacity exceeding 10 000 kVA
850431	Electric transformers, having a power handling capacity less than 1 kVA
850432	Electric transformers, having a power handling capacity of between 1 kVA and 16 kVA
850433	Electric transformers, having a power handling capacity of between 16 kVA and 500 kVA
850434	Electric transformers, having a power handling capacity exceeding 500 kVA

Source: Comext database and Jha (2009)

Annex 8D - List of EU-funded projects

Research projects focused on hydropower technologies only

Acronym	Rcn	Title	EU funding (EUR)	Programme	Topic
DIRECT DRIVE MINI BU	72319	Turbine bulbe mini-hydro a entrainement direct (DIRECT DRIVE MINI BULB-TYPE HYDRAULIC UNIT)	30 184	FP5-EESD	1.1.4.-5.
SEARCH LHT	89218	Development of small efficient axial reliable compact hydro low head turbine	712 368	FP5-EESD	-
VASOCOMPACT	86839	Development of a commercial concept for variable speed operation of unregulated submersible compact turbines	801 779	FP5-EESD	-
TNSHP	86943	Thematic Network On Small Hydropower	1 008 932	FP5-EESD	-
CAVISMONITOR	87002	Cavitation monitoring in hydraulic machines with aid of a computer aided visualization method	239 621	FP5-EESD	-
HYDROMAX	57649	Self-Optimising Modular Control Software for Small Hydropower Plants	130 349	FP5-EESD	1.1.4.-6.5.4
SCADAONWEB	57847	Web based supervisory control and data acquisition	1 443 897	FP5-IST	2000-4.3.2
SNOWPOWER	87177	Innovative in-situ snow parameter sensing system allowing accurate remotely sensed data calibration for improved forecasting of hydropower resources	546 277	FP5-EESD	-
HYDROGENIE	80115	Development and field testing of a compact HTS hydropower generator with reduced investment costs, lowered environmental impacts and strongly improved performance to reduce the price per KWh	2 192 352	-	SUSTDEV-1.2.3
WATERWINGPOWER	75032	Enabling renewable energy SMEs to develop submersible and cost-effective vertical axis turbines for energy exploitation in ultra low-head streams.	899 861	-	SME-1
SHYCA	75765	Promotion of small hydropower retrofitting and implementation in the Caucasus x and Carpathian region	193 598	-	INCO-D
SHAPES	86359	Small hydro action for the promotion of efficient solutions	867 679	-	SUSTDEV-1; SUSTDEV-1.1.8
HYLOW	86246	Hydropower converters with very low head differences	4 054 883	FP7	ENERGY-2007-2.7-01
HYPERBOLE	109879	HYdropower plants PERformance and flexiBle Operation towards Lean integration of new renewable Energies	4 359 461	FP7	ENERGY.2013.2.7.1
IFLOW	92816	Intake Flow Simulation and Optimisation for Hydropower	186 461	FP7-PEOPLE	FP7-PEOPLE-IEF-2008
PREDHYMA	109509	Prediction of Erosion Damages in Hydraulic MAchines	1 076 945	FP7-PEOPLE	FP7-PEOPLE-2013-ITN
HYDROACTION	87773	Development and laboratory testing of improved action and Matrix hydro turbines designed by advanced analysis and optimisation tools	2 408 226	FP7	ENERGY-2007-2.7-01; ENERGY-2007-2.6-01

HydroKinetic-25	201764	Commercialisation of a viable and proven HydroKinetic Turbine that will harness the power of the world's rivers, canals and estuaries in a sustainable, innovative and cost-effective way.	50 000	H2020	SIE-01-2015-1
RIVER-POWER	211165	Water flow kinetics energy exploitation for mini/micro hydropower plants.	49 157	H2020	SMEInst-09-2016-2017
DP Renewables	211106	A range of economically viable, innovative and proven HydroKinetic turbines that will enable users to exploit the huge potential of clean, predictable energy in the world's rivers, canals and estuarie	1 902 023	H2020	SMEInst-09-2016-2017
Hydrolowhead	200005	PROFITABLE LOW HEAD HYROPOWER	1 061 672	H2020	SIE-01-2015

Research projects focused on hydro-power technologies in combination with other RES technologies

Acronym	Rcn	Title	EU funding (EUR)	Programme	Topic
HYBRILA	89225	Hybrid renewable energy project supplying electricity to an Irish local authority	2 585 766	FP5-EESD	-
100%RES-EL HIERRO	70479	Implementation Of 100% Res Project For El Hierro Island Canary Island- (main Action: Wind-hydropower Station). First Phase	2 522 330	FP5-EESD	1.1.4.-5.3.1
AQUAGEN	97520	Development of cost-effective, water based power take-off system for marine energy applications	1 823 916	FP7	SME-1

Source: CORDIS (2018)
Notes: Some projects have missing data in CORDIS. The title of the projects and the other available data was included in the database of the study for completeness.

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KI-02-18-145-EN-N

This study assesses the impact that the EU Research & Innovation Framework Programmes funding has had on renewable energy technologies over the past twenty years (1995-2015). Eight renewable energy sectors are assessed: bioenergy, biofuels, geothermal, hydropower, ocean, solar PV, solar thermal and wind. The results show that the EU and its Member States play a leading role in R&D for most of the renewable energy technologies and that EU funding has contributed to acquire a leading academic position for all renewable energy technologies. Several technologies have already reached high levels of maturity, and renewable energy related jobs grew to 1 180 000 in 2016. EU industry turnover has constantly reached EUR 100 000 million over the past nine years. The development of innovative renewable technologies has also contributed to a growing share of renewable energy consumption in the power, heating & cooling (H&C) and transport market sectors.

Studies and reports

Publications Office