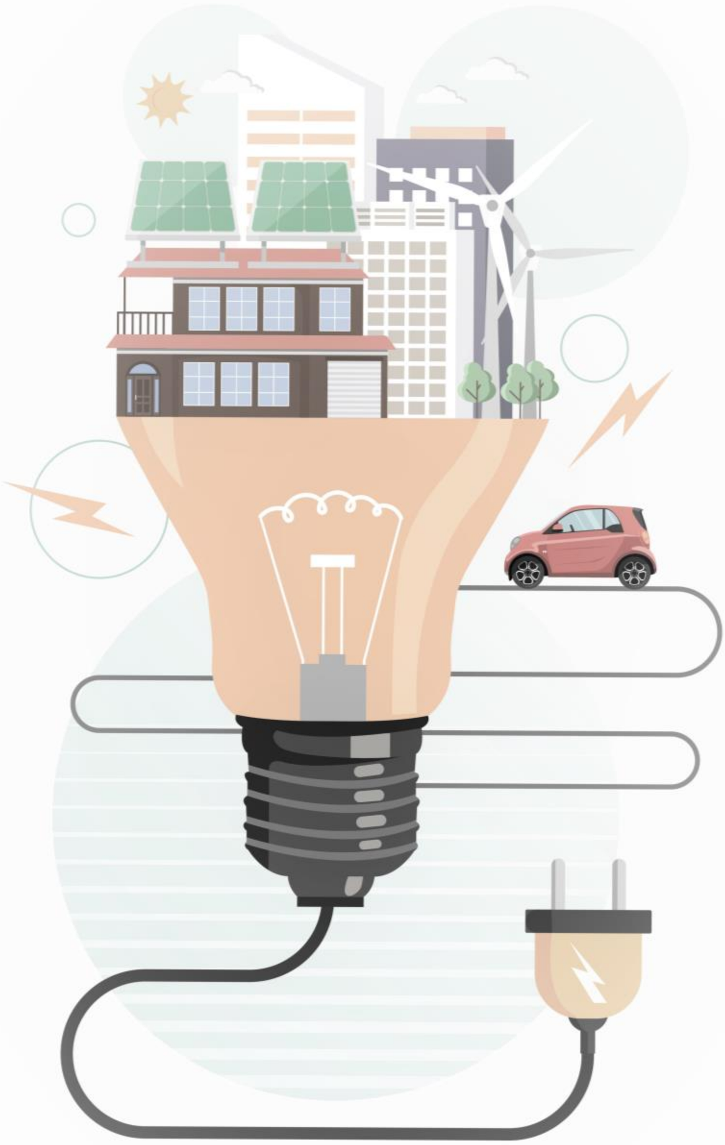
ASSET Study on

# Job creation related to Renewables



**AUTHORS**

Panagiotis Fragkos (E3 Modelling)

Leonidas Paroussos (E3 Modelling)

Pantelis Capros (E3 Modelling)

Sil Boeve (Ecofys)

Thobias Sach (Ecofys)

**EUROPEAN COMMISSION**

Directorate-General for Energy
Directorate for Renewables, Research and Innovation, Energy Efficiency
Unit C2: Innovation, clean technologies and competitiveness

*Contact:* Feilim O'Connor

*E-mail:* ENER-C2-SECRETARIAT@*ec.europa.eu*

*European Commission*
*B-1049 Brussels*

## Legal Notice



Luxembourg: Publications Office of the European Union, 2020



PDF ISBN 978-92-76-24726-5 doi: 10.2833/987987 MJ-01-20-649-EN-N

## About ASSET

ASSET (Advanced System Studies for Energy Transition) is an EU funded project, which aims at providing studies in support to EU policymaking, including for research and innovation. Topics of the studies will include aspects such as consumers, demand-response, smart meters, smart grids, storage, etc., not only in terms of technologies but also in terms of regulations, market design and business models. Connections with other networks such as gas (e.g. security of supply) and heat (e.g. district heating, heating and cooling) as well as synergies between these networks are among the topics to study. The rest of the effort will deal with heating and cooling, energy efficiency in houses, buildings and cities and associated smart energy systems, as well as use of biomass for energy applications, etc. Foresight of the EU energy system at horizons 2030, 2050 can also be of interests.

The ASSET project will run for 36 months (2017-2019) and is implemented by a Consortium led by Tractebel with Ecofys and E3-Modelling as partners.

## Disclaimer

The study is carried out for the European Commission and expresses the opinion of the organisation having undertaken them. To this end, it does not reflect the views of the European Commission, TSOs, project promoters and other stakeholders involved. The European Commission does not guarantee the accuracy of the information given in the study, nor does it accept responsibility for any use made thereof.

## Authors

This study has been developed as part of the ASSET project by a consortium of E3 Modelling and Ecofys.

**Lead author:** Panagiotis Fragkos (E3 Modelling)

**Authoring team:** Leonidas Paroussos (E3 Modelling), Pantelis Capros (E3 Modelling), Sil Boeve (Ecofys), Thobias Sach (Ecofys)

# Executive summary

## Jobs in RES and conventional energy forms are assessed in the entire chain of activities including equipment manufacturing, installation, O&M and fuel supply

Renewable energy technologies have been widely deployed in most of EU countries and have proven their potential to replace fossil fuels in several sectors, while contributing to reducing EU GHG emissions and improving energy security. The transition towards a low-carbon economy would lead to jobs being created in the manufacturing, installation and Operation & Maintenance (O&M) of renewable energy. In parallel some employment in other sectors would be substituted, or eliminated without replacement (e.g. jobs in coal mines and fossil fuel-fired power plants), and many existing jobs would be transformed and redefined (including electricians and construction workers) in terms of skills sets and work methods (OECD, 2012). **A bottom-up approach is used to estimate labour intensities in the entire chain of activities related to RES and fossil fuels, including equipment manufacturing, construction and O&M of power plants.** For fuel-based technologies, fuel supply jobs are also estimated, including jobs in fuel extraction or mining, fuel transformation (refining, bioenergy conversion and coke ovens), transport and distribution/sales of fuels.

Employment impacts of RET deployment has drawn attention of policy makers and researchers driven by expectations about employment gains from RES expansion (EC, 2012). The following classification of employment impacts is usually proposed in the literature:

- **Direct impacts**. Direct jobs are directly derived from RES manufacturing, equipment supply, onsite installation, O&M and all activities related to fuel supply.
- **Indirect impacts** refer to the supply chain effects of RES-related activities. Indirect jobs are associated with the manufacturing of equipment, components and materials used to build RES installations and with the services and materials used to operate and maintain RET.
- **Induced impacts**. Induced jobs are those created due to the overall economic impact of RES expansion. Their estimation requires the use of a macroeconomic model, which simulates both income and price-induced changes in the economic structure induced by RES deployment.

This study provides employment estimations using a net impact approach as it includes both positive and negative job effects from renewable energy. Solar PV and wind power use energy inputs that are freely available. These technologies typically involve jobs in the processing of raw materials, the manufacture of technology, project design and management, plant construction, O&M, and eventual decommissioning (IRENA, 2011). Depending on the technology, the range of occupations across different value chain parts varies, including engineers, scientists, power system designers, energy consultants and regulators, business managers and financial analysts, while construction workers, technical personnel and electricians are mainly used for installation purposes.

**The activities of construction, system integration and O&M of power plants create (to a large extent) activity and jobs domestically**. The manufacturing of technologies is a global market and jobs are located in countries that have developed industrial activities to produce the required equipment. The EU is a net fossil fuel importer and thus a large part of jobs in coal, oil and gas supply are not created in the EU but in fuel exporting countries. This study considers the different nature of jobs related to each RES activity; **jobs in the manufacturing and installation of power**

**generation technologies are linked to a specific year (transient), while jobs in the O&M of technologies last during the entire lifetime of power plants** and can be considered as full-time permanent employment.

## RES technologies involve complex supply chains and have several links with other industries

The manufacturing of RES technologies has rapidly expanded in recent years and exemplifies the dynamic and globalised state of industrial production including complex supply chains and markets. The RET supply chains include several links with other industries and each of them creates economic value. **Different stages of RES development include innovation (leading to technical progress), manufacturing of technology and its sub-components, construction of RES installation (e.g. wind farms), integration in the power supply system (e.g. grid development, cables) and O&M of RES plants.**

The manufacturing of RET establishes links between technology innovation and commercial market deployment. Business strategies about the location of clean energy manufacturing are guided (among others) by the: policy framework, the cost of labour, capital and energy, existing supply chains and infrastructure, availability of financial resources, automation of manufacturing processes, existence of synergistic industries and market characteristics (e.g. location, competing products and growth prospects). The vertical integration of domestic RES supply chain industries (mainly the suppliers of the required high-tech components) is a crucial ingredient to identify whether the RES expansion would be beneficial for employment in the EU.

**RET are characterized by a dominance of investment costs (CAPEX) in relation to operational costs (OPEX), as they have no fuel costs** (with the exception of biomass). Thus, they differ widely from fossil-fuel fired power plants in which OPEX costs account for a large share of their overall costs.

**Silicon-based PV modules are manufactured modularly via the discrete steps of polysilicon, wafer, cell, and module manufacturing, all of which rely on relatively standard product sizes and processes**. Modules are a commodity product, and the industry and supply chains are global. Due to the relatively limited product differentiation in PV modules, the basis for competition between PV producers is the price. The PV module cost typically accounts for 40-45% of the total PV system cost, depending on the size of the project and the type of PV module (Chung et al, 2016), while Balance of Systems (BOS) costs, including inverter and racking, account for about 25%, labour costs for installation of PV for 11% and services represent 22% of total PV costs (financial, sales, other professional and scientific services).

The supply chain of wind turbine industry includes the production of processed materials (steel, carbon fiber), the manufacturing of sub-components (generator, steel components, magnets) and end products (blades, tower, nacelle). The wind industry continues to evolve and has refined and improved materials, processes and design as well as installation and O&M regimes, while significant effort has been devoted to reduce the high transportation costs. **The cost of wind turbines constitutes about 60-65% of the total installation cost of a wind power project** (CEMAC, 2016). Manufacturing of blades accounts for 22% of total cost, while the tower 21% of the total cost. The nacelle accounts for about 20% of the total cost due to the complex equipment for the drivetrain/gearbox, control panels, generator, power converter and yaw assembly. Construction of wind farms is a labour-intensive activity representing 16% of total costs, while the share of grid connection cost is 9%. Services are also required for development of wind projects, while the cost of land and roads represents about 3% of the total installation costs.

**Biomass can be used for a variety of energy-related purposes**, including for transport (biofuels), for heating in households, and for the generation of heat and power. There are many pathways to convert biomass feedstocks into useful renewable energy. A broad range of waste, residues and crops grown for energy purposes can be used directly as fuels for heating and cooling or for power production, or can be converted into biofuels for transport. Many bioenergy technologies and conversion processes are now well-established and fully commercial, while conversion processes related to advanced biofuels production are maturing rapidly. The comparison of value added and jobs data from (Eurobserver, 2016) illustrates the lower labour productivity of biomass production relative to other RES sectors.

## The EU has a leading role in global RES manufacturing

Several of the most innovative and largest in terms of global sales companies in RET manufacturing are located in Europe. This is reflected in positive trade balances, especially in the wind manufacturing sector, where Danish, German and Spanish based companies are amongst the most competitive companies worldwide (Navigant, 2016).

Wind turbines

**The EU is a global leader in wind turbine manufacturing with a share of 44% in global production of wind turbines**. European companies like Vestas are pioneers in wind power technology. The EU is a major turbine exporter, as it accounted for 90% of global exports in 2015. The EU companies remain successful in securing a dominant position in the market until today despite increasing competition from China and the USA, which exhibit high demand for wind turbines. European companies were first movers in offshore wind technology and dominate the market until today with Siemens producing about 63% of the global market (Navigant, 2016).

The inner-European supply chain in combination with significant demand within the EU strengthens the EU's dominant position. In parallel, the EU wind industry constantly invests in innovation, thereby improving its products along the whole value chain to reduce costs faster than the market average and staying competitive (Vestas, 2016), relative to alternative power generation technologies and among wind manufacturing industries. Overall, the European wind power industry is competitive in global markets largely driven by the high expertise and quality levels developed over the past decades.

### Solar PV modules

Currently, **the world market for solar modules is dominated by China and Taiwan** (accounting for 67% of the global PV production), while the share of European manufacturers has decreased dramatically from 26% in 2008 to a mere 5% in 2015 due to intense competition from low- cost modules produced in China and in other Asian countries. Germany accounts for the bulk of EU production, while small-scale PV panel production capacities are located in other countries, mainly in Poland, Italy and France. There is, however, an emerging trend with new business models based on combinations of solar PV with stationary batteries, with EU-based companies like Sonnen, Senec and E3/DC being strong players.

### Lithium-ion batteries and electric cars

Plug-in hybrid and electric vehicles registrations have followed an explosive path in recent years and in 2015 the threshold of 1 million electric cars in the global car stock was exceeded. Ambitious targets, policy support and increased R&D investment have lowered battery and electric vehicle costs, extended vehicle ranges and reduced consumer barriers in a number of countries, mainly in Norway, the EU and the US.

**European electric car manufacturers are competitive in supplying electric vehicles as they currently account for about 30% of global production.** The EU has the potential to remain a particularly important player in the global electric car market (both in manufacturing and in sales); this highly depends on the strengthening of emission standards and the establishment of ambitious policies to support the EU's technology leadership in a highly competitive market. Given its ongoing investments in further production capacity and the rapidly expanding domestic demand, China is also expected to become one of the largest electric car markets (Transport and Environment, 2016).

**The lithium ion battery is the key component that will determine the development and eventual uptake of electric cars, as battery costs, availability and technical performance are key aspects for growth in e-mobility.** The global battery production is dominated by companies in Japan, S. Korea and China. The limited EU production of lithium-ion batteries implies a continuing dependence on imported batteries that limits the creation of domestic employment that Europe can get from the deployment of electric cars. However, this concern seems to decline with a number of striking announcements for new battery plants in Europe from companies including Volkswagen, Samsung, Ford, BMW and Tesla.

### Production of bioethanol and biodiesel

Driven by the EU renewable energy targets, concerns about energy security and high prices for refined oil products, the contribution of biomass and biofuels to the EU energy supply has grown. The EU is the world's largest biodiesel producer representing 49% of global production, followed by USA (20%) and Brazil (11%); on the other hand, the EU share in global bioethanol production is low (about 5%). The EU is a net importer of biofuels importing 10% of its demand; in an attempt to reduce biofuel imports, the EC enforced anti-dumping duties on biodiesel imports from 2013 leading to a considerable decline in imports in recent years.

## There are risks and opportunities for EU RES industries

Renewable energy markets are projected to increase strongly both in Europe and worldwide driven by ambitious climate policies, cost reductions and rising fossil fuel prices. This provides great opportunities for innovative European RET companies to further flourish. At the same time, increasing competition from other countries with significantly lower labour costs, high investment in R&D and steep learning curves poses high risks for the established European RET industries.

### Wind Onshore and Offshore

Currently, European companies have managed to keep up to rising contestants and stay competitive at the global level. However, this study illustrates that various factors can put the EU's leadership at risk, including: 1) contraction of domestic demand induced by gradual removal of support schemes and feed-in-tariffs, 2) losing market shares to low-labour cost competitors, 3) emergence of oil companies with long expertise in offshore applications and 4) grid-related integration challenges (e.g. curtailment). Although the threat posed by newcomers is not particularly high due to the high market entry barriers - the wind sector is capital intensive and requires very specific know-how - there is a trend of companies from the "old/conventional energy world" moving into the wind offshore sector, including Shell and Statoil (REN21, 2017).

Related to the increasing competition is an ongoing consolidation in the wind sector, as several companies expand their scale through merger and acquisition (M&A) activities. M&A constitute a great opportunity for European companies, which in combination with their excellent know-how and innovation potential can be of great importance to enable the penetration in rapidly growing emerging economies. An example is EDF entering the Chinese market by acquiring UPC Asia Wind Management. Besides opportunities to enter new markets, EU companies are in a top position to supply the domestic European market based on high innovation dynamics and on the development of integrated domestic supply chains.

### Solar PV modules

Over the years, the Asian solar industry has gone from infancy to domination of the global market. In 2016 Asian manufacturers accounted for about 90% of global solar panel production. Most global PV manufacturing is located in China with overseas PV module plants in South-Eastern Asia (Malaysia and Thailand). The EU solar PV production has rapidly declined in recent years, as a result of the competition from low-cost modules imported from Asia, the lack of financial resources and the contraction in EU's domestic PV installation market. The transition of RES support schemes from feed-in tariffs to a more competitive auctioning system combined with stagnation of EU electricity demand and grid congestion problems can pose additional risks in the EU solar PV industry.

Besides the risk of a continuation of this downward trend, there are also several opportunities to re-launch domestic EU solar PV manufacturing. Mergers, acquisitions and new partnerships can help companies to capture increased value in project development or to enter new markets. Crowdfunding can be an important means for financing projects as well as technology innovations. The latter can closely be linked to exploiting new business models based on solar PV panels combined with stationary batteries, where EU companies are already strong players in this emerging market.

### Innovation in EU RES industries

Ongoing innovation will be key for EU companies to remain competitive in the global RES markets, reduce costs and prices and improve yields. Significant Research and Innovation (R&I) efforts both from the private and public sector indicate that European companies are in a good position to maintain their leading position in RES markets. The European Union is currently one of the global leaders and largest public funders of clean energy research and innovation. However, China is already the largest R&D investor in solar energy (Chung et al, 2016) and it is also catching up quickly in wind power. It is expected that this focus on R&D and increasing international competition is a trend likely to continue in the future (Dai et al, 2014).

In order to maintain its leading position in clean energy innovation, the EU may need to adjust its R&D and innovation focus. With manufacturing industries gradually moving away, the focus should be less on serving the entire value chain (including manufacturing) and more towards "creating new ideas and concepts". This will result both in more fundamental research (i.e. novel and breakthrough technologies) as well as the development of new energy system concepts and integrated systems (i.e. smart houses, combinations of RES with storage systems, smart grids etc.). With the right innovation-enabling policy framework and strong related signals to investors, the EU may become the world leader in renewables and possibly also deliver strongly on jobs, growth and competitiveness (i24c, 2016).

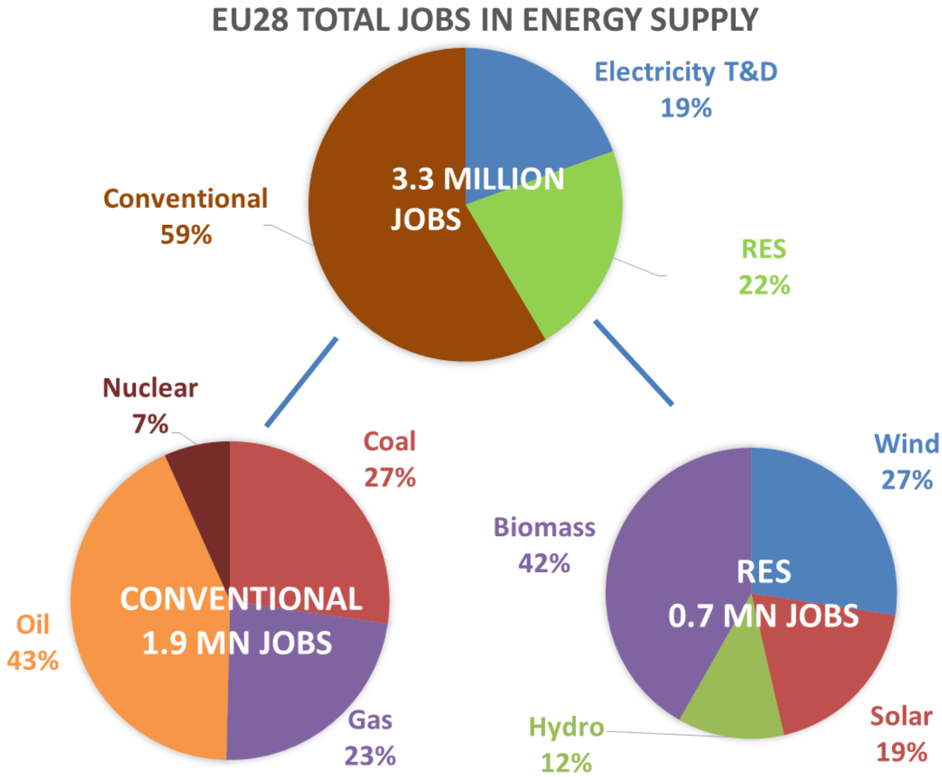
## Currently, direct EU energy supply jobs are estimated at 3.3 million, with about 700 000 in RES sectors

Direct and indirect jobs in renewable energy are estimated to exceed 9.8 million globally in 2016, while the European renewable energy sector employed 1.14 million people including direct and indirect jobs. The largest employers in the EU renewables sector are wind industries, solid biomass, biofuels and solar PV that jointly accounted for about 80% of direct and indirect RES jobs in 2015 (EurObserv'ER, 2016).

**The total number of direct jobs in the EU energy supply and transport sectors in 2015 is estimated at 3.3 million jobs, representing a share of about 1.5% of the European workforce**. The electricity sector is the largest employer supporting about 1.2 million jobs, with transmission, distribution and trade (T&D) accounting for 19% of direct energy supply jobs and power generation representing a share of 16%. The sector "sales of fuels" is included in the analysis with 630k jobs in the EU representing about 20% of direct energy supply jobs, with the majority employed in the retail sale of automotive fuels (480k jobs in 2015). Mining of coal and lignite has high labour intensity and this constitutes an important social and economic challenge as ambitious climate policies would lead to job elimination in these sectors, especially in countries with developed coal mining sectors. Increasing automatization and mechanization implies relatively low labour intensities for extraction of crude oil and gas and for refinery processes.

**EU RES direct jobs are estimated at about 720k in 2015 with bioenergy accounting for 42% of them** due to the relatively high labour intensity both in feedstock supply and in conversion processes. Direct wind jobs are estimated at about 200k (including turbine manufacturing), while solar PV, hydro-power and biofuels are also important job creators. Employment in conventional energy supply sectors is 1.9 million jobs in 2015, with petroleum products accounting for about 830k jobs, generated mostly in retail fuel sales (gas stations) and in refineries. Coal represents a significant share (27%) in conventional energy supply jobs, while coal-related jobs are mostly created in coal mining and in O&M of coal power plants. Gas-related jobs are estimated at about 450k and are relatively equally distributed in extraction of natural gas, distribution and manufacture of gaseous fuels and in O&M of gas-fired thermal power plants.

The analysis is based on a comprehensive data reconciliation process combining fully-fledged data sets (official Eurostat data derived from LFS and SBS databases) with information obtained from literature review to build up estimations for current employment levels in all energy supply and transport sectors in each EU country. A disaggregated breakdown of jobs by sector at four digits of disaggregation (NACE Rev.2) is estimated, while maintaining full consistency with Eurostat published figures.



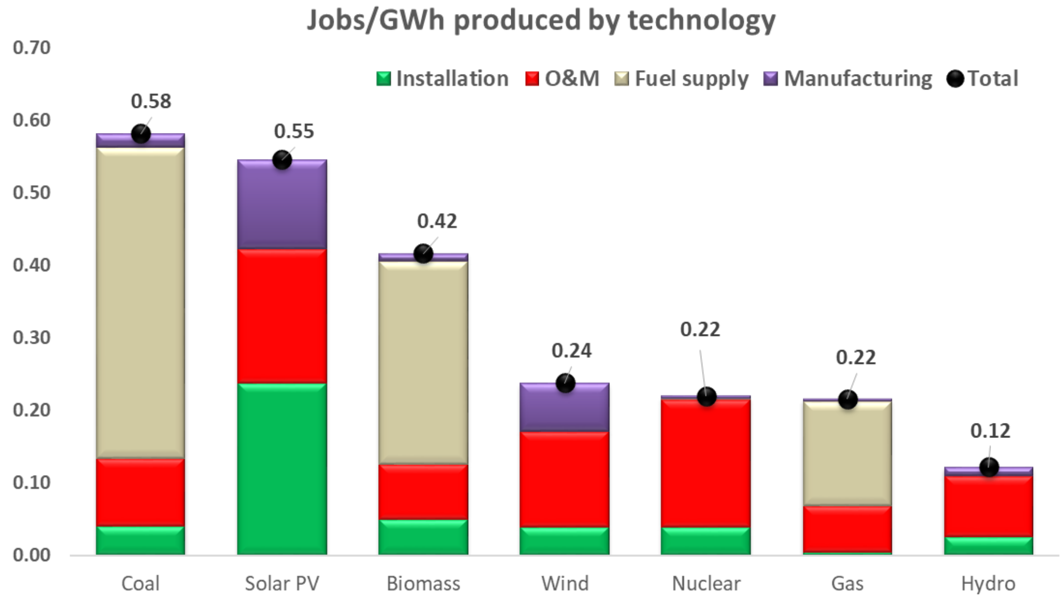

**Breakdown of EU direct energy supply jobs by energy form in 2015, Source: E3-Modelling calculations based on EUROSTAT LFS, SBS and other statistics**

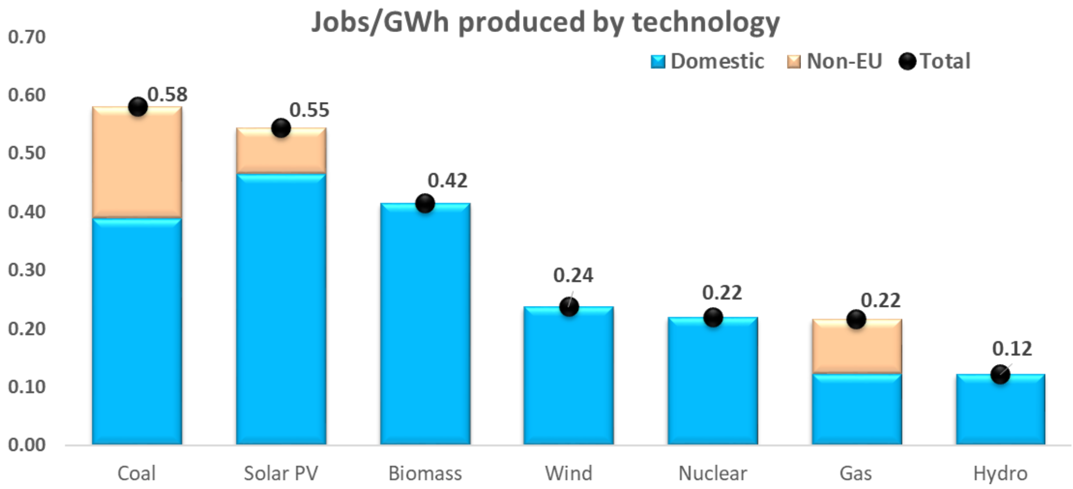
## RES technologies are more labour intensive than conventional fossil fuels in power generation

The analysis shows that taking into account jobs in the entire chain of related activities (equipment manufacturing, installation, O&M and fuel supply), renewable energy technologies are (on average) more labour intensive and have a higher EU domestic content relative to fossil fuels both in power generation and in road transport. In particular, **solar PV, biomass and coal-fired power plants are the most labour intensive types of power generation technologies measured as jobs per GWh of annual electricity production**. The different nature of jobs is taken into account, as jobs in O&M of power plants are permanent (during the lifetime of plants), while jobs in construction are short term since they are created when the investment takes place. In order to compare employment related to different activities, jobs in construction and manufacturing are averaged over the entire lifetime of power plants; thus, we calculate permanent Full Time Equivalent (FTE) jobs for each energy-related activity.

Solar PV systems have a high labour intensity because of their small unit size, the customised nature of installation work and the low capacity factors implying high capacity requirements to produce the same amount of electricity as conventional fossil-fuel technologies. **Solar PV and wind jobs are mainly generated in the construction stage and are inherently local; on the other hand, fuel-based technologies are more labour-intensive in the fuel supply activity**. The labour intensity of wind power, nuclear and gas plants is comparable, as these plants generate about 0.22-0.24 jobs per annual GWh, while large hydro plants generate only 0.12 jobs per annual GWh; this is mainly due to the long lifetime assumed (commonly 60 years). Gas-fired power plants are less labour-intensive than coal as construction periods are commonly shorter, gas extraction is less labour-intensive than coal and O&M are more streamlined.

**RES have a higher domestic job content relative to fossil fuels, as jobs in gas and coal supply are largely generated in non-EU countries**, as the EU imported about 69% of its gas requirements and about 45% of its coal demand in 2015. The EU produces domestically most of technological equipment it requires, except for solar PV modules that are largely imported to the EU from Asian countries.




**Labour intensities (in jobs/annual GWh of produced electricity) and domestic content of activities related to power generation technologies in 2015, Source: E3-Modelling calculations**

**Biofuels and electricity used in transport create more jobs per unit of energy relative to petroleum products in the road transport sector, while their domestic content is also higher**, as crude oil is largely imported in the EU. The estimation considers all activities including fuel production, processing, transport and, sales and distribution. The lower labour intensity of oil products is mainly a result of increased mechanization and streamlining of related processes. Activities related to oil refining, biomass feedstock & conversion, electricity production & T&D and fuel distribution are mostly generated domestically in the EU.

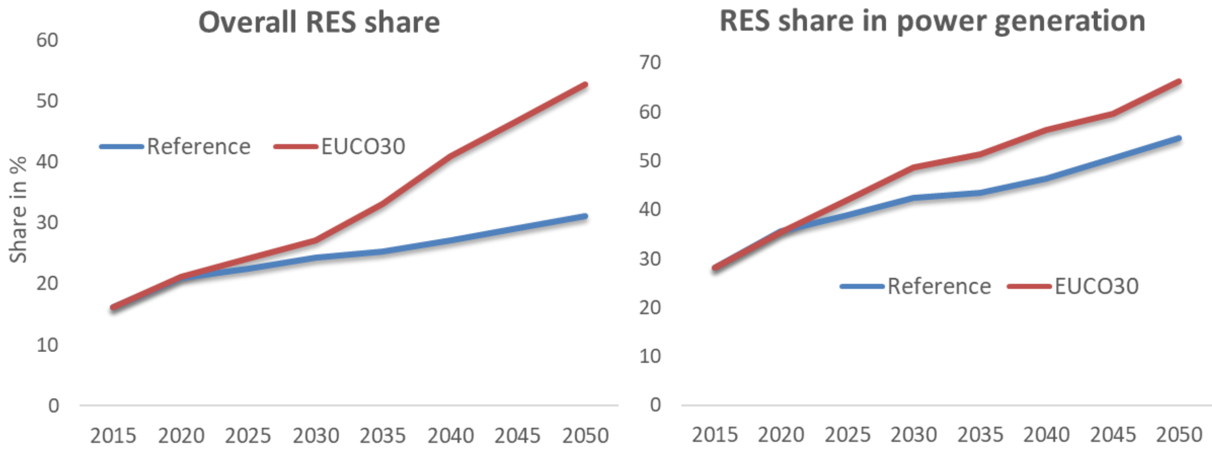
## High RES expansion is a key pillar for the EU's low carbon transition as described in the recent EU Clean Energy Package

Future employment implications from RES expansion are assessed in the context of the recent EC "Clean energy for all Europeans" – Winter Package – that puts the EU commitments to the COP21 Paris Agreement into legislation. The EUCO scenarios are used in the study because they reflect the most recent proposals of the EC and they include comprehensive projections for RES expansion in all energy system sectors, namely electricity, heating and cooling, and transport. EUCO scenarios are designed to achieve the 2030 targets as agreed by the European Council (EC, 2014) and are compatible with the long-term global 2°C temperature target. In particular, the EUCO30 scenario achieves the 40% GHG emission reduction target in 2030 (and the split of ETS/non-ETS reducing by 43%/30% in 2030 compared to 2005), a 27% share of renewables in gross final energy demand and the energy efficiency target of 30%.

**EUCO scenarios are designed by combining a set of overall systemic targets (GHG reduction, RES share) and concrete bottom-up policy measures**, including increased ETS linear reduction factor, efficiency standards, strengthening of $CO_2$ standards, more stringent eco-design, support for RES in heating and Best Available Techniques in industry. In the EUCO context, coordination policies are assumed to enable the low-carbon transition, including clean energy R&D, infrastructure development, behavioural changes of consumers, financial instruments and increased acceptance of RES (E3MLab, 2016).

Increasing ambition of energy and climate policies, security of supply concerns, rising fossil fuel prices and decreasing RET costs constitute the driving factors for the recent explosion of investment in renewable energy. The Renewable Energy Directive (European Commission, 2009 and 2016) also constitutes a key driver for RES expansion. In parallel, RES are relevant to all five dimensions of the Energy Union, as they can contribute to improved energy security, $CO_2$ reduction, innovation dynamics, reduction of energy intensity and integration in the competitive EU electricity market.

**High RES expansion is a key pillar towards the EU low-carbon transition as illustrated in the Clean Energy Package proposals, with RES share in gross final energy demand increasing from 16% in 2015 to 27% in 2030 and to 52% in 2050**. RES development is a key option towards deep $CO_2$ reduction in the power production sector, with solar PV and wind power accounting for 68% of total EU power generation investment in the period 2016-2050. Decarbonised electricity can then play a cross-sectoral role in the low-carbon transition, notably as a decarbonisation carrier in transport (electric vehicles) and in heating and cooling energy uses. The RES-E share is projected to increase to 66% in the EUCO policy scenario, driven by the massive deployment of solar PV and wind technologies, while renewables in heating & cooling also develop, albeit at a slower pace, driven by heat pumps and RES-based production of heat. The RES-T share includes biofuels and electricity used in transport; it increases rapidly after 2030, due to the penetration of electric vehicles and the deployment of advanced lignocellulose-based fungible biofuels in non-electrified transport segments (trucks, ships, aircraft) in the long term.




***EU RES shares in Reference and in EUCO30 scenarios, Source: E3-Modelling calculations***

## The EU's low-carbon transition leads to a large increase in RES jobs, while job losses are projected for fossil fuel sectors. The net impact is found to be positive in 2030 and 2050

Energy system transformation driven by high RES expansion would have large economic and employment implications for the EU induced by a significant reallocation of jobs and activity away from conventional fossil fuel sectors and towards RES. The analysis is based on the "employment factor" methodology for each activity related to energy technologies (equipment manufacturing, installation, O&M, fuel supply) in combination with detailed energy system projections, based on the Clean Energy Package scenarios (EC, 2016).

**The analysis shows a moderate increase in direct energy supply and transport jobs from 3.3 million in 2015 to 3.55 million in 2050 in Reference and to about 3.8 million jobs in the EUCO context**; the share of energy jobs in total EU workforce is projected to increase from 1.5% in 2015 to 1.9% in 2050 due to the declining EU labour force (EC Ageing Report, 2015). Employment in fossil fuel supply sectors would decline substantially from 1.9 million jobs in 2015 to 900k in 2050, while **direct RES-related jobs are projected to increase to about 1.9 million jobs in 2050, representing about 0.9% of the EU labour force**.

**The net employment effect of RES expansion is found to be positive, leading to 260 000 additional jobs compared to reference levels in 2050, with electricity and biofuels having the largest job creation potential.** The growth in electricity-related jobs is driven by: 1) increasing power requirements, 2) electrification of the energy mix (including deployment of electric cars) and 3) expansion of RES technologies that have higher labour intensity and domestic content than fossil fuels. In parallel, lower capacity factors of intermittent RES (solar PV and wind) imply increased capacity requirements and jobs relative to fossil fuels to produce the same amount of electricity. Overall, employment in the electricity sector is projected to increase from 1.4 million in 2015 to 2.3 million in 2050 with additional jobs created both in installation and O&M of RES and in T&D of electricity, induced by increased power capacities and increased grid requirements of intermittent RES. The structure of electricity jobs is projected to change drastically with the share of fossil fuels declining from 50% in 2015 to 14% in 2050, while solar PV and wind will jointly account for about 56% of electricity jobs in 2050; the share of nuclear jobs is projected to remain relatively constant to 2050.

**Job losses are projected to occur in conventional energy supply sectors and especially in coal mining, in refineries and in retail sales of petroleum products**

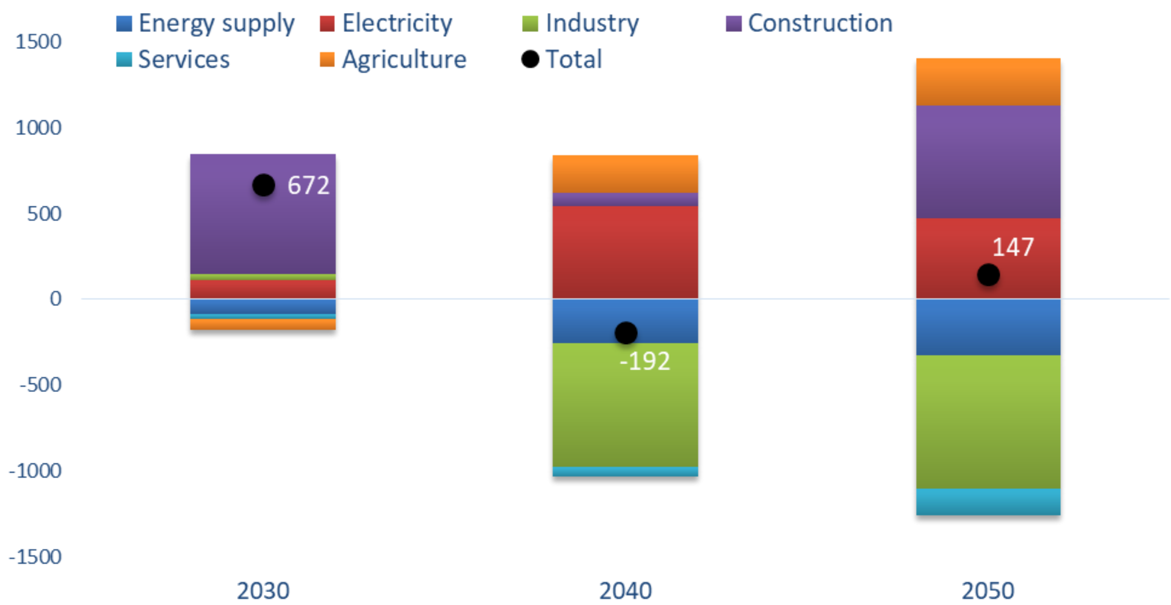
**in gas stations**. Employment related to extraction and manufacturing of fossil fuels is projected to decrease following historic trends and resource depletion. The EUCO scenario accelerates job losses in primary energy supply sector after 2030 leading to a reduction of 825 000 jobs from 2015 levels. Most job losses are projected to occur in coal mining as coal demand would strongly decline in the low-carbon context, while transport electrification would lead to a decline in the consumption of oil products and hence to significant job losses both in retail fuel sales (gas stations) and in the refining sector. On the other hand, in the EUCO policy context, conversion technologies related to advanced biofuels (Fischer-Tropsch process, fast pyrolysis) mature and are massively deployed after 2030 to decarbonise transport modes that cannot be electrified. **Advanced lignocellulose-based biofuels create domestic jobs both in biomass feedstock supply (that is produced domestically in the EU), in transport and conversion processes and in final use** (they use the same distribution infrastructure as oil products).

## RES expansion implies a reallocation of 1.4% of the EU jobs in 2050, while net employment impacts are projected to be positive

The bottom-up analysis based on employment coefficients is coupled with a model-based analysis based on the GEM-E3 model in order to evaluate the overall job impacts from RES expansion in the entire economy. The model version used includes modelling of the financial sector, discrete representation of clean energy manufacturing sectors, endogenous learning mechanisms for RES technologies, updated employment data and detailed links with fully-fledged energy system projections of the EUCO policy scenarios.

GEM-E3 results show that the low-carbon transition would lead to a reallocation of about 1.4% of EU jobs in 2050. **The net employment impact is positive with largest job gains in 2050 projected in the electricity sector (+470k jobs from Reference), agriculture due to biofuels production (+277k from Reference) and in construction** driven by increased investment in solar PV and in refurbishment of buildings. On the other hand, jobs in fossil fuel supply sectors and in energy intensive industries are projected to decline from Reference levels due to the introduction of ambitious climate policies including ETS carbon pricing; employment implications for the services sectors are limited due to their low energy and carbon intensity.

GEM-E3 assumes that firms and households can borrow in capital markets to finance investment in RES and energy efficiency without facing increasing unit costs of funding. Agents are modelled to annually pay back interest and principal of their loans at specific interest rates for a given period of time based on a reasonable debt to income ratio (E3MLab, 2016). In the EUCO policy scenario of the EU Clean Energy Package, the firms and households finance their low-carbon investment by borrowing from the capital market and by spending less on other commodities and investment purposes. **This mitigates the "crowding-out" effect that characterises standard CGE models** (E3MLab, 2016). **Employment results of the EUCO scenario indicate the high importance of the financing mechanism**; in 2030 there are large positive job impacts triggered by increased investment in clean energy and limited crowding-out (with the **creation of 672 000 additional jobs**), while in 2040 when loans are paid back the net impact on jobs is negative. **In the long term, GEM-E3 shows that the positive effects from energy system restructuring counterbalance negative job impacts in conventional energy supply sectors leading to the creation of 150 000 additional jobs compared to reference levels**. The consolidation of the leading EU position in the manufacturing of wind turbines, electric cars and innovative clean energy solutions would result in even higher employment gains for EU renewable energy industries. Therefore, assumptions about the financing scheme, RES technology learning and the role of the EU in global clean energy manufacturing are particularly important for the estimation of overall employment impacts.




**Changes in EU employment by sector in EUCO policy scenario compared to Reference (in thousands of jobs), Source: GEM-E3 results**

## The mitigation of adverse-side effects of RES expansion on labour market is important for policy making

The energy system transformation towards renewable energy and electrified transport provides major economic and environmental benefits, among which are an increased security of energy supply and reduced air pollution. **Low-carbon transition and RES expansion can also lead to positive job impacts, especially in countries that have established sophisticated manufacturing industries, effective innovation systems and highly-qualified human capital.** However, there is no obvious one-to-one relationship between RES expansion and a net change in the number of energy supply jobs. The switch of investment from fossil fuels to low-carbon energy technologies may increase or decrease employment on a net basis, depending on the mix of technologies deployed, the labour intensity and the domestic content of alternative energy sources, the domestic energy supply (for fossil fuels and bioenergy), the export potential of technology equipment manufacturing, the time period and various modelling assumptions.

Several studies have shown a positive employment impact of climate change mitigation policies for countries that are importers of fossil fuels and exporters of clean energy technologies, such as Germany and Denmark (Ragwitz et al., 2009, OECD, 2017). **Our study confirms employment gains for the EU region that is a major net fossil fuel importer and an exporter of clean energy equipment (mainly wind turbines).** However, job impacts in countries with significant fossil fuel production or related industries are not obvious. In parallel, the analysis shows that RES sectors require a higher share of highly-qualified workers than in coal mining (40-50% in RES sectors compared to 15% in coal mining activities). It is acknowledged that a shift in the required education levels of the labour force can have large impacts on job creation causing potentially a mismatch between labour supply and demand; **a potential shortage of highly skilled labour can undermine the cost-efficient low-carbon transition and causes intensification of competition between companies for skilled labour.**

In this context, the mitigation of possible adverse side effects of RES expansion on labour market (mainly in low-qualified coal mining jobs) is particularly important for EU policy makers especially in large fossil fuel producers like Poland and Romania. **The pursuit of social, economic and employment benefits from the transition to clean energy is important to maintaining the positive momentum of energy and climate policymaking in the EU** and its Member States towards the cost-efficient implementation of the 2020 and 2030 climate targets. An efficient long-term policy and regulatory framework is required to allow a smooth and predictable transition towards renewable energy, while climate and RES support policies should be consistently integrated in the EU economic, labour, innovation, trade and financial policy landscape.

# Table of Contents

# Introduction

European energy and climate policies aim to address the issues of security of supply, environmental sustainability and climate change, while ensuring economic competitiveness, technological innovation and employment (EC, Winter Package 2016). Increasing the deployment of Renewable Energy Sources (RES) in the energy mix is a central element in the current EU Energy and Climate Policy Framework. Massive deployment of RES combined with acceleration of energy efficiency improvements constitute key ingredients for the transition towards a low-carbon economy. Renewable energy technologies have been widely deployed in most of EU Member States and have proven their potential to replace fossil fuels as the main source of energy, while contributing to reducing EU GHG emissions and thus mitigating climate change. High RES deployment implies benefits for security of energy supply by reducing dependency on fossil fuels that are (to a large extent) imported from non-EU countries. The impact of increased RES deployment on economic growth, competitiveness and jobs is less clear. The economic and financial crisis of the Euro-zone combined with increasing energy costs (before 2015) that impact the competitiveness of the EU industries have intensified the policy debate about the relations of energy policy with employment and economic growth (Egenhofer et al., 2013).

In 2015, the share of renewable energy sources in gross final consumption of energy reached 16.7% in the European Union (EUROSTAT, 2017) nearly double 2004 levels (8.5%), while about 29% of the EU's electricity is generated from RES and further growth in RES-based generation is anticipated. The cost competitiveness of RES vis-à-vis conventional fossil fuels has improved significantly driven mainly by reduced RES costs (through economies of scale and practical technological experience); thus Wind on-shore turbines and solar Photovoltaic (PV) panels have reached grid parity in several countries and are considered as cost-effective power supply options. According to the International Energy Agency (IEA, 2016), renewable energy accounted for more than half of the global investment in power capacity, while renewable energy surpassed coal as the main source of power capacity in 2015 and RES-based generation is projected to become the world's number one source of electricity by 2035 surpassing coal and natural gas (IEA, 2015).

The European renewable energy sector[1] employed 1.14 million people including direct and indirect jobs, while total EU employment amounted to about 221 million in 2015 (Eurostat LFS, 2017). The European RES sector created a turnover of about €153 billion in 2015 (EurObserv'ER, 2016), while about 9.8 million people are employed directly or indirectly by the RES sectors globally (IRENA, 2016). Europe is still the global leader in wind energy, while acceleration of clean energy innovation is among the main priorities of EU policies. Employment in EU RES sectors is expected to increase in the future in the context of achieving the 20% RES share by 2020 and the 27% RES share by 2030 included in the 2030 Energy and Climate Policy Framework (European Commission, 2014) and the recent Winter Package 2016.

According to UNEP (UNEP, 2008), job creation induced by transitioning to renewables represents a keystone of progress to a low-carbon economy. It is already clear that transition towards a low-carbon economy would lead to jobs being created in the manufacturing, installation and Operation & Maintenance –O&M- of renewable energy. In parallel some employment in other sectors would be substituted, or eliminated without replacement (e.g. jobs in coal mines and gas-fired power plants), and many existing jobs being redefined as greened skills, methods and profiles (OECD, 2012). Effective

[1] Renewable energy sector includes wind power, solar PV and solar thermal technologies, hydro power plants, all forms of bioenergy (solid biomass, bioethanol, biodiesel, biogas, waste) and RES installations in households (solar thermal, geothermal and heat pumps).

labour market policies can make an important contribution to the successful transition by facilitating the structural change towards low-carbon jobs. The "greening" of the labour market will create new opportunities for workers, but it will also imply additional risks that could erode political and social support for green growth and climate policies, especially in countries and sub-regions that rely heavily on coal mining.

The low-carbon transition constitutes an opportunity for the EU to avail against the challenge of increasing economic growth while reducing both unemployment and greenhouse gas (GHG) emissions through the transformation away from fossil fuels and towards RES. The in-depth analysis and clarification of the benefits and losses of the low-carbon transition and the quantification of impacts of low-carbon jobs and sustainable growth is essential for enabling informed and cost-efficient policy choices and monitoring climate policy effectiveness. A critical question worth exploring is whether RES technologies are more labour intensive than conventional energy forms in delivering the same amount of energy when considering jobs in all stages related to each technology. This analysis aims to quantify the potential gains and losses in the EU economy and employment from RES expansion and identify the channels through which RES jobs would be generated.

The objective of the study is to present a detailed qualitative and quantitative analysis of the employment and labour market impacts induced by ambitious deployment of RES. The energy system transition from fossil fuels to RES and its potential implications on job creation are assessed in-depth from a holistic perspective, taking into consideration economic, technology and commercial impacts in the entire activity chain of RES technologies. The study attempts to capture both positive and negative implications of the transition to renewables on job creation, competitiveness and sustainable growth in EU-28 and in each member state up to 2030 and 2050. Creation of new jobs in RES sectors (and in sectors supplying RES-related equipment) and displaced jobs in fossil fuel extraction and processing and in carbon intensive power generation are explicitly quantified. Using extended literature surveys, detailed up-to-date data and utilizing a comprehensive modelling framework (PRIMES[2] and GEM-E3 models[3]), we evaluate whether the transition to a low-carbon economy brings aggregate/net gain or loss on overall employment with a special focus on jobs created in the renewable energy sectors. In this context, a detailed assessment and comparison of the labour intensity of the RES economy relative to the "brown" economy (based on fossil fuels) is performed, considering differentiation between energy technologies and EU member states. The impacts of RES expansion on EU's economic activity, investment and competitiveness are quantified to 2030 and 2050.

The study is divided into seven main chapters. After the introduction, the second chapter describes the value chains of wind turbines, solar PV panels, lithium-ion batteries and biomass technologies as well as the detailed breakdown of RES costs by technology. The third chapter examines the role of EU in global RES manufacturing market and quantifies future scenarios for domestic RES manufacturing based on a critical assessment of risks and opportunities for RES activities. Chapter four includes a detailed appraisal for the current energy supply jobs by sector and country based on extensive data collection and reconciliation work; the main focus lies in the quantification of employment in each activity related to RES and the holistic analysis of labour intensities of the "green" and "brown" energy supply activities. Chapter five describes the methodological framework used and the scenarios assessed in the study, which are largely based on the recent EC Winter Package proposal, while the next section, chapter six, presents

[2] Model manual available at: http://www.e3mlab.ntua.gr/e3mlab/PRIMES%20Manual/The%20PRIMES%20MODEL%202016-7.pdf
[3] Model manual available at: http://www.e3mlab.ntua.gr/e3mlab/GEM%20-%20E3%20Manual/GEM-E3_manual_2015.pdf

the most important findings of the economic and employment projections and the key factors determining them. Concluding chapter seven illustrates key findings of the study and provides policy recommendations.

# The RES value chain and costs

## Context of the analysis

The study assesses RES jobs in the EU along the entire chain of activities associated with the manufacturing and deployment of renewables. In this context, the assessment of clean energy technology manufacturing supply chains can help to identify opportunities, target high value-added links along the supply chain, and inform market strategies. The manufacturing of clean energy technologies (including RES) has rapidly expanded in recent years and exemplifies the dynamic and globalised state of industrial production including complex supply chains and markets. For example, solar panels "Made in Germany" may contain processed materials from Africa, subcomponents from China and intellectual property from the U.S., which maintains the highest share of PV patents (Noailly et al, 2017). The key links of the manufacturing supply chain are:

- Technology innovation process, driven by public and private R&D expenditure;
- Raw materials, extracted or harvested directly from the earth, e.g. raw biomass and iron ore;
- Processed materials, which have been transformed or refined from a basic raw material, e.g. steel, glass and cement. Value added is created from processing of raw materials into precursors that can be easily transported and used for subcomponent fabrication;
- Sub-components: Examples include generators for wind turbine nacelles and crystalline silicone (c-Si) wafers for PV modules. Value added is created from the manufacturing of subcomponents that can then be assembled with other subcomponents into end products;
- End products, including finished products from the manufacturing process that are ready for installation, e.g. c-Si PV modules, electric cars, wind turbines.

Global economic conditions combined with finance and business model innovations drive the growth of clean energy technologies, opening the market to new producer and consumer segments globally (Stark et al, 2015). Multiple factors guide the corporate/business strategy regarding the location of clean energy manufacturing factories, including:

- Indigenous factors (labour costs and skills, energy and electricity prices, resource availability);
- Policy framework, e.g. taxes, tax incentives, risk premiums and interest rates, availability of financial resources and investment capital, safety and regulations;
- Existing supply chains, existing infrastructure (e.g. transportation) and vertical integration of industries (synergistic industries);
- Automation of overall manufacturing/advanced manufacturing processes;
- Market characteristics (location, competing products, economic growth).

The value and employment requirements of renewable energy technologies (RET) is analysed across the entire manufacturing supply chain, including processing raw materials, manufacturing the required subcomponents, and assembling the final product. The development of RET creates value added both directly (payments to manufacturing workers, taxes paid on production and profits earned by company owners) and indirectly through the supply chain, i.e. purchase of inputs from industrial or services sectors. The comprehensive analysis of RES activities allows the evaluation of major producers and trade patterns in each part of the RES value chain, as an economy can be a net importer of the end product but may be a net exporter of processed materials (e.g. Germany is a net exporter of polysilicon but a net importer of PV modules).

## Cost structure of RES

The supply chains of clean energy technologies include several links with other industries and each of them creates economic value. Different stages/activities of renewable energy development include innovation (leading to technological progress), manufacturing of technology and its sub-components, construction of RES installation (e.g. wind farms), integration in the power supply system (e.g. grid development, cables) and finally operation and maintenance of RES plants (Figure 1).


**Figure 1: Stages for RES development, Source: E3-Modelling**

Upstream activities (innovation and manufacturing) related to RES technologies if developed domestically can bring important economic and employment benefits to EU countries. In addition, as most studies confirm (including Garret Peltier, 2016; CEMAC, 2016), a significant part of RES costs is related to the cost of materials and components that are supplied from other sectors. Labour costs account for about 10% of the overall cost of PV modules and wind turbines, while transportation and shipping costs are important mainly for wind turbines due to logistics challenges of moving oversized components (e.g. towers, blades) to project sites.

The analysis of RES cost structure points to the importance of developing an integrated supply chain for RES development domestically in the EU in order to create increased value added and jobs across the RES value chain. RES manufacturing is a sector that establishes links between technology innovation and development and commercial deployment in the market. In the upstream supply chain, innovation in RES development produces economic value in the intellectual property and research, while value added and jobs are created in the country where the manufacturing process takes place. Downstream, the installation, system integration, and O&M are highly localised activities and bring economic value through job creation, services, property taxes, and (indirectly through) reduction of environmental impact. Significant economic value can be found both in downstream (installation, system integration, O&M) and in upstream activities (innovation and manufacturing), while according to Ernst & Young (2015) the largest part of PV value added is created downstream.

The domestic development of RES supply chain in EU countries combined with the vertical integration of supply chain industries and mainly the suppliers of the required high-tech components is a crucial ingredient to identify whether low-carbon transition would be beneficial for employment and economic activity. On the other hand, trade and investment policies that are inconsistent with climate change goals can create barriers to investment in renewable technologies (OECD, 2016). The increasing use of import tariffs, anti-dumping duties and local-content requirements (LCRs) on solar photovoltaic and wind energy threatens to fragment rather than optimize global RES value chains. In parallel, non-tariff barriers (including divergent technical standards and regulations) also disrupt global RES value chains. Recent analysis of the solar PV and wind energy value chains suggests that import tariffs and LCRs may have limited or even negative impacts on domestic value added and job creation. The cost of downstream activities related to RES (installation, project development, system integration and O&M) increases as they cannot fully exploit cheaper intermediate inputs and thus employment declines in much larger downstream activities. According to recent estimates (E&Y, 2015), upstream manufacturing activities represent only 18-24% of total jobs in the solar PV sector, while more than 50-60% of PV jobs and value added are located in downstream activities. This means than policies targeting manufacturing activities may not be so effective in creating domestic jobs across the entire value chains of RES technologies.

The literature that provides estimates on the cost structure of energy technologies is extensive. Based on engineering and scientific reports and studies, Input Output (IO) tables are further extended so as to explicitly represent the RES technologies. Using IO multipliers, the indirect activity and employment created from RES expansion throughout the economy can be evaluated (this provides a first approximation of overall economic and employment impacts). Figure 2 visualizes the cost breakdown of key renewable technologies, which require inputs from the construction sector, from fabricated metal products, from electrical/electronic equipment, machinery, services and from agriculture (bioenergy). In particular, several sectors are involved in the wind turbine manufacturing due to the relative complexity of the technology. Machinery and construction account for the largest cost blocks, followed by electrical equipment and metal products. Similar sectors determine the major costs of solar PV, yet with different shares relative to wind turbines. Machinery, electronic products and electrical equipment jointly account for 55% of the solar PV cost. The cost structure of concentrated solar power (CSP) and hydro is dominated by the construction part, followed by services and machinery (included in the overall electrical/electronic equipment in the figure below). The analysis shows that the share of equipment costs is significantly smaller in CSP compared to wind and solar PV. Agricultural inputs account for the largest part of biomass costs, with services and equipment having smaller shares. The costs for geothermal power are distributed over several sectors, with construction and support mining activities having the highest shares.

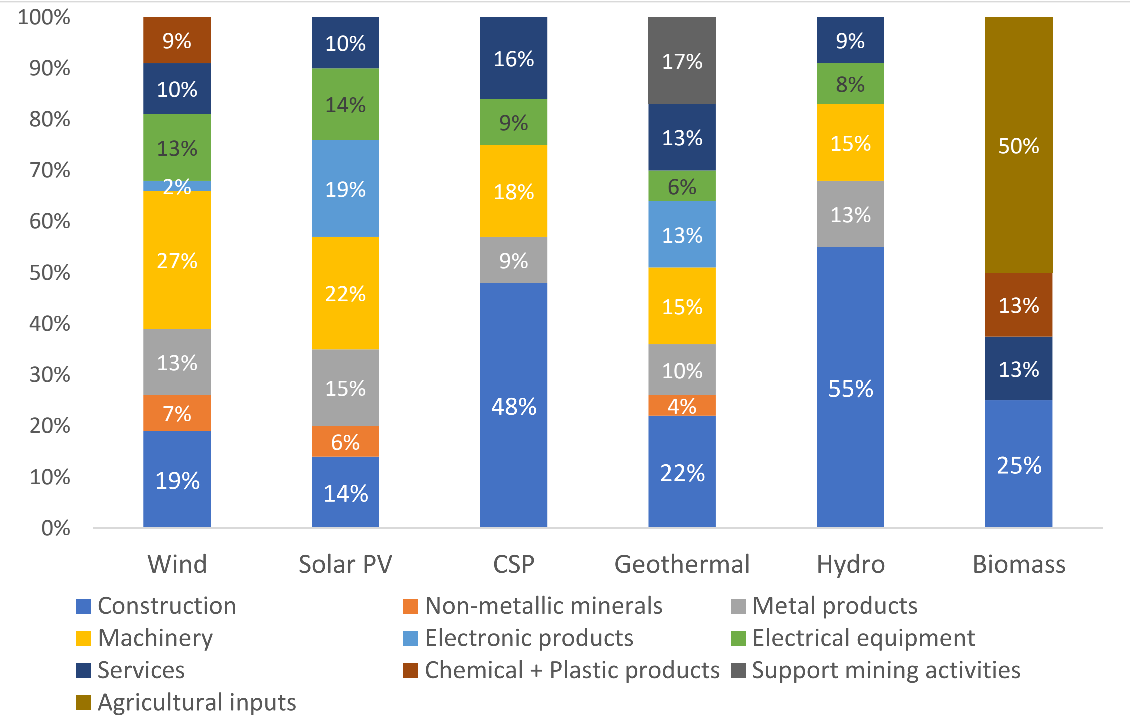



**Figure 2: Cost structure of RES power generation technologies, Source: ECOFYS and E3-Modelling calculations based on a variety of literature**

Renewable energy technologies (RET) are characterized by a dominance of investment costs (CAPEX) in relation to operational costs (OPEX), as they have no fuel costs (with the exception of biomass). Thus, they differ widely from conventional fossil-fuel fired power plants in which OPEX costs account for a large share of their overall costs (Table 1).

| Technology | Investment costs (EUR2017/ MW) | Yearly O&M costs - fixed (EUR2017/ MW) | O&M costs - variable (excluding fuels) (EUR2017/ MWh) | Fuel costs (EUR2017/ MWh) | Source |
|---|---|---|---|---|---|
| **Wind offshore** | €2,817,998 | €30,595 | €12 | - | IEA-RETD, 2016 |
| **Wind onshore** | €1,598,628 | - | €11 | - | IRENA, 2015 |
| **Solar PV - rooftop** | €1,841,405 | €15,474 | - | - | JRC, 2012 |
| **Biomass (stoker boiler)** | €1,570,378 | €50,252 | €3 | €90 | IRENA, 2015 |

**Table 1: Costs of different renewable energy technologies, Source: ECOFYS calculations based on a variety of sources**

Figure 3 shows the decomposition of total levelized costs of electricity (LCOE) of major power generation technologies into CAPEX, OPEX and $CO_2$ cost in EU in 2015. The figure also illustrates the impacts of ETS carbon pricing on cost decomposition in 2030 in the Reference scenario (EC, 2016) that assumes a moderate development of ETS price (reaching 30 €/tn $CO_2$ in 2030). ETS carbon pricing increases the costs for fossil fuel technologies. CAPEX costs account for about 89-94% of wind power and solar PV costs, while OPEX costs are the main cost components in fuel-based technologies (coal, biomass and gas). By 2030, the share of CAPEX declines further and accounts for only 11% of gas-based generation costs, while $CO_2$ cost accounts for about one third of the overall cost of coal-fired technologies.

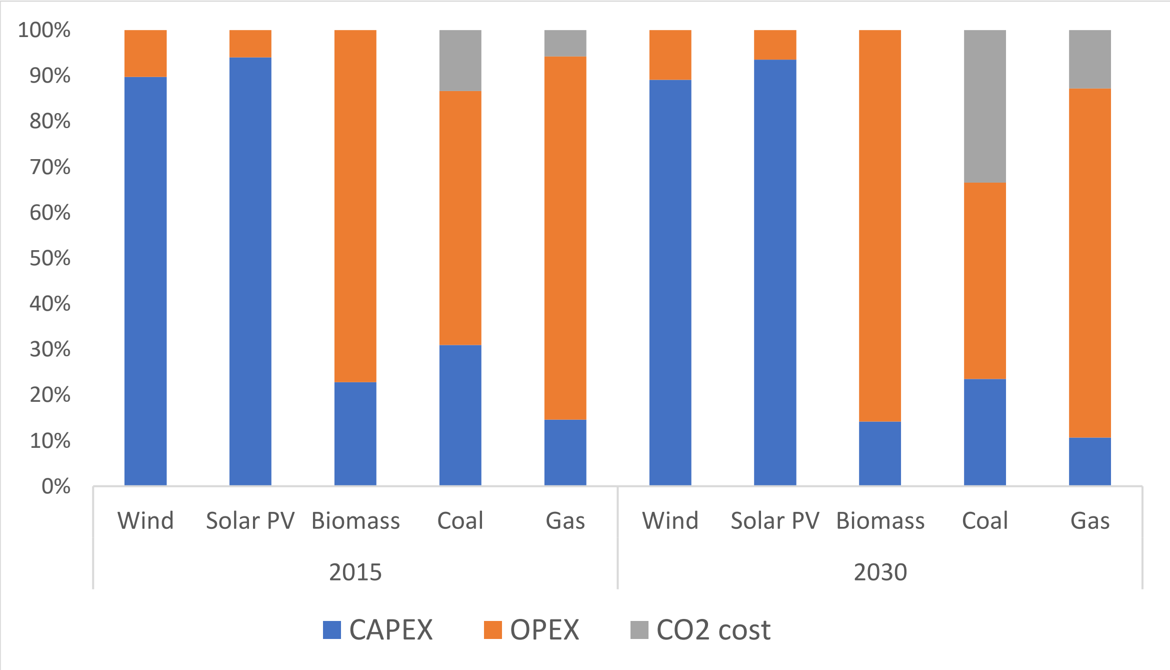



**Figure 3: Cost decomposition of power generation technologies into CAPEX and OPEX, Source: E3Modelling calculations largely based on EC, 2016 Reference scenario**

## Solar PV modules

The global manufacturing PV industry is largely dominated by crystalline silicon (c-Si) based PV. This technology is relatively well-established, yet opportunities for innovation in manufacturing remain including cost effective production of advanced cell architectures, polysilicon purity, and other areas contributing to higher cell and module efficiencies (CEMAC, 2016). Silicon-based PV modules are manufactured modularly via the discrete steps of polysilicon, wafer, cell, and module manufacturing, all of which rely on relatively standard product sizes and processes. Modules are primarily a commodity product, and the industry and supply chains are global. The key elements of the c-SI PV manufacturing chain include:

- Raw materials: silicon, aluminium, copper;
- Processed materials: polysilicon that can be traded in international markets;
- Sub-components (wafers and cells): The quality of fabrication of wafer and cells is critical to PV performance characteristics such as efficiency and yield;
- End products: Cells are electrically connected, laminated within encapsulants, and sandwiched between a glass layer and a protective back sheet. The entire assembly is then set within an aluminium frame, and a junction box is added, resulting in a complete PV module.

Global PV manufacturing is largely concentrated in China and in other Asian economies such as Taiwan and Malaysia. The European PV manufacturing has declined significantly after 2010 with module production representing about 5% of the global market in 2015 (2.5 GW), most of which is located in Germany, while the EU share in 2008 was about 30% (JRC, 2015). The main reasons for the Chinese dominance are related to the strong domestic demand, state support policies, economies of scale in production, lower labour costs and access to specialized manufacturing equipment. Chinese scaling advantages are also driven by preferred access to capital (indirect government subsidies) and incentives to create jobs domestically. China dominates in all stages of the c-Si PV value chain, namely in the manufacturing of polysilicon, wafers, cells and modules. Polysilicon production is the segment most equally distributed around the world, while wafer, cell, and module manufacturing is located in few countries, including among others China, Taiwan, Japan, Malaysia, the U.S. and Germany. It must be noted that Germany is a net exporter of polysilicon, but a net importer of PV cells and modules. Trade tariffs (mainly EU and U.S. import duties on Chinese and Taiwanese cells and modules) have a high impact on global trade and capacity expansion decisions across the supply chain, with Chinese producers adding new module and cell manufacturing capacities outside China in countries such as Taiwan, Malaysia, Vietnam and India.

Vertical integration exists across the PV manufacturing supply chain between wafer, cell and module production with integrated manufacturers reporting lower "in-house" production costs relative to those sourcing materials and components from third parties (CEMAC, 2016). In this context, major EU players are Solar World, which is an integrated PV manufacturer producing silicon wafers, solar cells and PV modules, and Wacker producing polysilicon. Both companies are located in Germany. Small scale producers have a large share in EU PV manufacturing, with Recom AG (Greece) operating a PV module production facility in Italy with 500 MW capacity, while Jabil Circuit (US) owns a module assembly plant in Poland, with a capacity of around 1GW that has been used by ReneSola to provide modules into the EU that avoid import duties and limitations to shipment quotas imposed in its manufacturing plants in China.

Due to the relatively limited product differentiation in PV modules, the basis for competition between PV manufacturers is the price. According to CEMAC, 2016 based on NREL[4] analysis, overall costs across nationally integrated supply chains indicate that PV module production is more expensive in Germany than in other major producing countries (China, Taiwan, Malaysia), with the cost difference from Chinese modules amounting to about 0.10-0.15 $/W which implies 20%-30% higher costs.

The PV module cost is typically between 40-45% of the total capital cost of a PV system, depending on the size of the project and the type of PV module (Chung et al, 2016), while Balance of Systems (BOS) costs, including inverter and racking, account for about 25%, labour costs for installation of PV for 11% of the overall cost and services represent 22% of total PV installation costs (financial, transport, sales, other professional and scientific services). IRENA (2012) shows that PV modules represent about 50% of the overall solar PV system costs. Most studies confirm that a large part in the PV value chain is related to the stages of "Balance of systems", installation and system integration, which have a large domestic content. EU counties have benefited from the globalised value chain that supported significant cost reductions in solar PV modules achieved in Asia;  investment in solar PV in Europe supports domestic activity and employment mainly in the installation phase. To put the above in perspective, Chung et al (2016) report benchmark prices for utility-scale solar PV systems of about 1600 €/kW, with modules accounting for 640 €/kW, BOS and inverter for 320 €/kW, racking[5] and installation for about 300 €/ kW (Figure 4).

JRC provided estimates for solar PV jobs in Europe split in different phases of the value chain (JRC, 2015). Employment data reveals the trend of declining EU PV jobs driven by large reductions in jobs in the upstream sector reflecting the relocation of PV manufacturing away from EU.  Installation jobs have also declined after 2011 due to the stagnation of PV installations in several EU member states; however jobs in O&M of solar PV plants have increased between 2011 and 2013 reflecting the accumulation of solar PV power capacities. The manufacturing of PV cells and modules and the construction of PV plants are found to be the most labour-intensive activities (in terms of jobs per MW). The production of polysilicon has a relatively low labour intensity and thus the activity supports only 5.000 jobs in EU, despite large production capacities in Germany. In case that the industries supplying cells and PV modules contract further, the willingness for R&D would weaken resulting in reduced innovation potential of the PV industry. This in turn would have impacts on jobs, especially in the upstream manufacturing sector.

[4] National Renewable Energy Laboratory, U.S.

[5] Balance of system (BOS) costs comprises all components of a photovoltaic system with the exception of PV panels. This includes wiring, switches, a mounting system, solar inverters, batteries and battery charger. However, the report (Chung et al, 2016) used in the current study provides a more detailed breakdown of cost components of solar PV installations. They provide separate estimates for the costs of inverters, racking systems and for the remaining parts of BOS including switchgear, transformers, combiner, fuses, breakers, conductors, conduit and all other ancillary equipment

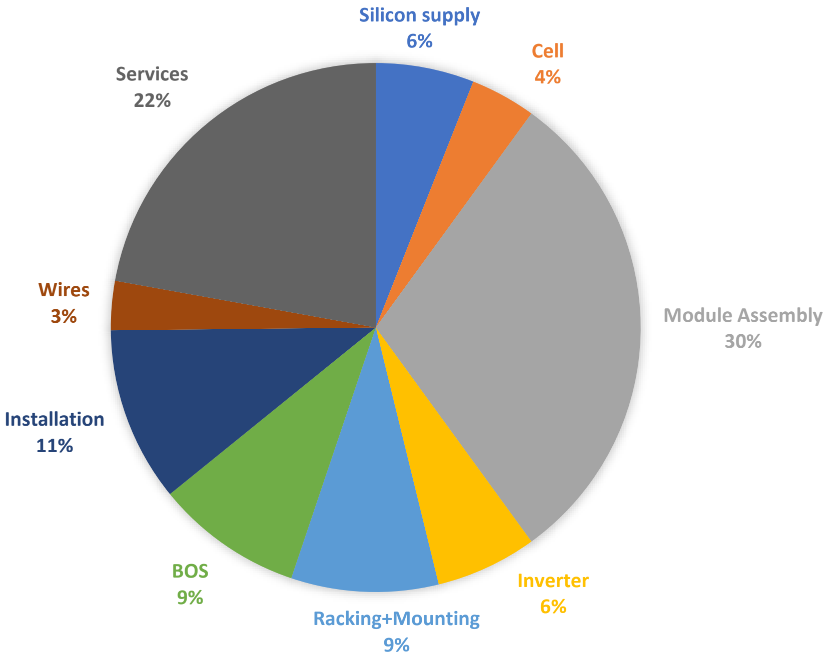



**Figure 4: Breakdown of total cost for installing solar PV, Source: E3-Modelling based on IRENA (2012) and Chung et al (2016)**

## Wind turbines

Wind energy has more installed capacity than any other non-hydro renewable energy source amounting to about 487 GW globally in 2016. Wind turbines are sold into a global market, and each main manufacturer (GE, Siemens, Vestas, Gamesa) has its own supply chain. The manufacturing of wind turbines has become an established global industry with a (direct and indirect) value added of 32.5 billion USD in 2014 (CEMAC, 2016). The supply chain of the wind production industry includes:

- Raw materials: Iron ore, silica, copper, aluminium;
- Processed materials: Steel, carbon fiber, fiberglass;
- Sub-components: Generator, steel components, magnets;
- End products: nacelle, blades, tower.

A specific feature of wind turbine manufacturing is that several parts of its supply chain connect well to established and mature manufacturing industries, such as steel production, industrial generator and gear production and carbon fiber manufacturing. Such complementarities create both opportunities and challenges for suppliers of wind turbine components. Europe has experienced robust wind power demand in the last decade and has established a sophisticated manufacturing sector. Given the existing skill sets and infrastructure, EU manufacturers continue to supply the vast majority of domestic EU demand and export wind turbines to other economies that have not yet developed local manufacturing capacity. On the other hand, high transportation costs imply limited opportunities for further EU export potential to non-EU countries. In parallel Chinese and U.S. manufacturers have increased their production capacity to cover anticipated growth of domestic demand. Raw materials, processed materials, and sub-components tend to be produced and shipped globally. In contrast, end product manufacturing facilities (i.e. blade production factories) are usually located proximal to large installation markets due to high logistics challenges and increased transportation costs of moving oversized components to project sites.

In the manufacturing of blades industry, technology differentiation drives competitive advantages (James et al, 2013) with blade sizes steadily increasing over the years, while blade designs vary to enable cost-effective harvesting of different wind resources. The most important factors influencing the manufacturing of wind blades include stable and predictable market and policy conditions, proximity to suppliers and end users, availability of infrastructure and access to skilled labour and R&D facilities. Different corporate structures exist among wind manufacturers. For example, Vestas is a vertically integrated company and produces most parts of turbine systems; on the other hand, General Electric (U.S.A) cooperates with a range of suppliers to acquire individual parts such as blades. Components of wind turbines are often designed for specific turbine systems, as a form to sustain firm-level competitive advantages while also serving customer needs.

Overall, wind energy technology continues to evolve, driven by mounting global competition; by the need to improve the ease and cost of turbine manufacturing and transportation; by the need to optimise power generation at lower wind speeds; and increasingly by demanding grid codes to deal with rising penetration of variable renewable sources. The wind industry has refined and improved materials, processes and design as well as installation and O&M regimes. Significant effort has been devoted to reduce logistical challenges and transportation costs. In parallel, innovation process is very important to ensure cost-efficiency and improved performance of wind turbines. Recent innovations include two-part blades, nesting towers and portable concrete manufacturing facilities for tower construction.

The development of a wind energy project includes the following stages:

- Development activities including wind resource evaluation, environmental impact assessment, planning of transmission and distribution infrastructure;
- Manufacturing: Extraction and processing of materials, production of various components;
- Installation/Construction of wind turbine at the project site;
- System integration and grid connection;
- Operation and maintenance of wind turbines that offers a long-term economic benefit, as turbine lifetime is about 20 years.

The various end products and wind turbine components (nacelles, blades and tower) are transported and assembled to the project installation sites; the installation of industrial machinery and equipment, electrical installation and technical testing are then performed. Ensuring cost and time efficiency during installation is essential to enable further cost reductions. Innovative manufacturers continue to explore opportunities for increased on-site fabrication and production of wind turbine end-products in order to enable the installation of larger and more efficient wind turbines while minimizing transportation costs. If these innovations are successful, wind turbine equipment fabrication and production may be increasingly moved on-site.

The cost of wind turbines constitutes about 60-65% of the total installation cost of a wind power project (IRENA, 2012b, CEMAC, 2016). Manufacturing of blades accounts for 22% of the total wind installation cost, while tower costs represent 21% of total cost. The nacelle is also an expensive component of a wind turbine, accounting for approximately 20% of the total cost due to the complex equipment for the drivetrain/gearbox, control panels, generator, power converter and yaw assembly. Construction of wind farms is a labour intensive activity representing 16% of total costs, while the share of grid connection cost of is 9%. Services are also required for the development of wind projects (including financial and consulting services), while the cost of land and roads is about 3% of the total installation costs.

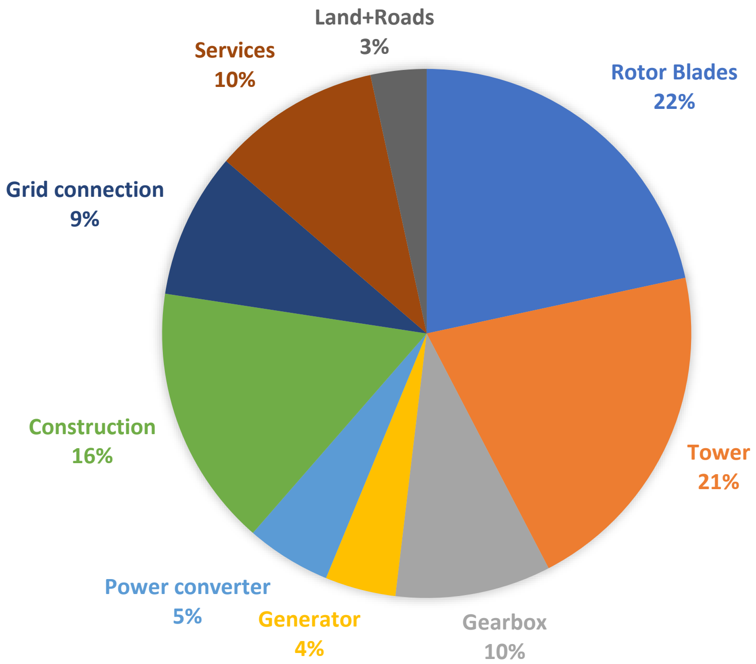



**Figure 5: Breakdown of total cost for installing a wind turbine, Source: E3-Modelling based on IRENA (2012)**

## Lithium-ion batteries

The global market for Lithium-ion battery cells used in electric cars has grown rapidly in recent years as electric vehicles penetrate the global passenger car market. The critical energy storage component of Li-ion batteries is the cell, that constitutes a large part of the cost structure of battery packs, and its performance drives the total cost and performance of battery pack. Due to the relative immaturity of the battery market, automotive cells are non-standardized and are often specific to the electric vehicles in which they are installed. Battery packs are designed by, or in close collaboration with the end application manufacturer, e.g. manufacturers of electric cars, while they must meet strict criteria with regard to performance, life cycle, weight and physical packaging and protection requirements. Future battery manufacturers may face the type of product commoditization observed in the solar PV module industry in cases where significant manufacturing capacity is installed (CEMAC, 2016).

Important supply chain elements in the production of Li-ion cells include specialty materials used to produce the cathodes and anodes; separator materials; and electrolytes. In particular:

- Raw materials: lithium, nickel, cobalt;
- Processed materials: cathode powder and anode powder, electrolytes;
- Sub-components: anode and cathode sheets, separator;
- End products: battery cell.

Japan, Korea and China have established clusters of key intermediate product manufacturing facilities, which contribute to regional supply chain advantages and cost benefits relative to cell manufacturers located outside of such clusters. A certain degree of vertical integration exists across Asian processed materials and cell production that contributes to lower input costs for certain battery manufacturers (CEMAC, 2016). Japan's Li-ion vertically integrated supply chain was developed due to sustained investment in Li-ion technology by consumer electronics companies in the 1990s bolstered by public

R&D funding and provision of low-cost capital. The establishment of Li-ion manufacturing plants enabled competitive advantages in portable consumer electronics applications (Brodd and Helou 2013). While Korean and Chinese producers initially relied heavily on Japanese suppliers, their efforts to build Li-ion clusters and supply chains have resulted in lower dependence on Japanese suppliers; this may lead to reduced costs for Korean and Chinese producers. Highly developed supply chains reduce import requirements for materials and sub-components and lead to increased creation of value added and employment. The U.S. and the EU, in contrast, host a relatively immature Li-ion battery supply chain, with most cell and battery plant operators being new to the industry.

The global annual demand for Li-ion batteries for automotive applications amounted to about 11.5 GWh in 2015 (Chung et al, 2016), with their cost declining rapidly to about 250-300$/kWh. As the technology is relatively immature, automotive battery production is not yet at the point of large-scale deployment and commercialization in vehicle applications. Technology perspective analysis has shown that cost improvements in Li-ion batteries are the most important factor influencing the penetration of electric cars. In 2015, Japan, South Korea, and China produced the vast majority of Li-ion cells for automotive applications and related products. European electric car manufacturers import almost all their demand for lithium-ion batteries with Germany being the largest battery importer.

The value chain analysis for best-in-class plug-in electric hybrid vehicle lithium-ion batteries in 2014 (CEMAC, 2016) estimates that about 40% of the total value added is created in the manufacturing of the final assembly of battery pack. Cell production represents 26% of the total cost of automotive Li-ion battery packs, while 34% of the value-added comes from electrodes and other processed materials (cathode and anode powders) required for the manufacture of Li-ion batteries (Figure 6).

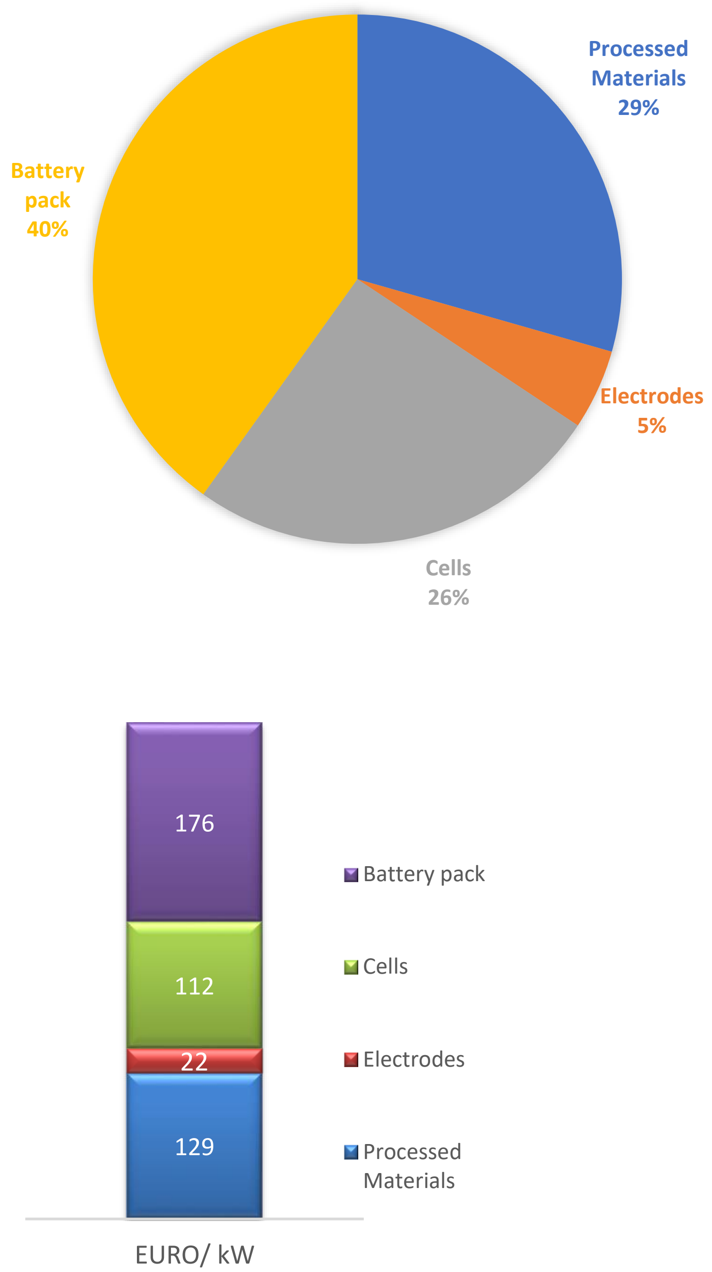



**Figure 6: Cost structure of Lithium-ion batteries, Source: E3-Modelling based on CEMAC, 2016**

## Biomass supply chains

Biomass can be used for a variety of energy-related purposes, including for transport (in the form of biofuels), for heating in households, and for the generation of heat and power (biogas, solid biomass). There are many pathways to convert biomass feedstocks into useful renewable energy. A broad range of waste, residues and crops grown for energy purposes can be used directly as fuels for heating and cooling or for power production, or can be converted into biofuels for transport. Many bioenergy technologies and conversion processes are now well-established and fully commercial. A further set of conversion processes – in particular for the production of advanced liquid bio-fuels – is maturing rapidly.

Biomass accounted for about 9% of EU's gross energy consumption in 2015 (i.e. 139 Mtoe), with the vast majority being produced domestically (96%); this share is projected to remain relatively stable in the Reference scenario up to 2050 (EC, 2016). In Europe, a very diverse set of industries is involved in delivering, processing and using solid biomass to produce electricity (and heat), ranging from the informal supply of traditional biomass, to the locally based supply of small-scale heating appliances, to regional and global players involved in power generation technology supply and operations and in large-scale district heating. The trend to convert large-scale power capacity from coal to wood pellets recently emerged, as the torrefaction of wood enables the production of pellets with a higher energy density and results in a product compatible with systems designed for coal. Although commercialisation of the technology has been slower than expected, promising developments occurred in 2016. The sustainability of bioenergy, and in particular the large-scale use of wood pellets is a controversial issue. The updated Renewable Energy Directive launched in 2016 stated the Commission's intent to reinforce mandatory sustainability criteria for bioenergy by extending the scope to cover (apart from biofuels) solid biomass and biogas for heating and cooling and for electricity generation.

The comparison of value added and jobs data from (Eurobserver, 2016) for various RES sectors illustrates that biomass accounts for a larger share in employment than in value added. This illustrates the lower labour productivity of sectors related to biomass production and transport (mainly agriculture and forestry) relative to RES manufacturing and installation sectors. The range of jobs profiles in the biofuel sector is wide, including:

- Biomass feedstock: farmers, equipment and chemical production workers, agriculture engineers
- Conversion: micro-biologists, technicians, chemical and mechanical engineers, plant operators;
- End use: power station workers, construction workers, consultants, chemists;
- Transport of feedstock and biofuels: truck drivers, truck filling station workers, pipeline operators.

Bioethanol is produced by fermenting the sugar components of plant materials. The most commonly used feedstocks are grains (corn, other coarse grain, and wheat kernels), sugarcane and starch crops. In the EU, bioethanol is mainly produced from grains and sugar beet derivatives, with wheat mainly used in north-western Europe and corn in Central Europe. (GAIN, 2016) estimates the required feedstock for EU ethanol production in 2016 at 8.9 MMT of cereals and 8.8 MMT of sugar beets; this represents 2.9% of EU cereal production and about 7% of sugar beet production. In recent years, about 80% of the bioethanol imports in the EU originate from countries that have duty-free access to the EU market, through Free Trade Agreements or other trade preferences, including Guatemala, Bolivia, Pakistan, Peru and Costa Rica (EPURE, 2016).

Biodiesel is produced mainly from oil crops. Rapeseed oil is still the dominant biodiesel feedstock in the EU, accounting for about 50% of total production in 2015 (GAIN, 2016), while Used Cooking Oil, sunflower oil, palm oil and soybean are also used. The majority of palm oil is imported, while a large share of soybean oil is crushed from imported soybeans. In contrast, the majority of rapeseed oil is of domestic origin. The EU domestic biodiesel production covers about 90% of domestic demand, while biodiesel imports originate mainly from Malaysia, Argentina and Indonesia.

Advanced biofuels are projected to play an increasingly important role in the context of low-carbon transition (EC, 2016) especially after 2030 as related technologies mature.

As there is no single definition for advanced biofuels, the literature uses three aspects to categorize a bioenergy commodity as being advanced.

- Feedstock criterion: Advanced biofuels are produced using lignocellulosic feedstock from agricultural or forestry origin or waste material (like Used Cooking Oil).
- Technology criterion: Advanced biofuels are produced using new technologies, unlike 1st generation ones that are produced via sugar fermentation and transesterification of oil seeds.
- Fungibility criterion: Advanced biofuels can fully substitute conventional oil-derived products, unlike non-advanced ones that can be blended up to a certain threshold with oil products.

EC commonly uses the feedstock criterion. Various conversion technologies and pathways exist for producing advanced biofuels, most of which include a conversion step still in the pilot and demonstration phase (Table 2). Technological developments will drive the maturation of advanced conversion technologies, most important of which are Enzymatic hydrolysis, Transesterification, Hydro-treatment, Anaerobic digestion, Fast Pyrolysis, Gasification and Fischer-Tropsch synthesis. Gasification and pyrolysis are the most promising options as they can produce a wide portfolio of energy products. Feedstock used for advanced biofuels is mainly woody biomass that refers to lignocellulosic input derived from agriculture lignocellulosic crops, forestry stemwood, forestry residues, agricultural residues and wood waste. Feedstock used for advanced biofuels is largely produced domestically in the EU, and therefore it is more beneficial for the creation of jobs and activity relative to conventional biofuels using (to a certain extent) imported feedstock.

| Feedstock | Conversion pathway | End-use energy products |
|---|---|---|
| Starch crops, Sugar crops | Fermentation | Ethanol |
| Woody Biomass | Enzymatic Hydrolysis and Fermentation | Cellulosic Ethanol |
| Woody Biomass (refers to lignocellulosic input which could be derived from agriculture lignocellulosic crops, forestry stemwood, forestry residues, agricultural residues, wood waste etc.) | Enzymatic Hydrolysis and Fermentation | Bio-gasoline and bio-ethanol<br><br>(advanced) |
| | HTU process, deoxygenation and upgrading | |
| | Pyrolysis, deoxygenation and upgrading | |
| | Pyrolysis, Gasification, FT and upgrading | |
| Woody Biomass, Black Liquor | Gasification, FT and upgrading | |
| Aquatic Biomass | Transesterification, Hydrogenation and Upgrading | |
| Oil crops | Transesterification | Biodiesel |
| Starch crops, Sugar crops | Enzymatic Hydrolysis and deoxygenation | |
| Oil crops | Hydrotreatment and deoxygenation | Biodiesel (advanced) |

| Feedstock | Conversion pathway | End-use energy products |
|---|---|---|
| Woody biomass, Black Liquor | Gasification and FT | |
| Aquatic Biomass | Transesterification and Hydrogenation | |
| Woody biomass | HTU process and deoxygenation | |
| | Pyrolysis and deoxygenation | |
| | Pyrolysis, Gasification and FT | |
| Woody biomass | Gasification and FT | Bio-kerosene |
| | HTU process and deoxygenation | |
| | Pyrolysis and deoxygenation | |
| | Pyrolysis, Gasification and FT | |
| Aquatic Biomass | Transesterification and Hydrogenation | |
| Woody biomass, Black Liquor | Gasification | Biogas/ Bio-methane |
| Organic Wastes, Starch | Anaerobic Digestion | |
| Woody biomass | Enzymatic Hydrolysis | |
| | Catalytic Hydrothermal Gasification | |
| Woody biomass | Hydrothermal Upgrading (HTU process) | Bio-liquids (for use in power generation, industry and shipping) |
| | Pyrolysis | |
| Black Liquor | Catalytic Upgrading of black liquor | |
| Landfill, Sewage Sludge | Landfill and sewage sludge | Waste Gas |
| Organic Wastes | Anaerobic Digestion | |
| Industrial Waste, Municipal Waste (solid) | RDF | Waste Solid |
| Woody biomass | | Small Scale Solid |
| Woody biomass | | Large Scale Solid |

**Table 2: List of biomass to bioenergy conversion pathways, Source: PRIMES-Biomass model**

# Current trends in global RES manufacturing

## Overview

The sectors producing clean energy technologies currently represent a relatively small global market size (about 0.1% of global GDP in 2010 according to CEMAC, 2016). However, there is a large potential for expansion of clean energy manufacturing and installation industries depending on the reduction of RES technology costs and adoption of ambitious energy and climate policies both at the EU level and globally. The RET market has been rising strongly both in Europe and worldwide. The share of RES-based electricity is constantly rising in the EU, and in 2016 RES constituted 29.6% (952 TWh) of total EU electricity generation[6]. This positive trend is projected to continue worldwide in the next decades. In the EU, it is backed up by the long-term goal to establish a low-carbon economy and the intermediate RES targets for 2020 and 2030 (EC, 2014).

Contrary to the installation and O&M of RET, which to a large extent create activity and jobs domestically, RET manufacturing is concentrated to a limited number of countries that have developed industrial activities. Several of the most innovative companies in RET manufacturing are located in Europe, which is reflected in positive trade balances, especially in the wind manufacturing sector, where Danish, German and Spanish companies are amongst the most competitive companies worldwide (Navigant, 2016). Overall, the European renewable energy industry is competitive in global markets largely driven by the high expertise and quality levels developed over the past decades. Huge investments in R&D, innovation and RET development in EU can lead to positive employment and growth impacts, especially in cases where strong climate policies are adopted worldwide and the EU may consolidate its role as a global first mover in clean energy technologies.

Trade in clean energy technologies and related equipment has also increased rapidly in recent years with the EU and China having prominent roles in wind turbine and solar PV exports respectively. Trade in renewable energy technologies is most easily tracked by identifiable end products (e.g. wind turbines) but the upstream links in the supply chain are complex, global, and dynamic, and thus are difficult to track with accuracy. Trade is crucial for manufacturers to exploit the global value chain for related materials and components; this is reinforced by the continued negotiations of the World Trade Organization on the Environmental Goods Agreement, which seeks to eliminate tariffs on a number of products including renewable energy technologies.

## Solar PV modules

The regional production of photovoltaics has undergone a rapid transformation in recent years with a fast erosion of the Japanese dominance and the emergence of China as the dominant player in the global market, largely due to the massive Chinese exports to Europe and USA. Currently the world market is dominated by China and Taiwan (accounting for 67% of the global PV production), while the share of European manufacturers has decreased dramatically from 26% in 2008 to a mere 5% in 2015 (JRC, 2015). Germany accounts for the bulk of EU production, while small-scale PV panel production capacities are located in other countries, mainly in Poland, Italy and France. There is, however, an emerging trend with new business models based on solar PV combined with stationary batteries, and EU-based companies like Sonnen, Senec and E3/DC are strong players. Still, the EU has the largest public R&D expenditures for solar energy

[6] Agora Energiewende (2017), p. 7 – preliminary data.

(152 M€ in 2015), followed by Japan, Korea, Norway and the USA (Figures for China are not available)[7].

The main reasons for the decline in EU PV module manufacturing are the intense competition from low- cost modules produced in China and in other Asian countries, the lack of financial resources to compete in the face of intense price competition, small or non-existent profit margins and a contracting domestic market (JRC, 2015). The revitalisation of the EU installation and manufacturing PV market combined with the high innovation potential and the establishment of integrated supply chains are critical in order to ensure a competitive European PV industry and support the creation of jobs, through:

- Consolidation of cost competitive manufacturing in EU (access to finance, process automation);
- Maintain PV value chain inside the EU by exploring synergies with R&D labs, research institutes, polysilicon producers, equipment manufacturers and manufacturing companies;
- Establishment of a robust policy framework in order to guarantee a steadily growing market for PV installations and support the revitalization of the EU PV industry with a coordinated industrial policy;
- Support EU PV manufacturers with a focus on small-scale companies producing innovative products.

## Wind turbines

The EU is a global leader in wind turbine manufacturing with a share of 44% in global production of wind turbines. European companies like Vestas are pioneers in wind power technology and can look back on more than 30 years of experience. They remain successful in securing a dominant position in the market until today despite increasing competition from US and Chinese companies. As depicted in Figure 7, European companies (located in Germany, Denmark and Spain) held major market shares in wind turbine production accounting for 44% of global turbine production in 2015 as a result of the EU's technology leadership (Navigant Research, 2015). The competitiveness of European wind energy manufacturing sector is also reflected in worldwide trade patterns (EurObserv'ER, 2016), with 90% of global wind turbine exports originating from the EU, with Danish (42%), German (30%) and Spanish companies (19%) having the highest shares in global exports of wind turbines and related sub-components. Strongest competitors are companies from China and the USA which also exhibit the largest demand for wind turbines outside Europe; however, the development of manufacturing activities in China and in the U.S. mainly serves the expansion of their domestic markets, with limited focus on exports.

In parallel, the EU has developed an integrated supply chain for materials and sub-components related to wind turbines. China produces large quantities of primary materials (e.g. steel) and sub-components (e.g. castings, generators, and towers) that serve the global wind industry. Germany has the largest wind turbine manufacturing in the EU as a result of its strong industrial sector, its commitment to exports, its transparent trading system and the policy framework that strongly support clean energy. Thus, Germany holds significant shares in manufacturing of wind turbines and in the entire supply chain, especially in nacelles, blades, towers and generators. Historically, Denmark's first mover position in wind power combined with the proximity to EU demand supported high levels of turbine manufacturing in Denmark. On the other hand, the U.K. is the

[7] EurObserv'ER (2017), p. 209

major net importer of wind turbines in the EU, but it produces domestically a large part of wind towers.

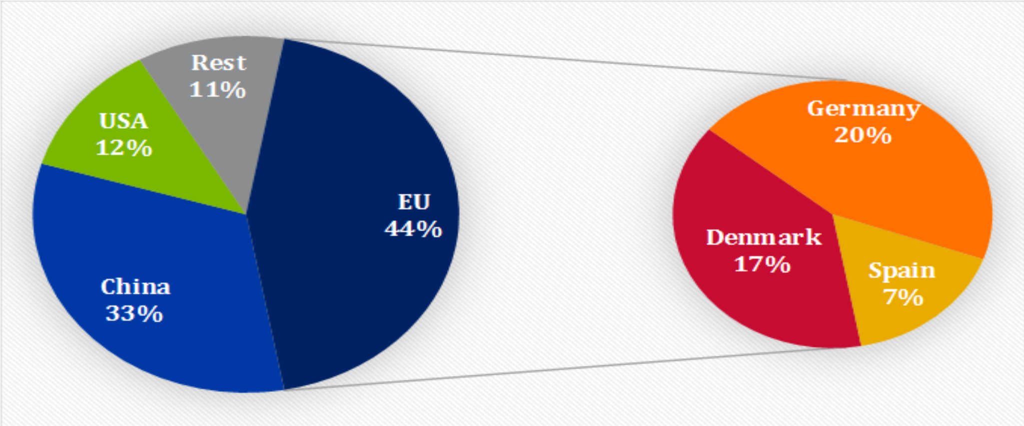



**Figure 7: Shares of major producers in global wind turbine manufacturing, Source: Navigant (2016)**

Similar to the onshore wind market, European companies were first movers in offshore wind technology and dominate the market until today (Figure 8). Siemens is the largest supplier of offshore turbines and represents 63% of the global production, while the share of EU manufacturers is estimated at more than 90% (in cumulative terms up to 2016). The inner-European supply chain in combination with significant demand within the EU further strengthens this position. The potential development of offshore wind can create new opportunities for innovation including taller, lighter towers; longer, lighter blades; larger rotor sizes; and lower nacelle and rotor weights. Offshore installations would require additional grid developments, as offshore turbines move further into deeper waters, and the average project size increases. Innovation needs and a growing resource exploitation have the potential to open new doors to non-traditional players and entrepreneurs around the globe.

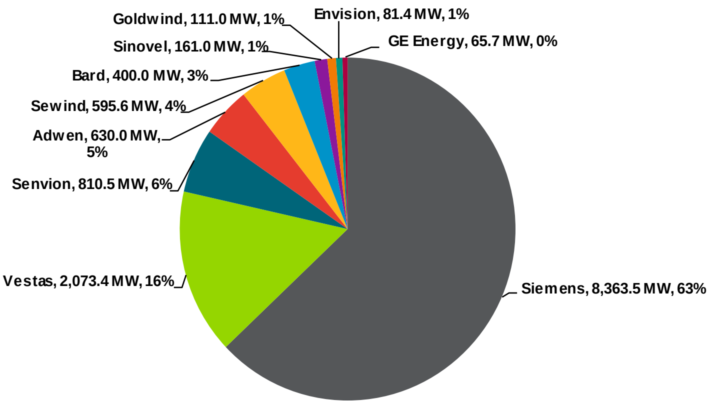



**Figure 8: Market shares in global market of major offshore wind turbine manufacturers (cumulative up to 2016), Source: ECOFYS based on Navigant Research, 2017.**

## Lithium-ion batteries and electric cars

In recent years, plug-in hybrid and electric vehicles registrations followed an explosive path and in 2015 the threshold of 1 million electric cars in the global car stock was exceeded (IEA, 2016) highlighting significant efforts of governments and industries over the past years. Ambitious targets, policy support and increased R&D investment have lowered battery and electric vehicle costs, extended vehicle ranges and reduced consumer barriers in a number of countries, notably in the EU, Norway, China and the U.S.

European electric car manufacturers are competitive in supplying electric vehicles (Figure 9) and the EU has the potential to remain a particularly important player in the global market (both in manufacturing and in sales). The EU electric car market highly depends on the strengthening of climate policies (mainly $CO_2$ standards in road transport) and the establishment of effective policies to support EU's technology leadership in a highly competitive global market. Given its ongoing investments in further production capacity for electric cars and the rapidly expanding domestic demand, China is also expected to become one of the largest markets both in the production and in sales of electric cars (Transport and Environment, 2016).

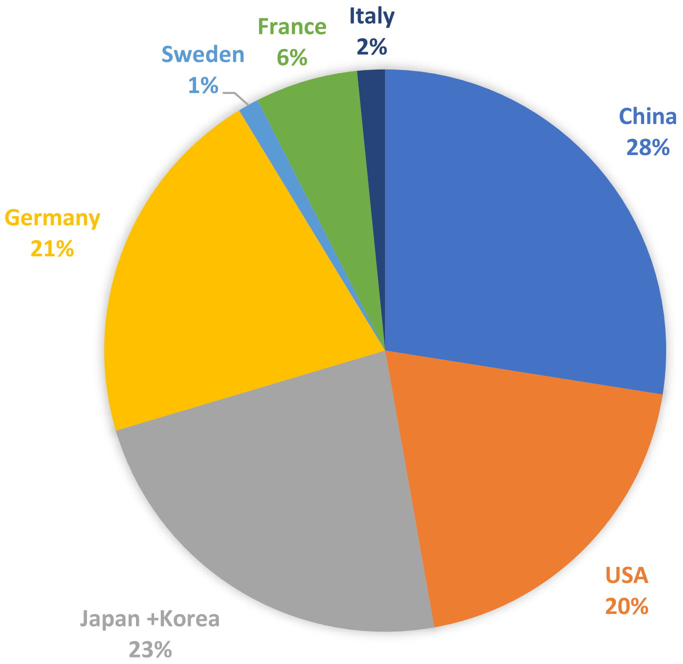



**Figure 9: Shares in global production of electric vehicles in 2015, Source: E3Modelling calculations based on Electric Cars Report (2016)**

The battery is the key component that will determine the development and eventual uptake of electric cars, as battery costs, availability and technical performance are key aspects for growth in e-mobility. Currently, lithium ion (Li-ion) are the most commonly used type of batteries in automotive markets due to the significant cost reduction achieved in recent years, the development of integrated supply chains and the accumulation of significant production experience in consumer electronics firms, much of which is transferrable to the production of Li-ion batteries. Since the 1980s battery production has been dominated by companies in South Korea and Japan, but in recent years the Chinese share has increased rapidly. Global battery production for automotive applications is currently dominated by Panasonic, which has a strategic partnership with Tesla to whom it sells most of its battery production (Cleantechnica 2016). Other important battery manufacturers for automotive applications include the Chinese BYD and the Japanese AESC (Figure 10).

The limited EU production of Lithium-ion batteries implies a continuing dependence on imported batteries manufactured in the Far East that limits the creation of value added and employment that Europe can get from the deployment of electric cars. However, this concern seems to decline with a number of striking announcements for new battery plants in Europe, e.g. Volkswagen has outlined plans for a €10 billion battery factory in Germany, Samsung and LG Chem plan to invest in EV battery factories in Hungary and

Poland respectively to exploit the rapidly growing EU demand, while Ford, BMW and Tesla also consider building battery factories in Europe. In parallel, Tesla in 2014 has announced plans to build a Li-ion manufacturing facility in Nevada, U.S. with a capacity of 35 GWh that would reshape the global production and trade of Li-ion batteries. A part of the facility has already been completed and has begun production of battery packs using imported sub-components.

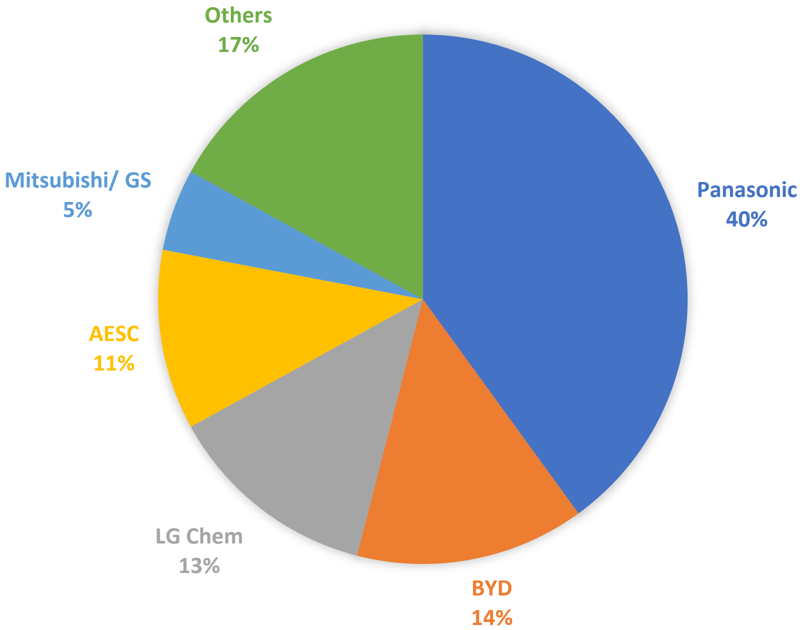



**Figure 10: Shares in global Battery production in 2015, Source: E3-Modelling calculations based on Cleantechnica 2016 and Transport and Environment, 2016**

## Biofuels (bioethanol and biodiesel)

Driven by the EU renewable energy targets, concerns about energy security and increased prices for refined oil products, the contribution of biomass to the EU energy supply constantly increases. Bioenergy production is expected to account for roughly half of the renewable energy use in 2020 (European Commission, 2016). Bioenergy can be used in several segments/sectors of the energy system, i.e. generation of heat and power, heating in buildings and for transport. Bio-power and bioheat are particularly local markets that use forest and agricultural residues and waste as feedstock. On the other hand, feedstock required for the production of biofuels is (to a certain extent) imported in EU countries, such as palm oil for biodiesel. The mandatory targets for the use of renewable energy in transport have boosted the use of biofuels in the EU, while the global biofuels market has increased significantly driven by wide deployment of biofuels (especially mixed with gasoline and diesel) in several parts of the world notably in the U.S., EU and in Brazil.

The USA leads the global bioethanol market as it produces about 60% of the world ethanol, while Brazil is also a major producer accounting for 29% of the global market. Ethanol trade is rather limited and accounted for about 3.5 Mtoe in 2015, as in most countries indigenous production keeps up with domestic consumption. USA and Brazil account for more than 75% of global ethanol exports, while the EU is a net ethanol importer; in 2015 the EU imported about 16% of its ethanol demand, with net ethanol imports amounting to about 550 ktoe. In 2014, EU bioethanol production peaked at about 5.3 billion liters. This development was driven by low feedstock prices and restrictive measures on bioethanol imports with EU reaching self-sufficiency (GAIN, 2016). The EU bioethanol market has been affected by shrinking gasoline consumption and the downward adjustment of blending mandates in several EU countries. Lack of financial resources forced plants to discontinue production in the UK, Netherlands and Spain, while plants in Germany, Poland, and Romania are under pressure due to lack of profitability (GAIN, 2016).

The EU is the world's largest biodiesel producer representing 49% of global production, followed by USA (20%) and Brazil (11%). Other major biodiesel producers include Argentina, Indonesia and Malaysia. The USA is the major importer of biodiesel with net imports amounting to 1.8 Mtoe in 2015, originating mainly from Argentina and Indonesia. In an attempt to reduce biodiesel imports from Argentina and Indonesia, the EC enforced anti-dumping duties on biodiesel imports from 2013 leading to a considerable drop in EU imports (imports from these countries stopped in 2014); in 2015 biodiesel imports amounted to about 1.1 Mtoe and represented only 9% of domestic EU consumption as a result of the increased domestic production and the imposition of anti-dumping duties.

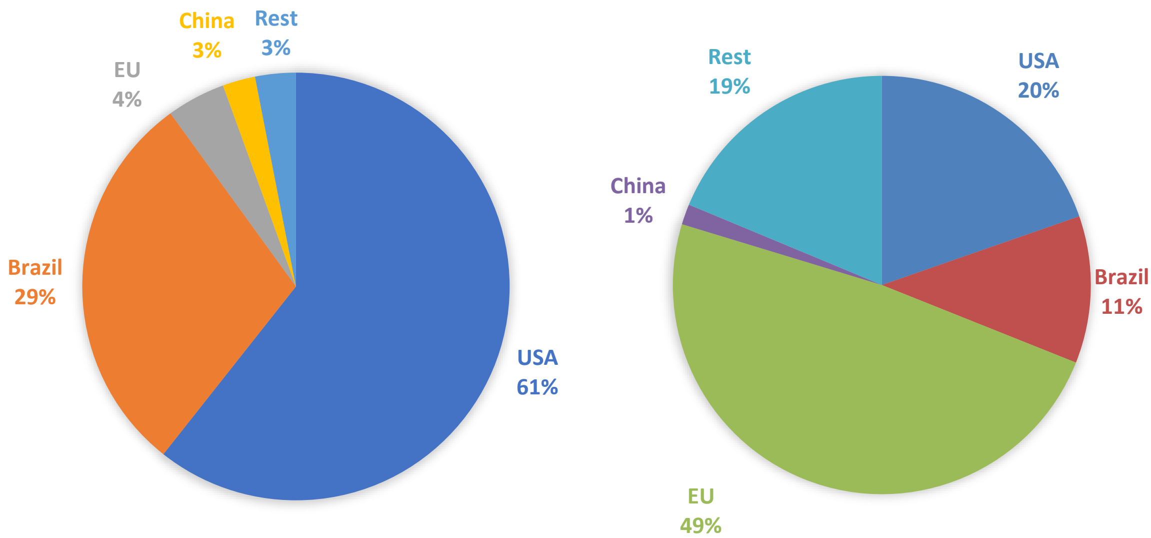



**Figure 11: Country shares in global ethanol (left graph) and biodiesel production (right graph) in 2015, Source: E3-Modelling calculations based on ENERDATA (2016) and GAIN (2016)**

China dominates the patents regarding biofuels, followed by the EU and USA. This is the only technology where the USA have a significant number of patents relative to their size. And, unlike other technologies, the EU patents are spread relatively evenly across European member states (EurObserv'ER, 2016 edition).

## Risks and opportunities for EU RES manufacturers

Renewable energy markets are projected to increase strongly both in Europe and worldwide driven by energy and climate policies, cost reductions, increased fossil fuel prices, energy security concerns and the potential to boost domestic economic activity, employment and competitiveness through innovation. The global rise of RET bears great opportunities for innovative European RET companies (like Vestas, Enercon and Siemens) to further flourish. At the same time, increasing competition from other countries with significantly lower labour costs, high investment in R&D and steep learning curves poses high risks for the European RET sector.

### Wind Onshore and Offshore

Wind power is a key renewable energy technology today and will gain even higher importance for electricity supply in Europe and across the world in the future. The large and promising global resource potentials combined with wind turbine cost reductions imply a clearly positive outlook for the wind industry. At the moment, there are no constraints in the global wind turbine supply chain. In the short-term, key components are likely to face the challenge of overcapacity, while some turbine parts (bearings and rare earth materials) are expected to be in short supply (scarce) through 2018. In addition, a strong regional imbalance exists for some wind turbine components, such as control systems, castings and forgings (FTI Intelligence, 2015).

European companies currently dominate the global wind turbine market; Danish, German and Spanish producers account for 90% of worldwide exports. The global wind power sector is a very concentrated market dominated by companies from EU, China and USA, while the competition between existing players is very strong, yet, still increasing. The race for leading positions in the market is reflected in expenditures for research and innovation, with Japan, Germany, Denmark and the U.S. having the highest public R&D expenditures in wind technology in 2015. Although there are no data for Chinese R&D expenditures, the number of patents filed by China[8] indicates its high innovation potential, while India is lately becoming more competitive. Another development related to increasing competition is the ongoing consolidation in the sector, as several companies expanded their scale through merger and acquisition activities. Examples are the completed takeover of Acciona Windpower by Nordex and the merger of Siemens and Gamesa, which now constitute the world's largest wind power company, measured in installed capacity.

The threat posed by new actors is not particularly high due to the high market entry barriers; the wind energy sector is capital intensive and requires very specific know-how. Yet, there is a trend for companies from the "old/conventional energy world" moving into the wind energy sector. In 2016, Shell (Netherlands), Statoil (Norway) and Keystone (United States) used their offshore oil expertise to push into the wind offshore development sector (REN21, 2017). The most important risks faced by EU wind industries are:

*Related to general market development:*

- Competition by fossil power (mainly gas) and increasingly also by solar PV;
- New capacity investment is still vulnerable to policy changes;
- (Grid-related) power system integration challenges persist, i.e. curtailment issues in China;
- Problems with public acceptance and environmental impact of large-scale wind power plants.

*Related to EU manufacturing and maintenance of a leading market position:*

- Losing market shares to competitors established in rapidly growing Asian (mainly Chinese) markets as transportation costs for wind turbine equipment are significant
- Losing market shares to new actors from other sectors with specific expertise for parts of the wind power value chain, e.g. oil companies moving into the wind offshore sector.
- Relocation of EU wind manufacturing activities to lower labour cost Asian countries.

[8] China filed the highest number of patents, with the EU close by as second, followed by the Korea, Japan and the USA. Source: EurObserv'ER (2017), p. 218.

- Lack of skilled labour in niche markets can restrict the European wind business in the near future.

On the other hand, there are high opportunities for EU companies to consolidate their leading position in the global market for wind turbines and across the entire supply chain.

- European companies have a top position to supply domestic European market. The European supply chain in combination with high domestic demand (also in the off-shore sector) further strengthens this position.
- The existing excellent know-how and innovation potential can be of great importance to enable the penetration in rapidly growing emerging economies. Examples for this is EDF entering the Chinese market by acquiring UPC Asia Wind Management.
- Knowledge and gained experience in the wind offshore sector can be of special importance, as it is a highly specialized and still evolving market with a high expansion potential worldwide.

Concluding, it can be said that there is increasingly strong competition in the maturing wind onshore energy markets worldwide as well as in the emerging offshore markets. EU companies have managed to keep up to rising competitors and stay competitive at the global level. However, increasing competition from Chinese and U.S. manufacturers of wind turbines and sub-components can put the EU's leadership at risk. Ongoing innovation will be key for EU companies to stay in the game, reduce costs and prices and improve yields. Significant R&I efforts indicate that European companies are in a good position to do so.

### Solar PV modules

Solar PV is a key clean energy technology and in 2016 it was the world's leading source of new power capacity installations, with Asia dominating global investment in solar PV. In terms of capacity additions, China, U.S., Japan and India are the largest markets in 2016, while PV in Europe faces challenges related to (among others): i) changing support regimes (from feed-in tariffs to auctioning-based subsidies), ii) stagnating electricity demand and iii) conventional utilities that are lobbying to maintain their position (REN21, 2017). In general, the global outlook for solar PV is positive, especially in emerging Asian markets.

Over the years, the Asian solar industry has gone from infancy to domination of the global market, as in 2016 Asian manufacturers accounted for about 90% of global solar panel production, with about 2 million people employed by the industry (REN21, 2017). Most global PV manufacturing is located in China with overseas PV module plants in South-Eastern Asia (Malaysia and Thailand), spurred by trade disputes and in order to avoid US and EU import duties. Although Europe and the U.S. have imposed import duties to Chinese PV modules, both still import most of the required solar PV equipment (REN21, 2017).

The EU share in the global production of PV modules has rapidly declined in recent years, driven by the competition from low- cost modules imported from China and Taiwan, the lack of financial resources and the contraction in EU's domestic PV installation market. The main risks faced by EU companies include:

- Continuing downwards pressure on module prices would challenge EU manufacturers whose costs have not declined as quickly and who are faced with small profit margins.
- Transition of support schemes from feed-in tariffs to a more competitive auctioning system for large-scale systems combined with stagnation of electricity demand in several EU countries.

- Grid congestion problems and curtailments started to become a serious challenge in 2015 in China and problems increased during 2016 due to inadequate transmission grids (REN 21, 2017).

The analysis has identified several opportunities to enhance domestic EU solar PV manufacturing:

- Mergers, acquisitions and new partnerships can help companies to capture increased value in project development or to enter new markets (locations or applications);
- Crowdfunding is an important means for financing projects as well as technology innovations, with new platforms launched in 2016;
- Exploiting emerging new business models based on solar PV panels combined with stationary batteries, with EU companies being strong emerging players. For instance, decentralized small-scale solar PV can be a part of larger integrated clean energy solutions, such as smart home systems, combined with storage and digitalization options;
- Low capital expenditures and improvement in equipment efficiency and capacity factors are helping in order to drive down cost for manufacturers and developers.

Strong global competition and decreasing module prices led to market consolidation with even the most competitive manufacturers in and outside of China laying off workers and some companies even fail. On the other hand, falling prices and expanding markets for solar PV have lured new players to enter the market. For example, in 2016, Apple supplier Foxconn purchased Sharp that faced financial troubles and started making PV cells already in the 1960s; and Tesla partnered with Panasonic (Japan) and acquired US installer SolarCity with plans to make an integrated solar PV-storage-EV product. In addition, several top wind turbine companies (GE, Gamesa, Goldwind and Mingyang) have entered the solar industry by 2016 (REN21, 2017).

## Innovation in EU RES industries

Innovation is at the core of the European clean energy transition. The European Union is one of the global leaders and largest public funders of clean energy research and innovation (European Commission, 2016). In addition, EU companies have leading global positions in renewable energy technologies through constant innovation. Although the role of R&D in the value chain of renewable energy cannot directly be translated to the implementation of new ideas and/or a change in energy costs and prices (Chung, et al., 2016), it is clearly fostering innovation. Especially targeted research and innovation (R&I) funding is an essential driver for innovation in the RES sector. The EU's most important instrument to stimulate clean energy innovation is the Horizon 2020 programme, which funds R&D, pilot and demonstration projects as well as the societal challenge 'secure, clean and efficient energy'. In total, Horizon 2020 offers over €10 billion to dedicated clean energy research and innovation (European Commission, 2016). In addition to fundamental research on RET, the Horizon 2020 programme focuses also on market-creating innovation with regard to the integration of renewables and digitalisation in the context of the low-carbon economy.

Besides Horizon 2020, other instruments are implemented to stimulate the realisation of first-of-a-kind commercial-scale demonstration projects (Energy Demonstration Projects) or investments in highly innovative low-carbon technologies (Innovation Fund Energy Demonstration projects, as successor of NER300) (European Commission, 2016). Other initiatives to stimulate R&I in the EU is fostering new strategic partnerships, especially with emerging non-EU countries, to ensure Europe's role as a strong global actor, drive innovation and create new business opportunities in clean energy markets. In this context, the EU joined the Mission Innovation initiative and committed to doubling their public funding for clean energy research over five years.

Alongside public R&D funding, corporate investments in innovation are essential to ensure competitiveness of the European RES sector and keep global top positions for European companies. This is especially true for the European wind and bioenergy sectors, but also applies to the remaining European solar companies and emerging RES sectors and business models related to new integrated energy system services (e.g. small scale RES coupled with batteries) and digitalisation. Innovation is an essential business area for European companies itself, yet innovation affects all parts of the RES value chain aiming for cost reductions and further technological improvements.

In the **wind energy** sector, key European companies like Vestas, Enercon and Siemens-Gamesa heavily invest in innovation. They aim to constantly improve their products along the whole value chain and to reduce costs faster than the market average and thereby stay competitive (Vestas, 2016). Competition here is twofold, European wind energy companies compete within the global wind sector as well as against other technologies including natural gas and solar PV capacities. The innovation focus of EU companies has been on maximising turbine efficiency and reliability, improving towers and foundations as well as enhancing operation and maintenance. An example for significant improvements is the development of capacity factors; While onshore wind farms were struggling to reach a capacity factor 20% in early 2000's, factors are now around 30 percent, with some facilities as high as 50 percent (Bloomberg Markets, 2016).

In the **solar PV** market, most of the highly technology-intensive R&D and capital equipment segments were mainly located in Europe, the United States, Japan and South Korea (Gallagher & Zhang, 2013). Also the production of polysilicon has typically been dominated by European, American and Russian firms. However, by acquiring Russian technology providers as well as developing their own technology, China is emerging as a major R&D supplier (Gallagher & Zhang, 2013). Recent focus areas of innovations across the solar PV value chain include manufacturing, product efficiency and performance, installation and O&M (REN21, 2017). The development was driven largely by price reductions and growing demand[9].

European companies in the **bioenergy** sector have been investing in innovation, mainly in the development of high-end equipment, putting them in a position to be global supplier of cutting edge equipment.

### Impacts of innovation on RES employment

According to IRENA (IRENA, 2017), in 2016 the global RES sector provided 9.8 million jobs (direct and indirect). China is currently the largest renewable energy employer in the world, hosting over 3.6 million jobs in 2017 (IRENA, 2017) followed by the EU (1.1 million jobs), Brazil (0.9 million jobs) and the U.S. (0.8 million jobs). Within the EU, Germany is hosting most of the RES- related jobs (over 334,000), followed by France (162,000). In IRENA, 2017 there is no break-down of RES jobs into the entire chain of activities, including innovation. The 2017 German figures include 7,700 jobs in publicly funded R&D and administration (IRENA, 2017), which is about 2% of the total RES-related jobs in Germany. This is slightly lower than in 2016, when 8,300 jobs in publicly funded R&D and administration were reported (IRENA, 2016). It is unknown how these R&D jobs are divided over the different renewable energy technologies.

[9] Examples are big players like SolarWorld (Germany) and REC Solar (Norway) upgrading production lines to Passiva-ted Emitter Rear Cell (PERC) technology, module manufacturers continuously increasing the number of busbars to redu-ce internal electrical resistance, as well as reducing barren spaces on modules to enhance light trapping, REN21, 2017

Another indicator for the importance of innovation in renewable energy technology and related jobs are R&D expenditures. The EU remained the largest investor in renewable energy R&D spending 2.2 billion USD, closely followed by China (2.0 billion USD) and the United States (1.5 billion USD) (REN21, 2017). The U.S have a strong focus on biofuels in R&D expenditures, while the spending of the other countries, including the EU, is typically spread more evenly, with a slight focus and wind and solar power (EurObserv'ER, 2017).

### Global and EU innovation potential in RES industries

The European Union is currently one of the global leaders and largest public funders of clean energy research and innovation (European Commission, 2016). In order to keep and strengthen its position in the future, a closer look is provided to their closest competitors in this area: China and the United States. Historically, the United States and the EU have been global leaders in clean energy R&D and innovation. Both European and American renewable energy research have relied on excellent research institutes and universities and are covering a wide array of renewable energy technologies in different parts of innovation value-chain, from fundamental research to the deployment of mature technologies. This is reflected in clean energy R&D expenditures and patents (IRENA, 2017; UNEP & EPO, 2015). Their activities initiated the creation of European and American renewable energy manufacturing industries, driving R&D and innovation to improve effectiveness and reduce costs.

Over the past years, manufacturing industries have been moving away from Europe and United States towards countries such as China, to lower production costs. It is expected that this will (significantly) affect employment in (industrial) R&D, as this will be moving alongside, improving China's position on clean energy R&D and innovation. Today, China is already the largest R&D investor in solar energy (Chung, et al., 2016) and it is also catching up quickly in wind power. Over the past 30 years, the Chinese wind energy sector has changed from import-driven, cheap and low quality technology, towards a high-quality technology that can now serve a large part of the internal market (Dai, et al., 2014). It is expected that this focus on R&D and increasing international competition is a trend likely to continue in the future (Dai, et al., 2014).

In order to maintain its leading position on clean energy innovation, the EU may need to adjust its R&D and innovation focus. With manufacturing industries moving away, the focus should be less on serving the entire value chain (including manufacturing) and more towards "creating new ideas and concepts". This will result both in more fundamental research (i.e. novel and breakthrough clean energy technologies) as well as the development of new energy concepts and integrated systems (i.e. system integration, smart grids, power storage options etc.). The EC already formulated new topics and areas to raise industrial competitiveness and exploit emerging clean energy export opportunities (European Commission, 2016):

- Development of new generation renewable energy technologies. Energy concepts that go beyond the development of existing technologies, but focus on breakthrough technological solutions. This type of research is typically supported by government funding as it requires high levels of upfront investment and has large uncertainties regarding cost, performance and market integration;
- Systems with very high shares of RES that require both fundamental research in energy technologies and new configurations of the energy system, in close collaboration with industry;
- Development of affordable and integrated energy storage solutions in order to facilitate full integration of renewables at domestic, commercial and grid scale combined with energy storage systems;

- Full decarbonisation of transport and a more integrated urban transport system. Focusing on electro-mobility, advanced battery design, recharging infrastructure, etc. (European Commission, 2016);
- Full decarbonisation of the building stock by 2050. Buildings have still a large untapped energy-savings potential and once renovated and upgraded, they can help to generate extra renewable-sourced power or provide key energy storage capacity.

The abovementioned topics and areas are already embedded to some extent in the current clean energy innovation programmes and research activities of European research institutes and universities. Due to lack of sufficient employment data, it is hard to estimate the impact of low-carbon transition on clean energy innovation jobs. It is expected that the low-carbon transition would shift R&D-related jobs from conventional energy forms (fossil fuels and nuclear) to clean energy induced by increased clean energy R&D expenditures. This shift is expected to be made also in other major developed and developing economies leading to country competition for clean energy R&D jobs. However, with the right innovation-enabling policy framework and strong signals to investors, the EU can become the world leader in renewables and possibly also deliver strongly on jobs, growth and competitiveness (i24c, 2016).

# Appraisal of the current EU energy supply jobs

## Classification of energy and RES jobs

The first reference to the employment benefits of sustainable development and green growth can be found in the 1993 White Paper (EC, 1993) that includes an analysis for the creation of jobs through environmental protection-related activities. In the 2012 Employment Package (EC, 2012), the European Commission defined green jobs as "jobs that depend on the environment or are created, substituted or redefined (in terms of skills sets, work methods, profiles greened, etc.) in the transition process towards a greener economy". According to the U.S. Bureau of Labour Statistics (BLS), green jobs include employment in: 1) renewable energy; 2) energy efficiency; 3) pollution reduction and removal, GHG reduction, and recycling and reuse; 4) natural resource conservation; and 5) environmental compliance, education and training, and public awareness. UNEP defines Green jobs as those that contribute appreciably to maintaining or restoring environmental quality and avoiding future damage to the Earth's ecosystems (UNEP, 2008). The current study focuses on employment implications for the EU from the expansion of renewable energy in the context of low-carbon transition up to 2030 and 2050 as described in the recent Winter Package (EC, 2016).

Even though there are several broad definitions of low-carbon employment (as described above), there is a lack of a clear and precise definition of "low-carbon jobs". The vague concept of low carbon employment causes that different categories of low-carbon jobs cannot be systematically and statistically measured. One of the critical issues related to green jobs is the question of whether "brown jobs" in the value chain of clean energy technologies should be considered as green as long as they ultimately contribute to green growth according to the above definitions, e.g. jobs in the steel industry that supply wind turbine manufacturers or jobs in copper smelting plants used for the manufacturing of solar thermal equipment. Previous analyses (EurObserv'ER, 2015) include "brown" jobs in supply industries in the overall estimation of RES jobs. Another factor that needs to be taken into consideration is that as technology progresses and newly emerging technologies evolve, different standards of "low-carbon" jobs would apply.

Employment impacts of ambitious climate policies and RET development has drawn attention of policy makers and researchers driven by expectations about employment benefits due to their higher labour intensity compared to fossil fuels (European Commission, 2012). The following classification of employment impacts is usually proposed in the literature:

**Direct impacts**. Direct jobs are those directly derived from RES manufacturing, equipment supply, onsite installation and O&M. For example, solar PV development creates direct jobs in the manufacturing of cells, modules and inverters, in installation of PV modules and in O&M of solar power plants. The direct effects are usually measured using data from case studies, existing databases and engineering bottom-up analysis. Direct employment also includes the jobs associated with the production of biomass feedstock and its transport and conversion to bio-energy (solid biomass, biofuels, biogas, waste).

**Indirect impacts**. Indirect impacts refer to the supply chain effects of "upstream" and "downstream" activities. Jobs associated with the manufacturing of equipment, components and materials used to build RES installations and with the services and materials used to operate and maintain RES installations. The degree of extension in the calculation of indirect impacts is related to the extent of the supply chain considered in the analysis (IRENA, 2011).

**Induced impacts**. Induced jobs are those created due to the overall economic impact of RES expansion. The calculation of induced impacts requires the use of a macroeconomic model, usually a Computable General Equilibrium (CGE) model including several production sectors; the CGE model simulates a new economic equilibrium as a result of RES development leading to income and substitution effects in the entire economy. Budget/income effects refer to changes in disposable income and private consumption of households as RES deployment influences commodity prices. Substitution effects occur when additional spending on a specific section displaces spending on other sectors (e.g. higher spending on RES displaces spending on fossil fuels), thereby having an impact on jobs.

Most studies in the literature include direct jobs, while indirect and induced employment impacts are more rarely examined. However, the impacts of RES expansion in other economic sectors across the value chain are particularly important and thus deserve an in-depth quantitative assessment.

Another distinction in employment impact assessment is the calculation of gross and net impacts. Gross impacts focus only on the positive effects of RES expansion, usually including direct and indirect impacts. For the calculation of net job impacts, the evaluation includes both positive and negative effects on employment driven by elimination of jobs in fossil fuel sectors and in related activities. In any case, net job effects of RES expansion are much smaller than gross employment effects. The consistent estimation of net job impacts from RES deployment is more policy relevant and thus this approach is followed in the current study.

Renewable energy can be divided into three sectors, similarly to the classification followed by the definition of the RES-shares by the European Commission: RES-E (renewables used in electricity generation), RES-H&C (direct uses of renewables in heating and cooling, plus heat pumps) and RES-T (RES used in transport). The renewable technologies used in power generation include conventional hydro, small hydro run-of-river, solar photovoltaic, wind energy (onshore and offshore), concentrated solar power (CSP), tidal and waves energy, geothermal, biomass (solid, gas, liquid) and waste (solid, gas). RES used in heating and cooling include solid biomass and waste, solar thermal, biogas, geothermal applications and heat-pumps. RES in transport include directly biofuels (ethanol, biodiesel, biogasoline etc.) and indirectly electricity produced from RES.

Direct renewable energy jobs are classified into jobs in the manufacturing of RES equipment, in construction and in Operation and Maintenance (O&M) of RES installations. Several publications aggregate manufacturing and installation jobs into a single employment factor. In contrast, the current analysis examines installation and manufacturing of RES separately, as installation jobs are more likely to be created domestically than manufacturing jobs. The latter depend on the development of industries that manufacture RES equipment and components; currently a small group of countries accounts for the bulk of RES technology manufacturing with China, Germany, Denmark, and the U.S. playing prominent roles (as analysed in chapter three).

## Identification of jobs in energy supply and RES-related activities

Fuel-free technologies, such as solar, wind and hydro, use energy inputs that are freely available. These technologies typically involve jobs in the processing of raw materials; the manufacture of technology; project design and management; plant construction; O&M and eventual decommissioning (IRENA, 2011). Depending on the technology, this can draw on a range of occupations across different parts of the value chain. As an example, direct jobs related to PV include engineers and technicians to process silicon and semiconductor materials and to assemble the system components at the manufacturing stage; Project development requires qualified personnel to conduct solar resource assessments, solar PV system designers, energy experts, business managers and financial analysts, while construction workers, technical personnel and electricians will then be required for installation purposes. Maintenance during the lifecycle of the project also involves technical staff and decommissioning needs construction workers and jobs related to materials recycling.

The supply chain of wind power includes a wide range of products and components, each requiring specific skills: supply of raw materials (casting, forging, fibres), manufacturing of components (gearboxes, generators, transformers), manufacture of wind turbines, nacelles, blades and towers, project design and development, construction and O&M. Different skills are needed at each step of the value chain; Jobs in the manufacture of towers requires experience with steel, while experience in high precision production processes is needed in turbine manufacture; Project design requires experts in resource assessment, engineering and in finance. The construction of wind farms is carried out by specialised construction workers, electricians and technical personnel, while O&M tasks require a wide set of skills from monitoring the smooth operation of turbines to cleaning blades and calibrating electronic sensors (Ayee, et al 2008).

Geothermal electricity production requires specialised resource assessment entities, deep drilling companies, civil engineering services, supply companies, project developers, and power plant builders. Drill and process engineering skills are also needed for heating and cooling technologies (IRENA, 2011). A wide range of indirect jobs are also created in the supply chain of RES. Scientists and engineers contribute to the innovation and development process through R&D activities. In parallel, various industries (steel, cement, machinery) supply materials, while RES expansion is also facilitated by transport and logistic professionals (IRENA, 2011). Energy specialists contribute to energy planning and administration personnel is required in the entire value chain. Energy consultancy firms and regulators are required in the project development stage.

Fuel-based technologies require energy inputs that are not freely available and the value chain of these technologies includes the production of primary energy sources (coal, gas, oil or biomass feedstock), their processing into fuel (e.g. refineries, biomass conversion processes) and then combustion of fuel in power plants. In the case of bioenergy, jobs related to feedstock production depend on the type of feedstock used. For dedicated energy crops, agricultural jobs (farmers and seasonal labour) are required, while industrial bio-residues involve jobs in their collection and pre-treatment. Refining ethanol and biodiesel transesterifcation requires chemists, industrial workers and engineers (AEBIOM, 2015). The use of biomass for power and heat production creates similar jobs during feedstock production; jobs involved in the rest of the value chain depend on the type of fuel and technology used.

Solid biomass is largely used in EU industries to produce heat and power on site. Typically, solid biomass is produced as a by-product of the industry's primary production process, thus requiring no jobs related to transport, while logistic and transportation jobs are required in case that logging residues are processed on site into wood chips and then transported to a combustion site to produce power in dedicated plants (IRENA, 2011). Wherever combustion takes place, jobs are involved in the construction and O&M of power plants, including technical and financial analysts, engineers, construction workers, plant operators, technicians and maintenance staff.

## Current status of RES jobs in EU

We estimate jobs related to the entire value chain of renewable and conventional energy forms. The study includes explicit accounting of employment in the construction of projects, jobs in O&M of RES installations, jobs in the supply of biomass feedstock, in transport and conversion of bioenergy and jobs in the manufacturing of RET equipment. Indirect jobs created in the entire supply chain of RET (materials, equipment and services supporting the RES) also deserve attention, while a clear distinction between jobs created domestically and jobs related to imported goods is implemented. For example, biofuels have a high potential for job creation in agriculture and bioconversion technologies, and in particular when advanced lignocellulose-based biofuels would be deployed and the associated energy crops would be developed. Renewables installed at highly dispersed scales in buildings are also known to be high job creators mainly for the construction sector.

Direct and indirect jobs in renewable energy are estimated to exceed 9.8 million globally in 2016, with EU accounting for about 12% (REN21, 2017). The European renewable energy sector employed 1.14 million people including direct and indirect jobs and created a turnover of about €153 billion in 2015 (EurObserv'ER, 2016). The largest employers in the EU renewables sector are wind industries, solid biomass, biofuels and solar PV that jointly accounted for about 80% of direct and indirect RES jobs in 2015.

An analysis of EurObserv'ER data shows an overall flat development in EU RES jobs in recent years. Job losses in RES sectors in 2016 are registered in several EU countries (most importantly in Germany and in Italy) driven by policy changes (planned replacement of Feed-in-Tariffs-FIT- by tendering, removal of priority dispatch for RES), decreased investment and rising automation. The political context is not clear enough for investors to sustain more positive market dynamics, while global and EU economic uncertainties (global energy prices, climate policies and the aftermath of the financial crisis) constitute further barriers. On the other hand, the EU renewable energy industries start to re-emerge after years of market contraction. In this context, the recent EU winter package (EC, 2016) and the adoption of the Paris climate agreement combined with more ambitious climate policies in major non-EU economies can lead to further expansion for EU RES market.

In recent years, employment in solar PV has declined driven by a large reduction of investment in solar PV in most EU countries and by a large-scale shift of PV panel manufacturing away from EU and towards Asian markets. The transition from FIT incentives to competitive tenders and feed-in-premiums for large-scale solar PV systems, combined with stagnation in EU electricity demand and reduced gas and coal prices imply additional challenges for new solar PV installations. In this context, electricity market design and new business models for solar utilities are receiving increased attention. Wind-related jobs have increased from 270.000 in 2011 to 332.000 in 2015. According to Eurostat, more than 12.3 GW of wind turbine capacity was installed across the EU in 2015, which is its highest installation level since 2012. Wind turbine manufacturing has also increased in EU confirming the leading role of the European wind power industry, driven mainly by German and Danish companies.

Figure 12 includes a breakdown of direct and indirect RES jobs into main technologies in EU in 2015 based on data from EurObserv'ER, 2016. Wind industry remains the largest RES employer accounting for 30% of overall RES-related jobs. Bioenergy forms account for about 42% of RES employment, most of which are located in solid biomass sector (28%), while the production of biofuels accounts for 8% and biogas for 6% of total RES jobs respectively. The share of solar PV jobs has drastically declined after 2011 and it represented only 10% of RES employment in 2015, while the share of small hydro power plants is 4%. The country allocation of EU RES jobs (Figure 12) shows that Germany is the largest RES job market with 322.000 jobs (28% of EU RES jobs); however Germany has lost about 50.000 jobs in 2011-2015 period mainly in the solar PV sector, while wind turbine installations and employment has increased. France, the UK, Italy and Spain are the next largest markets in terms of RES employment in the EU. Despite their relatively small size, Sweden and Denmark have a sizeable RES market; RES jobs in Denmark are concentrated on the manufacturing of wind turbines (Vestas) and in Sweden on the production of bioenergy and small run-of-river hydro power.

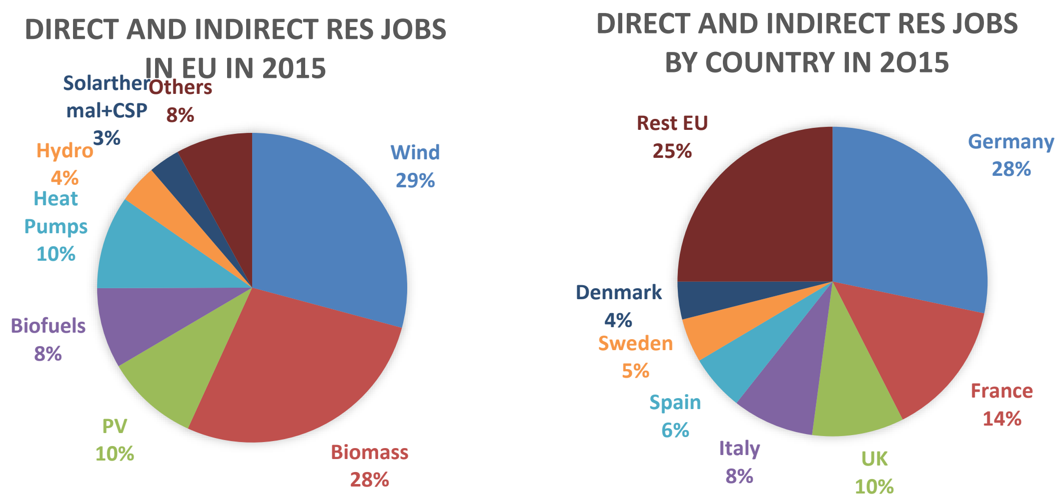



**Figure 12: Breakdown of direct and indirect RES jobs in the EU by technology and by country in 2015, Source: E3-Modelling based on EurObserv'ER, 2016**

Table 3 presents RES direct and indirect jobs by technology in EU countries in 2015. It must be noted that jobs in wind and solar PV are mostly concentrated on large market players, while jobs in solid biomass and hydro exhibit relatively wider geographical distribution across EU countries. This is related to the fact that the manufacturing of wind turbines and PV modules takes place in countries that have large domestic RES markets and have established the related RES manufacturing industries and supply chains (e.g. Germany, Denmark and Spain supply wind turbines to all EU countries). On the other hand, solid biomass is used for electricity production in almost all EU countries with biomass feedstock being produced predominantly in the same country (i.e. limited trade of solid biomass and related feedstock). Solid biomass includes all the solid organic components to be used as fuels including wood, wood waste (wood chips, sawdust, etc.), wood pellets, black liquors from the paper industry, straw, animal waste and other plant materials and residues. Germany is the largest wind and solar PV employer in the EU with 143 000 and 32 000 direct and indirect jobs respectively in 2015, while France is the dominant job market in solid biomass and in the emerging market of heat pumps.

| | Total | Wind | Biomass | PV | Biofuels | Heat Pumps | Biogas | Hydro | Solarther-mal +CSP | Geo-thermal | Waste |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Germany | **322300** | 142900 | 45400 | 31600 | 22800 | 16100 | 45000 | 6700 | 10600 | 1200 | |
| France | **162100** | 22000 | 50000 | 16150 | 22000 | 34700 | 4400 | 3900 | 5500 | 2850 | 600 |
| UK | **109200** | 41100 | 22300 | 16900 | 3900 | 8600 | 2800 | 5500 | 750 | 50 | 7300 |
| Italy | **97100** | 26000 | 22000 | 12500 | 6000 | 10000 | 5500 | 5000 | 3000 | 6000 | 1100 |
| Spain | **66400** | 22500 | 15800 | 6500 | 7500 | 7500 | 500 | 1600 | 4000 | 50 | 450 |
| Sweden | **52200** | 6500 | 27400 | 750 | 4500 | 7800 | 100 | 4000 | 100 | 50 | 1000 |
| Denmark | **44900** | 31250 | 4800 | 2500 | 1100 | 2400 | 250 | 50 | 1850 | 100 | 600 |
| Poland | **43300** | 11500 | 18800 | 1100 | 6000 | 750 | 800 | 1450 | 2750 | 100 | 50 |
| Austria | **37100** | 5500 | 15450 | 3400 | 1200 | 2200 | 650 | 5850 | 2800 | 50 | |
| Finland | **31350** | 3300 | 23700 | 50 | 1800 | 1600 | 250 | 400 | 50 | 0 | 200 |
| Nether-lands | **26850** | 6300 | 4100 | 7000 | 2800 | 4400 | 500 | 0 | 250 | 150 | 1350 |
| Portugal | **22650** | 2500 | 7800 | 750 | 1600 | 7000 | 150 | 2000 | 450 | 100 | 300 |
| Belgium | **22200** | 2800 | 3500 | 3400 | 7500 | 3000 | 550 | 350 | 450 | 50 | 600 |
| Romania | **17200** | 1100 | 11100 | 1300 | 650 | 0 | 50 | 2600 | 200 | 200 | |
| Czech | **16300** | 100 | 8900 | 1700 | 1400 | 650 | 900 | 1750 | 600 | 50 | 250 |
| Greece | **12950** | 2000 | 2800 | 1900 | 750 | 0 | 200 | 2500 | 2700 | 100 | |
| Hungary | **7550** | 100 | 4250 | 900 | 650 | 100 | 150 | 100 | 150 | 1000 | 150 |
| Bulgaria | **7500** | 200 | 3500 | 700 | 500 | 1900 | 100 | 400 | 50 | 100 | 50 |
| Latvia | **6600** | 50 | 6000 | 50 | 100 | 0 | 150 | 150 | 50 | 0 | 50 |
| Croatia | **6350** | 750 | 4600 | 150 | 150 | 0 | 150 | 250 | 200 | 100 | |
| Lithuania | **5450** | 1000 | 3600 | 100 | 300 | 50 | 150 | 50 | 50 | 100 | 50 |
| Estonia | **5300** | 100 | 3600 | 50 | 50 | 1350 | 50 | 50 | 50 | 0 | |
| Ireland | **4700** | 2500 | 600 | 50 | 400 | 300 | 200 | 200 | 250 | 0 | 200 |
| Slovakia | **4650** | 50 | 2700 | 400 | 550 | 50 | 200 | 400 | 100 | 150 | 50 |
| Slovenia | **3750** | 50 | 1800 | 300 | 200 | 400 | 100 | 750 | 50 | 50 | 50 |
| Luxem-bourg | **2100** | 50 | 150 | 150 | 1400 | 50 | 50 | 150 | 50 | 0 | 50 |
| Cyprus | **600** | 150 | 50 | 100 | 50 | 0 | 50 | 0 | 200 | 0 | |
| Malta | **400** | 0 | 0 | 300 | 50 | 0 | 0 | 0 | 50 | 0 | |
| **EU-28** | **1139050** | **332350** | **314700** | **110750** | **95900** | **110900** | **63950** | **46150** | **37300** | **12600** | **14450** |

**Table 3: RES direct and indirect jobs in EU countries in 2015 by technology, Source: EurObserv'ER, 2016**

## Employment in conventional energy supply sectors

The study aims to assess the current status of energy-related jobs based on granular, detailed statistical figures at sector and country level, including employment levels in energy sectors, employment structure and labour intensity. This section presents a detailed appraisal of the current situation regarding the employment characteristics of the EU energy supply sectors covering direct jobs in energy activities.

The approach used to reconcile employment data at the required level of sector disaggregation combines comprehensive data sets with information obtained from literature review to build up estimations for current employment levels in energy sectors in each EU country. As a starting point, the analysis exploits official employment statistics published by Eurostat, which provides two different statistical sets[10] for job figures: the Labour Force Survey (LFS) and the Structural Business Statistics (SBS). The LFS database is dedicated to the labour market with data originating from private households and covers employment by sector, unemployment and inactivity (Eurostat, LFS, 2017). SBS data are derived from enterprises and cover business activities in manufacturing, construction and services. Due to differences in methodology, figures in LFS statistics are generally higher than in SBS for most sectors. The analysis uses Eurostat's LFS data according to the Statistical Classification of Economic Activities in the European Community (NACE Rev.2). The following categories in NACE Rev.2 are relevant for the study of the energy sector and RES-related employment:

- B05.10: Mining of hard coal
- B05.20: Mining of lignite
- B06.10: Extraction of crude petroleum
- B06.20: Extraction of natural gas
- B07.21: Mining of uranium and thorium ores
- B09.10: Support activities for petroleum and natural gas extraction
- C19.10: Manufacture of coke oven products
- C19.20: Manufacture of refined petroleum products
- D35.11: Production of electricity
- D35.12: Transmission of electricity
- D35.13 and 35.14: Distribution and trade of electricity respectively
- D35.21: Manufacture of gas
- D35.22[11] and 35.23: Distribution and trade of gaseous fuels through mains (respectively)
- G46.71: Wholesale of solid, liquid and gaseous fuels and related products
- G47.30: Retail sale of automotive fuels in specialised stores

The analysis of energy-related employment requires a disaggregated breakdown of jobs at four digits of disaggregation (NACE Rev.2), while maintaining full consistency with Eurostat published figures. In particular, SBS data are used to apportion LFS figures to the required level of disaggregation (four digit). Remaining gaps at the country level due to poor data availability are covered using approximations, e.g. using labour intensity factors (in terms of jobs/ktoe) of countries with similar economic and employment structure. In cases that 2015 data are not available for a subset of countries and sectors, data for previous years (commonly for 2014) are used. The methodology ensures full consistency between employment and energy-related data, i.e. mining of hard coal implies job creation in the specific sector. The Eurostat figures for EU28 are often different from the sum of figures reported at country level. The main reason is that the sample at country level might be too small to comply with confidentiality standards. This can also occur for aggregations where Eurostat sometimes reports missing values for more

[10] National accounts are not used in the current study, as data for the energy sector are often incomplete.

[11] The sector D35.3 "Steam and air-conditioning supply" is not considered in the study, as it includes activities like the production and distribution of cooled air, production and distribution of chilled water for cooling purposes and the production of ice for food and non-food purposes, which are not related to the energy supply.

disaggregated figures. For internal consistency, the country figures are forced to sum up to the aggregated sector figures at the EU28 level. Overall, job figures used in the study remain comparable to the Eurostat LFS figures (Eurostat, LFS, 2017) by country and sector NACE Rev.2 at two digit level.

The total number of direct jobs in the EU energy supply and transport sectors in 2015 is estimated at 2.7 million jobs representing a share of about 1.2% of the European workforce. Figure 13 shows the shares of most important sectors in overall EU direct energy supply and transport jobs in 2015. The electricity sector is by far the largest employer supporting about 1.2 million jobs, with transmission, distribution and trade accounting for 24% of direct jobs in the energy supply sector and power generation representing a share of 20.2%. Coal and lignite mining jointly account for 11% of energy-related jobs, with oil and gas extraction employing about 8%. Other oil and gas-related activities (including oil refining, manufacture and transmission of gas) account for 14% of EU direct energy supply jobs in 2015. The sector "sales of fuels" is included in the analysis with 630k jobs in EU representing about 23% of direct energy supply jobs, with the majority employed in the retail sale of automotive fuels (480k jobs in 2015). It must be noted that jobs in fossil fuel extraction activities concern primary energy produced domestically in the EU. Employment in the refining, manufacturing, and distribution of fuels refers to the domestic processing of both domestic fuel production and imported volumes. The employment in fossil fuel extraction sectors in EU has been declining in recent years as a result of reduced production of coal, oil and natural gas and growing mechanization of mining and extraction activities.

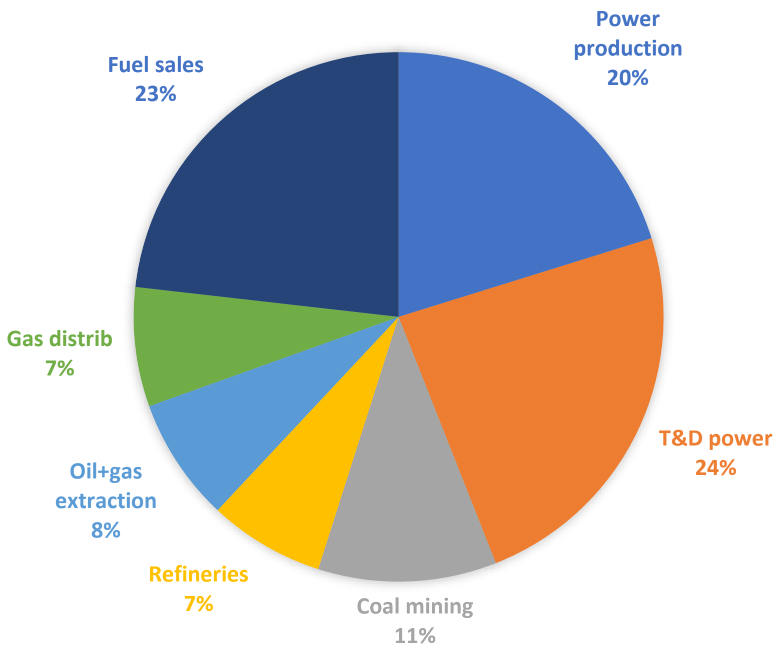



**Figure 13: Breakdown of direct energy supply jobs by sector in EU in 2015, Source: E3-Modelling calculations based on EUROSTAT LFS, SBS and other statistics**

As shown in Figure 14, three countries (Germany, the UK and Poland) account for 47% of direct EU-28 energy supply jobs. France and Italy register high employment figures representing about 8% of total EU energy-related jobs in 2015, with Spain and Romania following with a 6% share. In Germany and France, the electricity sector accounts for the large majority (about 65-75%) of overall direct energy jobs. In contrast, the share of electricity jobs is significantly smaller in the UK, in Romania and mainly in Poland; in these countries energy supply jobs are mostly generated in the extraction, manufacturing and sales of fossil fuels.

Mining of coal and lignite has a relatively high labour intensity (Table 4) and this constitutes an important social and economic challenge as ambitious climate policies would lead to elimination of most jobs in these sectors. Increasing automatization and mechanization implies relatively low labour intensities for extraction of crude oil and gas, while refinery processes require only 0.3 jobs[12] per ktoe produced. On the other hand, the high labour intensity of the electricity sector is an indicator of the importance of the sector in terms of employment. The retail sale of automotive fuels also registers high labour requirements with 1.34 jobs per ktoe of energy.

The large differences between EU Member States are mainly due to the diversity in their energy systems and economic/employment structure. A noticeable example is Poland that exhibits the highest number of employees in the coal mining sector accounting for 54% of EU jobs in this sector; coal mining accounts for 43% of all direct energy supply jobs in Poland (while the EU average is about 11%). In Romania, hydrocarbons' extraction accounts for 42% of total energy supply jobs in 2015. Therefore, employment in these countries is more vulnerable than most EU countries to ambitious climate policies (as those in Winter Package). In contrast, countries with limited domestic production of fossil fuels would tend to benefit from ambitious climate policies leading to substitution of imported fossil fuels with domestically produced RES.

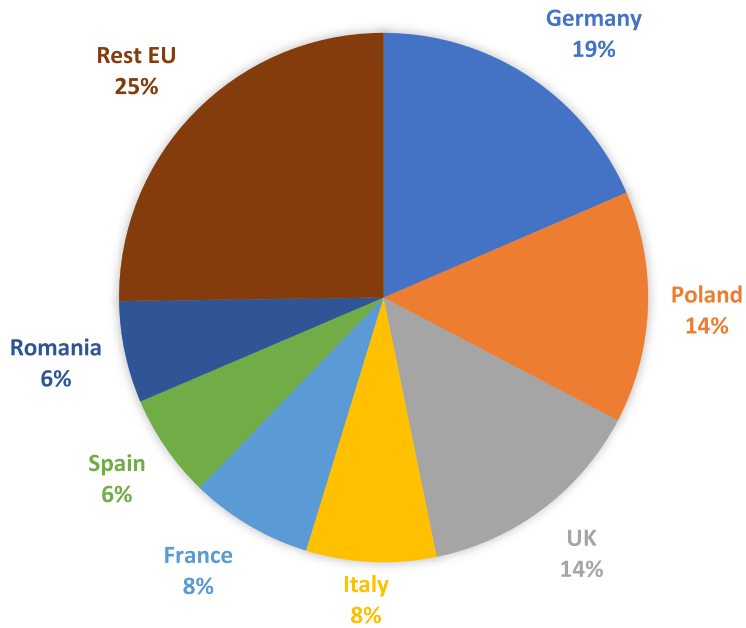



**Figure 14: Breakdown of EU direct energy supply jobs by country in 2015, Source: E3-Modelling calculations based on EUROSTAT LFS, SBS and other statistics**

[12] Labour intensity of energy-related activities is measured in terms of personnel years per unit of energy produced on an annual basis.

| | | Direct jobs (in 000s) | Energy (in ktoe) | Jobs/ktoe |
|---|---|---|---|---|
| B05 | Mining of coal &lignite | 295200 | 148196 | 1.99 |
| B.06 | Extraction of crude oil & gas | 89700 | 196967 | 0.46 |
| B06.10 | Extraction of crude oil | 46821 | 78529 | 0.60 |
| B06.20 | Extraction of gas | 42879 | 118438 | 0.36 |
| B09.10 | Support activities for crude oil & gas | 115029 | 196967 | 0.58 |
| C.19 | Manufacture of refined oil and coke | 191400 | 647936 | 0.30 |
| D.35.1 | Electricity | 1193013 | 265737 | 4.49 |
| D35.11 | Electricity production | 547347 | 265737 | 2.06 |
| D35.12-14 | Electricity T&D | 645666 | 265737 | 2.43 |
| D.35.2 | Gas transport and manufacturing | 197364 | 387731 | 0.51 |
| G46.71 | Wholesale of solid, liquid and gaseous fuels | 146011 | 1245426 | 0.12 |
| G47.12 | Retail sale of automotive fuels | 482638 | 360838 | 1.34 |

**Table 4: Labour intensity of energy supply activities in EU in 2015, Source: E3-Modelling calculations based on EUROSTAT LFS, SBS and other statistics**

The inclusion of RES-related jobs in the EU-28 increases the number of direct energy supply jobs to 3.3 million in 2015, representing about 1.5% of total EU workforce. RES direct jobs include jobs in the manufacturing, construction and O&M of power plants and jobs in bioenergy supply (agricultural feedstock), transport and conversion processes (for solid biomass, biofuels, biogas and waste). EU RES direct jobs are estimated at about 720k in 2015 with bioenergy accounting for 42% of them due to the relatively high labour intensity both in feedstock supply and in conversion processes (a detailed analysis on bioenergy jobs is included in section 4.5). Direct wind jobs are estimated at about 200k (including turbine manufacturing), while solar PV, hydro-power and biofuels are also important job creators. Employment in conventional energy supply sectors is 1.9 million jobs in 2015, with petroleum products accounting for about 830k jobs, generated mostly in retail fuel sales (gas stations), in refining and in extraction of crude oil. Coal represents a significant share (27%) in conventional energy supply jobs, while coal-related jobs are mostly created in coal mining (295k) and in O&M of coal power plants (155k). Gas-related jobs are estimated at about 450k and are relatively equally distributed in extraction of natural gas (90k), distribution and manufacture of gaseous fuels (210k) and in O&M of gas-fired thermal power plants (90k).

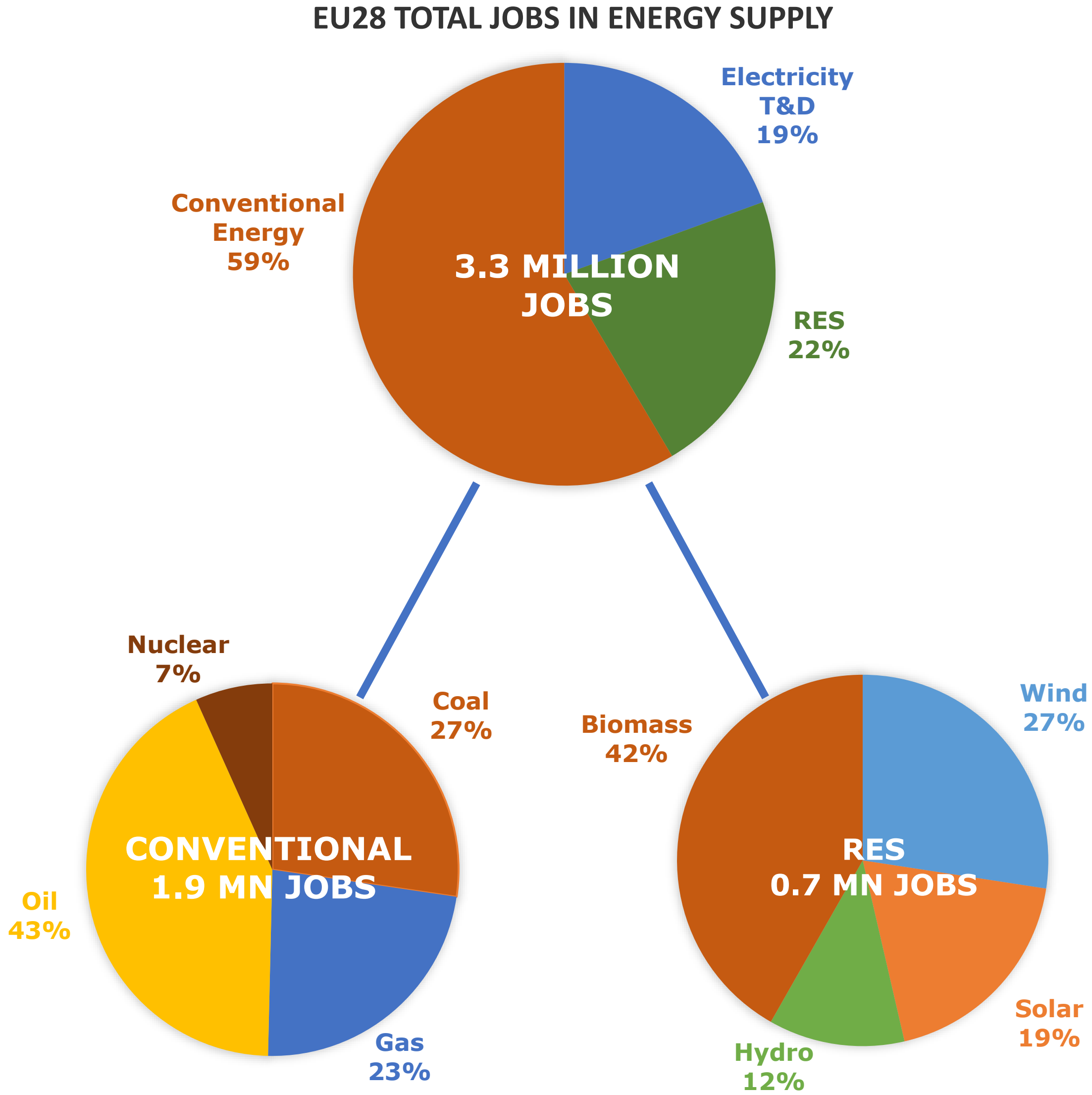



**Figure 15: Breakdown of EU direct energy supply jobs by energy form in 2015, Source: E3-Modelling calculations based on EUROSTAT LFS, SBS and other statistics**

### Employment in energy efficiency and manufacturing of electric vehicles

Energy efficiency can create job opportunities in the context of the low-carbon transition of the EU economy. However, it is difficult to define energy efficiency related jobs, since most of the relevant employment is embedded in a broad range of existing industries, like construction, vehicle manufacturing, lighting, heating and cooling equipment, electronics, appliances, and so on. For some aspects of energy efficiency jobs (such as jobs in building refurbishment and thermal insulation), the identification of direct employment is feasible; on the other hand the quantification of the proportion of a factory's employees required to make a hybrid car or a low-energy lightbulb is very difficult (IEA, 2017). Furthermore, the qualitative identification of energy efficient jobs is also challenging, as a jobs in building the hybrid drivetrain can be categorised as "efficiency" jobs, while employment in producing and installing other parts of the hybrid car (i.e. windows, seat belts, doors) has no connection to energy efficiency.

Energy efficiency employment involves (almost entirely) upfront jobs in the investment and construction stage, as there are usually no jobs related to the O&M of energy efficient equipment. Energy efficiency in buildings involves both investment in the retrofitting of buildings and deployment of energy efficient equipment (boilers, heating, ventilation and air conditioning systems, appliances and lighting). Most of energy-efficiency jobs in buildings are associated with the labour-intensive activity of refurbishing existing buildings, while for new buildings a small number of highly-skilled employees are required for the design of the building envelope and the heating, ventilation and air conditioning (HVAC) system.

A series of macro-economic studies for the EU have shown that energy efficiency measures tend to have positive employment impacts resulting mainly from the high domestic employment content of investment in thermal insulation, especially compared to activities related to fossil fuels, which are to a large extent imported in most EU countries. Previous studies suggest that a USD 1 million annual investment in building renovation would support 10-20 direct jobs and an additional 10-20 indirect jobs. Job types created in "green" energy efficient buildings include green designers, architects, auditors, engineers, project managers, and various jobs in the construction trades, such as pipe fitters, metal workers, and general construction workers. Most energy efficiency-related jobs are created during the initial construction period and are likely to be local jobs. Other jobs related to the "green economy" include jobs in the recycling industry, in smart grids and in the construction of battery recharging transport infrastructure (Bell, 2012; Pikas et al., 2015)

Despite the relatively small size of the electric car market, employment in the manufacturing of electric and plug-in hybrid vehicles (EVs) is increasing. However, as with other types of highly efficient products, it is challenging to separate EV-related jobs from total employment in car manufacturing, as many popular EVs like the Renault Zoe model, share a manufacturing platform with conventional internal combustion engine (ICE) cars (IEA, 2017). US DOE, 2017 estimated that the number of US workers involved in the production of EVs and related components is 12 000 direct manufacturing jobs and 42 000 indirect jobs along the entire value chain (US DOE, 2017). The main employment impacts from the large-scale electrification of road transport would be associated with the production and installation of the electric drivetrain, including the battery, compared to an internal combustion engine. On the other hand, the production of ICEs involves complex supply chains and requires more engineering resources than making an electric motor, but this difference may be offset by higher employment in battery manufacturing. The study (IEA, 2017) estimates that current battery manufacturing employs 8-12 employees to produce 1 000 EV batteries per year, which is slightly higher than jobs related to internal combustion engine manufacturing. As the deployment of EVs increases, there are large uncertainties for the impact of economies of scale and manufacturing maturity on labour requirements and therefore estimations for EV manufacturing jobs are highly speculative and would not be included in the study.

## Current status of employment in the electricity sector

Jobs in the electricity sector are derived from the Eurostat LFS database and are disaggregated into jobs in: i) power generation, ii) transmission, iii) distribution and iv) trade of electricity using appropriate shares from SBS statistics (Eurostat, SBS 2017). The analysis shows that the production and distribution of electricity are the largest job creators, while Germany has the highest number of employees in electricity. For the sector 'production of electricity', the NACE.Rev.2 classification does not allow further breakdown into distinct power generation technologies; however, this split is available in the North American Industry Classification System (NC-NAICS 2012) with job data derived from (Bureau of Labour Statistics, 2017). The analysis of employment impacts from RES expansion requires a breakdown of power generation jobs into distinct technologies. Due to the lack of a comprehensive database, the breakdown of power generation jobs to distinct technologies is based on employment factors for direct O&M jobs by technology as derived from published literature combined with official statistics of Eurostat, LFS database (LFS, 2017) and with official US data (BLS, 2015).

Extensive literature is used to estimate appropriate employment factors for direct jobs in O&M of power generation technologies. Employment factors have been estimated by various studies for different RES, most commonly for wind and solar PV technologies. However, few studies estimate labour intensities for all power technologies including fossil fuels and nuclear; this complicates the comparison of employment factors between renewable and conventional power generation technologies. The analysis focuses on: (1) studies including up-to-date estimations for employment factors, (2) studies including all power producing technologies and (3) studies for EU countries. Thus, employment factors from three recent comprehensive studies, namely Greenpeace (2015), Wei et al (2011) and UNEP (2008), are combined with official USA data (BLS, 2015) and their average is utilised for the EU. For solar PV technology, data derived from (JRC, 2015) are used, as the study is heavily focused on EU and includes consistent labour intensity estimations.

| | Green-peace 2015 | Wei 2011 | USA 2017 | UNEP 2008 | Average |
|---|---|---|---|---|---|
| Wind | 0.25 | 0.24 | 0.05 | 0.08 | **0.20** |
| Photovoltaics | 0.70 | 0.52 | 0.13 | 0.17 | **0.15** |
| Concentrated Solar Power | 0.60 | 0.50 | 0.13 | | **0.31** |
| Tidal & wave | 0.30 | | | | **0.30** |
| Geothermal | 0.40 | 1.70 | 0.28 | | **0.51** |
| Large hydro | 0.20 | 0.48 | 0.06 | | **0.18** |
| Small hydro | 4.90 | 1.14 | 0.06 | | **0.28** |
| Biomass power plants | 1.50 | 0.24 | 0.08 | 0.16 | **0.24** |
| Coal | 0.24 | 0.18 | 0.13 | 0.22 | **0.20** |
| Oil | 0.14 | 0.10 | 0.11 | 0.11 | **0.15** |
| Gas | 0.14 | 0.10 | 0.11 | 0.11 | **0.14** |
| Nuclear | 0.60 | 0.70 | 0.46 | | **0.59** |

**Table 5: Labour intensity of O&M of power technologies (in jobs per MW), Source: E3-Modelling based on Greenpeace (2015), Wei et al (2011), UNEP (2008) and USA data (2015)**

Jobs in the manufacturing and installation of power generation technologies are commonly reported in terms of person-years per MW in order to reflect the transient nature of these jobs as the process of construction and manufacturing is usually linked to a specific year (1 person-year implies full-time employment of one person for a duration of one year). In contrast, jobs related to the O&M of power plants last during the entire lifetime of the power plant. Direct jobs in the construction of power plants are created during the installation phase and have a particularly high domestic/local content. The phases of construction and manufacturing are examined separately in contrast to most studies. The main reason for this is related to the different nature of manufacturing and installation jobs, as the latter are to a large extent domestic, while the manufacturing of technologies is a global market and jobs are located in countries producing the required equipment. The range of published employment factors for installation stretches roughly over an order of magnitude divergence between minimum and maximum values, while regional differences are large. In the current study, the construction employment factors from (Rutovitz et al, 2015) are used, as the study used recent data for Europe and includes a comprehensive estimation for all power generation technologies.

The construction and manufacturing of equipment are generally more labour intensive than O&M of power plants, as relatively few jobs are involved in running and maintaining most types of power stations. This implies that in order to sustain jobs over time, continual capacity additions are needed (IEA, 2017).

| | Manufacturing | Installation | O&M |
|---|---|---|---|
| **Wind** | 4.35 | 2.60 | 0.20 |
| **Photovoltaics** | 5.36 | 10.40 | 0.15 |
| **CSP** | 3.65 | 8.00 | 0.31 |
| **Tidal & wave** | 10.20 | 10.20 | 0.30 |
| **Geothermal** | 5.40 | 11.20 | 0.51 |
| **Large hydro** | 3.50 | 7.40 | 0.18 |
| **Small hydro** | 10.90 | 15.80 | 0.28 |
| **Biomass** | 2.90 | 14.00 | 0.24 |
| **Coal** | 5.40 | 11.20 | 0.30 |
| **Oil** | 0.93 | 1.30 | 0.15 |
| **Gas** | 0.93 | 1.30 | 0.14 |
| **Nuclear** | 1.30 | 11.80 | 0.59 |

**Table 6: Employment factors for the manufacturing, installation and O&M of power technologies (in jobs per MW), Source: E3-Modelling based on Rutovitz et al, 2015 and Cameron et al, 2015.**

The volatility in construction and manufacturing jobs is high as they depend on investment, market and competitiveness dynamics that can rapidly change; this is demonstrated by the large decline in solar PV jobs (Figure 16) from 220 000 in 2011 to 120 000 in 2015 due to the drop in capacity investment (from 21 GW in 2011 to 8 GW in 2015) and the relocation of solar PV manufacturing to Asia (with EU production dropping from 7 GW in 2011 to 2.5 GW in 2015). On the other hand, wind jobs have increased from 143 000 in 2011 to 200 000 in 2015, as the EU has expanded domestic turbine manufacturing (including exports to non-EU countries) and domestic wind turbine installations. This enables the creation of both direct jobs in wind turbine manufacturing and indirect jobs in sectors supplying the required materials and sub-components. Jobs in the O&M of wind farms and solar PV power plants are constantly growing as a result of increasing RES capacity and RES-based electricity production. The above show the importance of the domestic establishment of clean energy manufacturing and the development of integrated domestic supply chains in order to maximise job creation potential from RES expansion and low-carbon transition.

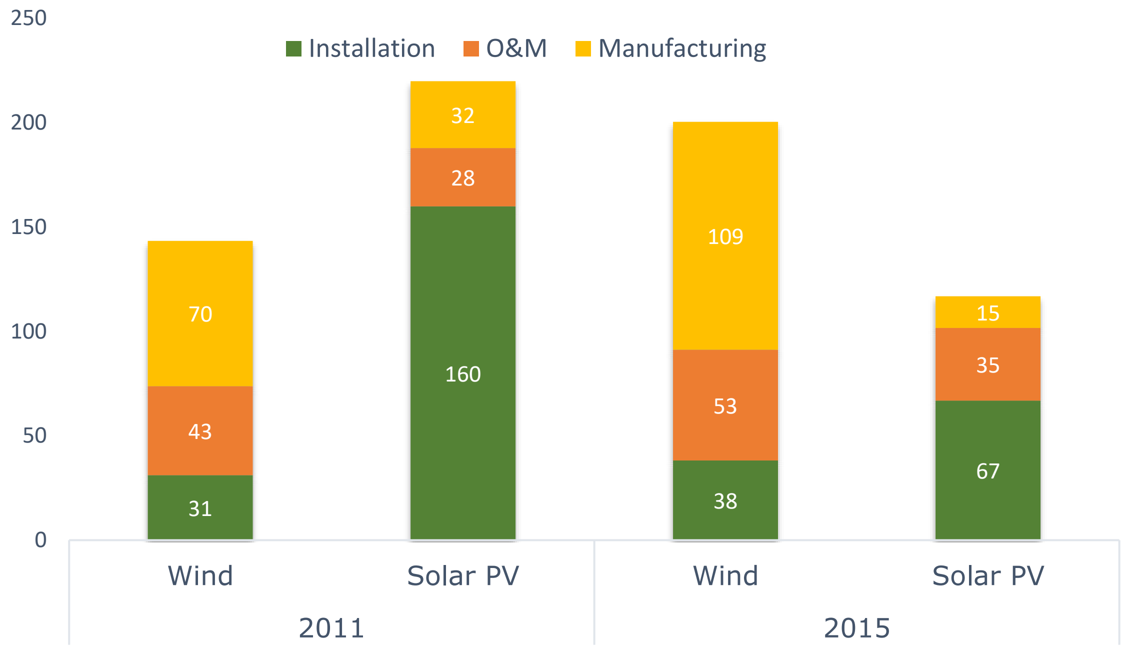



**Figure 16: EU direct wind and solar PV jobs in 2011 and in 2015 (in 000s), Source: E3-Modelling calculations based on EurObserv'ER, 2016 and JRC, 2015**

Fuel supply also creates direct jobs when domestically-produced energy forms are used. The estimation of fuel supply jobs for conventional power generation technologies takes into account jobs in the entire value chain including the sectors: a) coal mining, b) oil and gas extraction, c) support activities for oil and gas, d) refinery processing, e) gas transport, f) fossil fuel sales. In parallel, biomass supply creates employment in the agricultural sector and in processing industries, but also in research, engineering, and distribution. Direct bioenergy supply jobs are derived from the breakdown of (Eurobserver, 2016) data into direct and indirect jobs based on shares calculated by Nathany et al, 2012 for major EU economies. The analysis considers the main bioenergy sectors separately and in particular solid biomass, biofuels, biogas and waste. Upstream fuel supply activities in agricultural, farming and forestry sectors[13] are included, while the analysis separates jobs in the production of biomass feedstock and in conversion processes. Direct jobs in the production of biofuels by country are derived from (Ronzon et al, 2017). Direct and indirect jobs related to bioenergy are estimated at 490.000, with solid biomass accounting for about two thirds (Eurobserver, 2016). The breakdown methodology leads to an estimated EU-28 labour intensity of 1.63 jobs/ktoe for biomass supply (including feedstock, conversion and transport) which is consistent with recent estimates by Wei et al, 2016 (1.51 jobs/ktoe), Greenpeace, 2016 (1.75 jobs/ktoe) and lower than AEBIOM, 2015 (2.2 jobs/ktoe). The analysis also considers that different bioenergy inputs are used in power plants, ranging from solid biomass to biogas and waste, while detailed results from the PRIMES Biomass model are used to estimate the domestic content of each type of feedstock used and each bioenergy conversion process. Most of production and jobs related to solid biomass and its feedstock is created domestically, as there is minimal bioenergy trade in EU countries.

Figure 17 summarises the estimations for direct jobs in power generation technologies including activities of installation, manufacturing, fuel supply and O&M of power plants

[13] It must be noted that the activity of "self-production/consumption" of wood by individual households and the informal market is not included in the analysis.

in 2015. RET dominate EU investment in power generation as they account for 70-80% of capacity additions in 2011-2106 (Eurostat, 2017). Combined with the high labour intensity of RES in the construction stage (especially for solar PV), this implies that RES account for 43% of power generation jobs in 2015, while their share in electricity production is 29%. On the other hand, nuclear jobs are estimated at about 150k (in line with Foratom, 2010 estimations) representing about 13% of total EU power production jobs, almost half of their share in electricity generation.

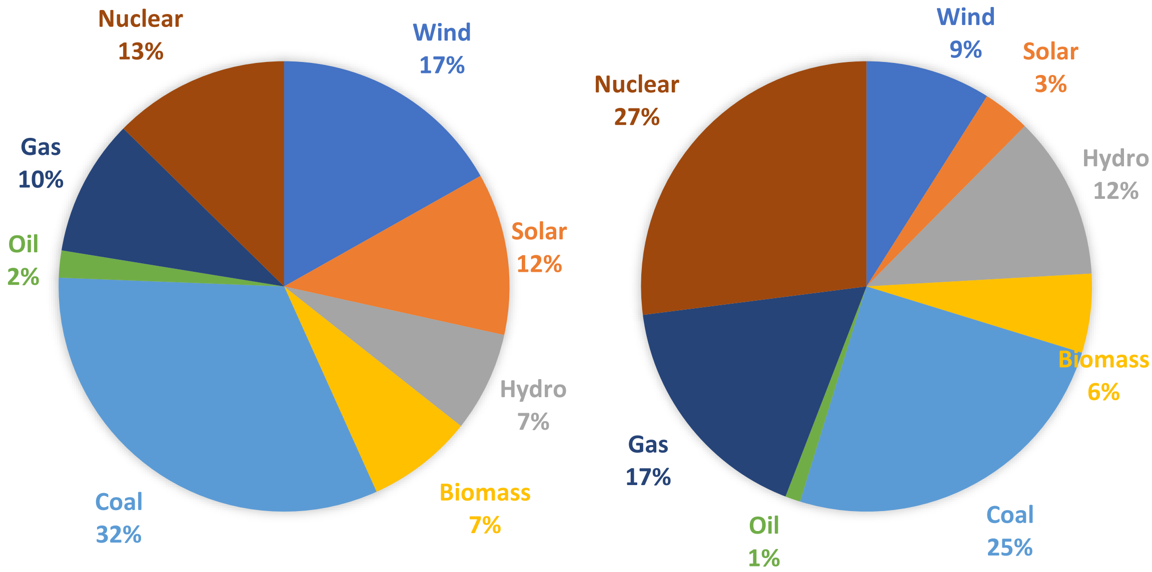



**Figure 17: Jobs in power technologies in 2015 in manufacturing, installation, fuel supply and O&M of power plants (left graph) and EU electricity production in 2015 (right graph), Source: E3-Modelling calculations based on EUROSTAT LFS, SBS, EurObserv'ER, 2016 and other statistics**

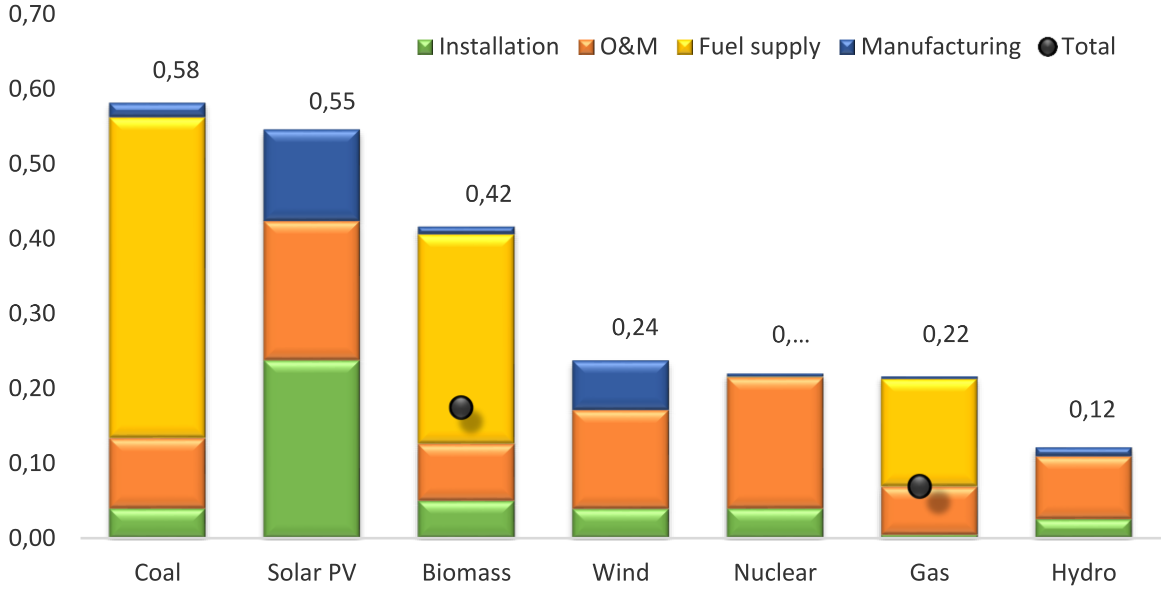
## Comparative analysis of labour intensities in power generation and in road passenger transport

Our analysis on the job creation potential of alternative power generation technologies illustrates that solar PV and coal-fired power plants are the most labour intensive types of generating technology measured as jobs per GWh of annual electricity production (Figure 18). The study includes estimations for direct jobs in the entire chain activities, namely in the manufacturing of equipment, in the construction of power plant, in the O&M and in fuel supply (for fossil fuels and biomass technologies). The analysis takes into account the different nature of jobs, as jobs in O&M of power plants are permanent (during the lifetime of plants), while jobs in construction and manufacturing of equipment are created when the investment takes place. In order to consistently compare employment related to different activities, jobs in construction and manufacturing are averaged over the entire lifetime of power plants; thus, we calculate permanent Full Time Equivalent (FTE) jobs for each activity related to generation technologies. The estimations are based on installation and manufacturing employment factors from multiple recent studies (described in previous section), while official data from EUROSTAT (LFS and SBS statistics) and from USA (BLS, 2015) are combined to derive consistent estimates for jobs in O&M of power plants by technology. Fuel supply jobs are directly derived from Eurostat databases (Eurostat, LFS 2017).

Solar PV jobs are mainly generated in the construction stage and are inherently local. PV systems have a high labour intensity because of their small unit size, the customised nature of installation work and the low capacity factors implying high capacity requirements to produce the same amount of electricity as conventional fossil-fuel technologies. Fuel-based technologies are more labour-intensive in fuel supply for coal, biomass and gas. This would create job losses in countries producing large amounts of coal domestically like Poland and Romania in case of power system restructuring away from fossil fuels. The labour intensity of wind power, nuclear and gas-fired power plants is comparable, as they generate about 0.22-0.24 jobs per annual GWh, while large hydro power plants generate only 0.12 jobs per annual GWh; this is mainly due to the long lifetime assumed for hydro power plants (commonly 60 years). Gas-fired power plants are less labour-intensive than coal as construction periods are commonly shorter, gas extraction is less labor intensive than coal (as shown in section 4.4) and O&M are more streamlined. O&M account for a significant share of employment related to coal-fired power plants and nuclear power stations. The results of the analysis are consistent with recent labour intensity estimates for alternative generating technologies of the International Energy Agency (IEA, 2017).

Installation and O&M of power plants create jobs domestically, while jobs in equipment manufacturing are located in major industrial players producing power generation technologies and not necessarily in countries where investment and installation take place. In general, RES have a higher domestic job content relative to fossil fuels, as jobs in gas and coal supply are largely generated in non-EU countries; the EU-28 region imported about 69% of its natural gas requirements and about 45% of its coal demand in 2015. The industrial manufacturing of technologies is a global market and jobs are concentrated on main industrial producers, with the EU producing domestically most of technological equipment it requires, except for solar PV modules that are largely imported to the EU from Asian countries (imports to the EU account for about 65% of the EU solar PV demand in 2015).

Technological progress has been a key component of the improving competitiveness of RET, partly by reducing their labour intensity. This is especially the case for solar PV, as the production of PV panels has benefited from standardisation and mass manufacturing due to the rapid expansion of PV installations. Wind power, which is significantly less labour-intensive than solar PV, has seen major improvements in labour productivity through technological advances in recent years induced by the increasing size and capacity factor of wind turbines (IEA, 2017). On the other hand, manufacturing larger capacity wind turbines does not need proportionally more workers. Similarly, the number of construction jobs per MW of solar PV and wind power has declined in recent years. The above are illustrated by the declining employment factors for the O&M, construction and manufacturing of RET reported in related studies, in particular in (Wei et al, 2011) and in (Cameron et al, 2015) that provide a detailed literature review for the topic based on more than 70 studies and data sources.



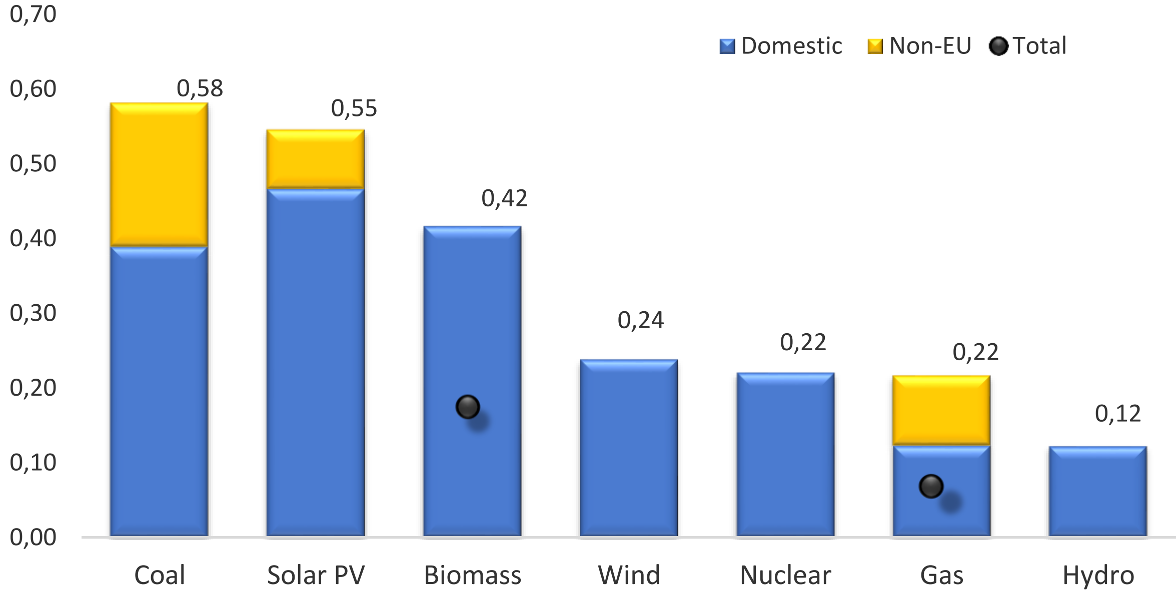




**Figure 18: Labour intensities (in jobs/annual GWh of produced electricity) and domestic content of activities related to power generation technologies in 2015, Source: E3-Modelling calculations**

Figure 19 shows direct employment intensities in the entire chain of activities of road transport fuels, including production/extraction, processing, transport and fuel sales and distribution (mainly via gas stations). Electricity and biofuels are estimated to be more labour intensive relative to oil products (in terms of jobs per ktoe), while their domestic content is also higher, as petroleum products are largely produced in non-EU countries and are then imported to EU (this is especially the case for the extraction of crude oil). The low labour intensity of oil products is mainly a result of mechanization and streamlining of related extraction and refining processes. The EU imported a small share of its biofuel feedstock requirements in 2015. Activities related to the refining of oil products, biomass feedstock and processing, electricity production and T&D, fuel sales and distribution are mostly generated domestically in the EU.

It is important to estimate job intensities of fuels with respect to the transport activity (e.g. per vehicle-km). The high efficiency of battery electric and plug-in hybrid cars implies lower demand for electricity and hence lower creation of jobs relative to biofuels and petroleum products to satisfy the same amount of mobility requirements. On the other hand, biofuels are more labour intensive and have a higher domestic content than other options; this can be particularly important for the EU low-carbon transition, in which advanced 2nd generation biofuels are massively deployed after 2030, creating domestic jobs in feedstock supply, transport and conversion processes.

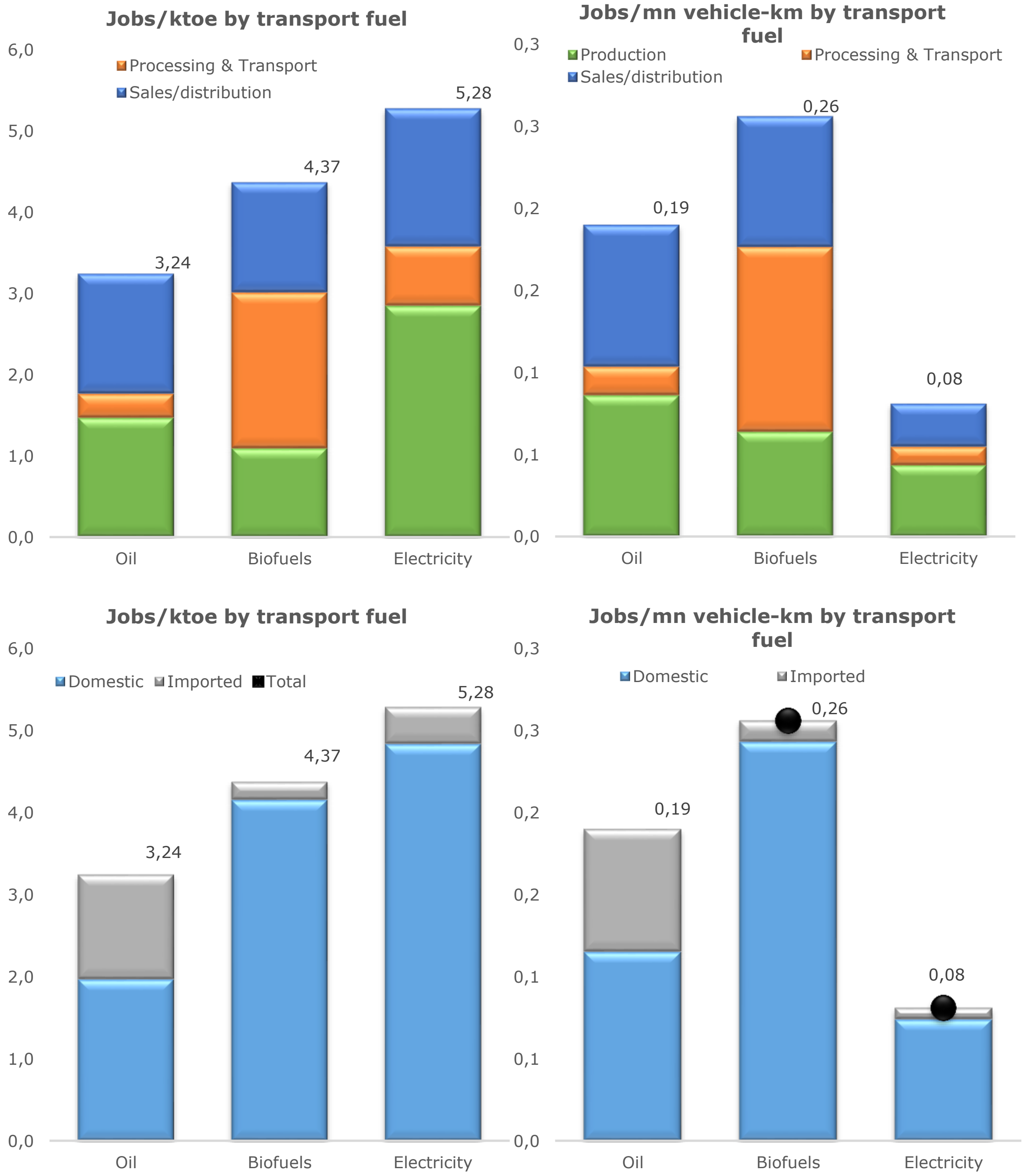



**Figure 19: Labour intensities and domestic content of energy activities related to passenger car technologies in 2015, Source: E3-Modelling calculations**

## Skill qualifications in RES and conventional energy sectors

The assessment of the employment structure in the energy sector in terms of education level is crucial for the analysis of job impacts from RES expansion. It is acknowledged that a shift in the required education levels of the labour force can have large impacts on job creation causing potentially a mismatch between labour supply and demand. Cedefop (the European Centre for the Development of Vocational Training) has developed a three level classification of education and qualification levels ranging from low to medium and high education levels. The Skills Forecasts online database of Cedefop (2013) provides estimations for the number of low, medium and highly qualified workers per energy activity.

According to Cedefop data, oil and gas extraction and the manufacture of fuels (gas and electricity) have the highest share of highly qualified workers (about 35-43% of overall employees). The analysis shows that the distribution of qualification levels is roughly similar for all conventional energy supply activities, with low-qualified employees accounting for about 10% of the labour force, medium-qualified for 50-60% and high qualified having a share of about 40%. The major exception is solid fuel mining, requiring the lowest share of highly qualified workers (15%). Taking into account all EU economic sectors, 22% of the EU labour force is categorised as low-qualified, 48% medium qualified, and 30% highly qualified (Cedefop, 2013); therefore, the energy supply sector employs a relatively higher-qualified labour force compared to the overall economy.

| Activities | Low-qualified | Medium-qualified | High-qualified |
|---|---|---|---|
| Mining of coal and lignite (B05) | 10% | 75% | 15% |
| Oil and gas extraction (B06+B09.1) | 11% | 47% | 42% |
| Manufactured fossil fuels (C19) | 11% | 46% | 43% |
| Electricity supply (D35.1) | 8% | 55% | 37% |
| Transportation of gas (D35.2) | 7% | 60% | 33% |
| RES sources (based on studies) | 5% | 50% | 45% |

**Table 7: Assessment of required qualification levels in energy supply sectors, Source: Cedefop (2013) and other studies (Lehr, 2011), (RenewableUK, 2013), (Herrero, 2010)**

The employment structure of the renewable energy sector is not included in official Eurostat and Cedefop data. Several job types related to renewable energy require a highly skilled workforce with industrial surveys in Germany indicating that RES-related jobs are on average more high-skilled than conventional energy supply industries with 40% of employees having a university degree compared to an industrial average of 10% (Lehr, 2011). Studies from the Observatory for Sustainability in Spain found that 50% of the RES sector workforce has a tertiary degree (Jimenéz Herrero and Leiva, 2010). A study from UK (RenewableUK, 2013), shows that 43% of the people employed in the UK wind and marine energy industries are highly qualified. Overall the analysis shows that RES sectors require a higher share of highly-qualified workers than in coal mining (40-50% in RES sectors compared to 15% in coal mining activities).

Thus, energy system decarbonisation and large-scale RES expansion would result in a replacement of low and medium qualified jobs in coal mining by highly qualified jobs in RES industries. This should be incorporated in the assessment of employment impacts of RES expansion as a potential shortage of highly skilled labour can undermine the cost-efficient transition towards RES, while causing intensification of competition between companies for skilled labour.

However, it is difficult to establish explicit figures on the exact proportion of skilled jobs in different RET, due to large variation in the context of different studies and the different educational norms in each country. In wind and solar PV technologies, high-level qualifications are required in activities such as engineering, project development, R&D and financial analysis. By contrast, construction jobs require vocational qualifications, while unskilled jobs are also created indirectly (transport and administration). Biomass technologies involve jobs in the production and collection of feedstock (farmers), as studies from Brazil have estimated that unskilled workers make up 60% of the biofuels workforce, while skilled labor accounts for about 30% (APEC EWG, 2010). However, increased mechanization can change the picture with jobs of low-skilled farmers been replaced by mechanical harvesters. Pollin et al (2009) showed that manufacturing and construction accounted for most wind and solar PV jobs, while agriculture represented about 60% of employment in the biomass sector. Highly-skilled professional occupations including lawyers, financial managers, accountants, specialised energy system designers and scientific personnel are required in renewable energy sectors. In contrast, resource extraction and administrative/professional occupations account for the majority of jobs in fossil fuel sectors.

The transition to a low-carbon economy and green jobs should be as equitable as possible and specific policies should be designed to alleviate negative impacts in low-qualified workers that commonly have low incomes. The low-carbon transformation would impact EU workers with many benefitting (especially highly-skilled personnel), while others will face problems as certain industries and occupations will decline, i.e. coal miners. Policies directed to support the employment transition should be enforced (including job retraining programs, incentives for lifelong learning, increased flexibility in labour markets) in order to allow for an equitable and social just transition to the low-carbon economy with limited negative implications for the poorer income classes.

# RES evolution in alternative scenarios

## The Reference context

The Reference scenario conceptualises the benchmark scenario that assumes continuation of present trends and full implementation of energy and climate policies adopted or concretely decided until the end of 2014, which however are not sufficient for the transition to a low carbon economy by 2050 as targeted by the EC, Winter Package 2016. The Reference scenario used in the study is based on the publication of the European Commission (EC Reference scenario, 2016).

The main EU climate policies simulated in Reference scenario include: i) the EU ETS Directive with the annual reduction factor of 1.74% continuing to 2050, ii) the Renewable Energy Directive (Directive 2009/28/EC) including National Renewable Energy Action Plans, iii) implementation of adopted energy efficiency policies including the Energy Efficiency Directive (EED), Ecodesign and labelling measures and Energy Performance of Buildings Directive (EPBD), iv) $CO_2$ standards regulations for cars and vans for 2020 which are kept constant after 2020, v) GHG Effort Sharing Decision including the binding 2020 targets for non-ETS emissions, and vi) other relevant directives on electricity and gas markets, fuel quality, grid expansion, F-gas regulation and a spectrum of relevant national policies. Reference policies (including energy efficiency, RES support measures and $CO_2$ standards for cars) are assumed to continue but not to be intensified post-2020, except for ETS.

The Reference scenario develops on exogenous assumptions on the main socio-economic drivers, which build on recent demographic and economic projections for the EU countries provided by Eurostat and the joint work of the Economic Policy Committee and the European Commission. In particular, the "2015 Ageing Report" is the starting point providing medium and long term population and GDP growth trends while the short term GDP growth projections are derived from DG ECFIN. Fossil fuel import prices are projected to increase after their collapse in 2014-2016 period driven mainly by low-ambition climate policies worldwide, rapid motorization of emerging economies and tighter global supply in oil and gas markets; fuel import prices are derived from (EC Reference scenario, 2016).

RES are projected to expand significantly in the Reference context, driven mainly by rapid cost reductions, increased fossil fuel prices and the continuation of RES support policies. The Reference scenario assumes that the binding RES 20% target for the EU and Member States will be met by 2020, while RES share is projected to constantly increase to 24% in 2030 and 31% in 2050. RES expansion is accelerated in the 2015-2020 period so as to meet the EU RES target, while after 2020 a deceleration in RES investment is projected; this reflects the lack of binding targets for the period after 2020, sustainability considerations for bioenergy products, efficiency improvements in final demand sectors and the limited expansion of biofuel use following recent policy signals. On the other hand, a large growth is projected for wind and solar PV, which jointly account for 36% of EU-28 power generation in 2050 (up from 12% in 2015).

## The Winter Package (EUCO context)

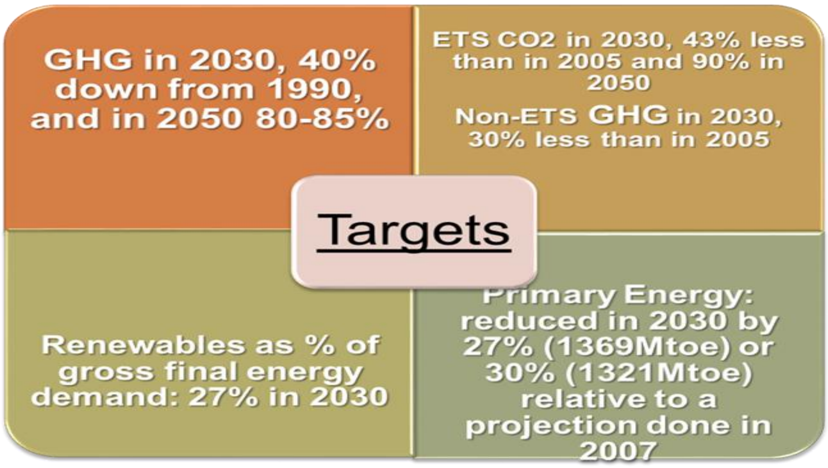
Future employment implications from RES expansion are assessed in the context of the recent “EC winter package” and in particular the EUCO30 projection. EUCO scenarios are used in the study because they reflect the most recent proposal of the EC and because they include comprehensive projections for RES expansion in all sectors of the energy system, namely electricity, heating and cooling and transport. The projection includes also all the necessary details to identify developments in the entire value chain of RES technologies and mainly in biomass/waste, the feedstock producing bio-energy, the conversion industry, as well as imports of bioenergy and related feedstock.

The EUCO scenarios are designed to achieve the 2030 targets as agreed by the European Council (EC, 2014). In particular, the EUCO30 scenario achieves the 40% GHG emission reduction target (and the split of ETS/non-ETS reducing by 43%/30% in 2030 compared to 2005), a 27% share of renewables and the energy efficiency target of 30%. EUCO scenarios are compatible with the European INDC submitted to Paris COP21 Agreement and with the long-term global 2ºC temperature target (European Commission, 2014). The scenario reflects the current EU energy and climate policy design when modelling the cost-effective achievement of 2030 targets (E3MLab & IIASA, 2016). After 2030, EUCO scenarios achieve also the long-term milestone to reduce GHG emissions domestically in the EU by 80% in 2050.

EUCO scenarios use a combination of policy instruments including ETS carbon pricing, energy efficiency standards, strengthening of $CO_2$ standards in road transport, reduction of market barriers as well as broad incentives/obligations related to energy efficiency and renewable energy policies. Policy instruments are applied in a coherent manner across Member States, taking into account the current policy framework and national conditions. In particular, the EUCO scenarios assume: a) Increased ETS linear factor to 2.2% after 2020 and implementation of the Market Stability Reserve, b) RES support policies in electricity, transport and in heating sectors, c) Increased energy efficiency policies, more stringent eco-design, enhancement of EED, support for heat-pumps and Best Available Techniques in industry, d) Strengthening of $CO_2$ standards for cars and vans, e) reforms in power and gas markets enhancing integration of balancing and competition.

Overall, the EUCO scenarios reflect a cost-efficient achievement of GHG reduction targets in the context of alternative efficiency and RES targets and existing policy mix. The EUCO30 scenario essentially implements the European Council guidance of "having in mind a target of 30%" for the review of the Energy Efficiency target for 2030. In EUCO context, coordination policies are assumed to enable the long-term decarbonisation of the energy system. Coordination policies include policy instruments that ensure the materialisation of the necessary conditions for decarbonisation by 2050 (E3MLab & IIASA, 2016). Coordination policies are related to infrastructure developments that would enable a larger exploitation of cost-effective emission reduction options after 2020, such as grid developments, as well as R&D towards clean energy technologies and increased public acceptance that are expected to be required to meet long term decarbonisation objectives.

The achievement of the 27% RES share target for 2030 is ensured by the imposition of appropriate RES values applied in the electricity, heating & cooling and transport sectors. In parallel, acceleration of energy efficiency improvements is driven by the establishment of efficiency values in all sectors, the increasing rate and depth of renovation as well as behavioural changes and dedicated national policies depicted by the application of energy efficiency values. Financial instruments and other financing measures on the European level facilitate access to capital for investment in thermal renovation of buildings. Specific policies are applied in relevant sectors, including reduced CO2 standards in road transport, more stringent eco-design standards in industries and policies facilitating the uptake of heat-pumps in households (E3MLab & IIASA, 2016).




## The role of RES in the low-carbon transition context

Increasing awareness for climate change, growing security of supply concerns, rising fossil fuel prices and decreasing RET costs constitute the driving factors for the recent explosion of investment in renewable energy. Economies of scale, support policies and learning by doing effects are the major drivers towards RET cost reductions in recent years, allowing consumers to benefit from competitive RES-based energy services. The EU is at the forefront of RES development, while in the Energy Union Framework (EC, 2015) the EU commits itself to become the world leader in renewable energy and the global hub for clean energy innovation and development of the next generation renewable technologies. The EU has also set a target that at least 27% of the energy consumed in the EU in 2030 should be from renewable sources.

The Renewable Energy Directive (European Commission, 2009 and 2016) constitutes a key driver for RES expansion. In parallel, RES are relevant to all five dimensions of the Energy Union.

- RES contribute to improved energy security with estimated fossil fuel import savings amounting to €16 bn in 2015 and to €58 bn in 2030 in the low-carbon EUCO policy context
- Renewable energy is one of the key decarbonisation pillars contributing to lower GHG emissions
- RES can be integrated into the competitive EU electricity market driven by rapid cost reductions. The recast of the RES directive (EC, 2016) together with Market Design proposals will further enable the participation of RES on an equal basis to other energy sources.
- RET play a major role in making the EU a global leader in innovation, while the EU is a pioneer in RES, holds 30% of RES patents globally and prioritizes R&D for clean energy sources (EC, 2015)
- Renewables can contribute to energy efficiency improvements, as they have lower energy intensity relative to fossil fuels in the electricity and heating sectors.

Despite their advantages, renewable sources often face non-economic barriers that vary across countries and sectors (e.g. different technology standards). The EC winter package assumes effective removal of barriers for RES as an important part of the overall policy context towards decarbonisation of the EU energy system (E3MLab & IIASA, 2016). EU and national policies are crucial for ensuring a positive investment environment, predictability of policy and economic framework, sufficient rates of return on initial investment (or a limited payback period) and for mobilising the required amount of financial resources. Coordination policies also relate to the development of clean energy infrastructure that enables increased and cost-effective exploitation of RES. EU and national policies are crucial to ensure the efficient implementation of the 2030 targets, going beyond typical time horizons in the business world. Key policies towards a low-carbon transition include (among others):

- Feed-in premiums for RES technologies in power generation sector
- Reform of the EU ETS market towards reduction of ETS allowances and tighter supply conditions
- Sectoral RES policies and targets to enhance penetration of RET in all energy sectors
- Phase out of subsidies for carbon intensive industries (mining of solid fuels and oil extraction)
- Establishment of policies to promote domestic RET manufacturing activities
- Ambitious and coordinated targets for GHG reduction, RES deployment and energy efficiency
- Regulatory tools and mechanisms to drive the development of RET and “green” jobs.
- Increases in eco-taxes that are already implemented in several European countries
- Adopt stringent eco-labelling for all products and goods to ensure responsible purchasing decisions of individual consumers (and hence encouraging manufacturers to design low-carbon products)
- Provision of higher public funding for clean energy innovation

The above policies should be integrated in the economic, investment, trade, innovation and labour market policy context of the EU, in order to ensure cost-efficiency and effective coordination of low-carbon policies with the overall EU macro-economic targets. In this way, negative distributional implications of clean energy policies for the low-income classes and low-qualified workers would be avoided, while consistency between climate, trade and investment policies would improve their activity growth and employment potential.

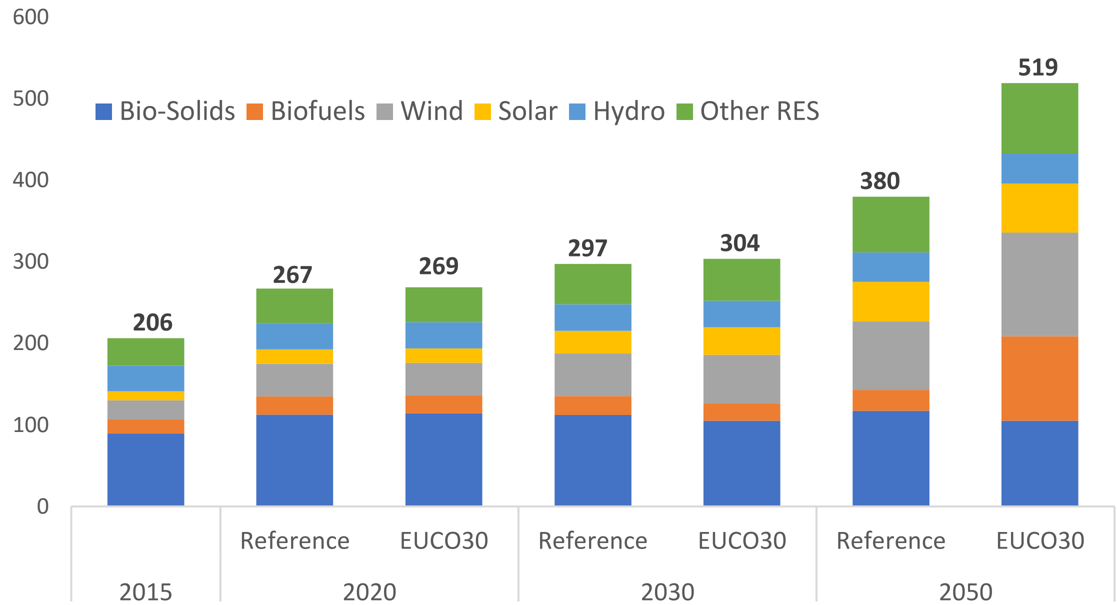



**Figure 20: EU RES demand in Reference and in EUCO30 scenarios in Mtoe in 2015-2050, Source: E3-Modelling calculations based on EU Reference scenario, 2016**

Future development towards 2020 and 2030 targets for RES expansion involves significant increases in RES shares in all sectors, namely in power generation, heating & cooling and in transport (Impact Assessment of revised RES directive, 2016). The RES share in gross final energy demand increases from 16% in 2015 to 31% in Reference in 2050 and to 52% in the EUCO context (Figure 21). RES development is a key option towards deep $CO_2$ emission reduction in power production; decarbonised electricity can then play a cross-sectoral role in the low-carbon transition, notably as a decarbonisation carrier in transport (electric vehicles) and in heating and cooling energy uses. The RES-E share is projected to increase to 66% in EUCO policy scenario, driven by the massive deployment of solar PV and wind technologies, while renewables in heating & cooling also develop, albeit at a slower pace, driven by heat pumps and RES-based production of heat (solar thermal and geothermal). Biofuels in transport constitute the main growing market for bioenergy, as biofuels are essential for reducing emissions in non-electrified transport segments[14]. Advanced biofuels, mostly advanced lignocellulose-based fungible biofuels in the long term, get a significant market share in the non-electrified segments of the transport sector (trucks, ships, aircrafts) as related conversion technologies mature and their costs would decline.

[14] The RES-T includes biofuels and electricity used in transport (mainly in electric cars and trains)

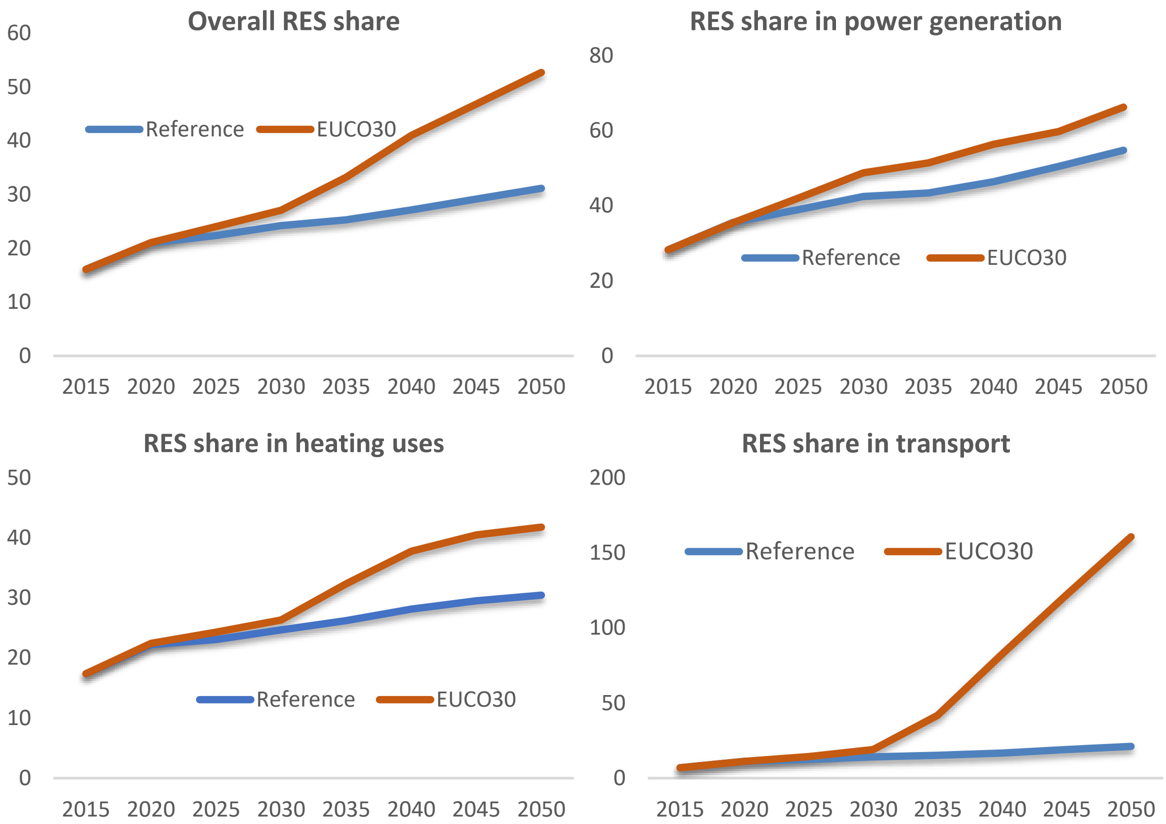



**Figure 21: EU RES shares in Reference and in EUCO30 scenarios, Source: E3-Modelling calculations based on EUCO and Reference scenario, 2016**

A complete restructuring is projected for the power generation sector, with rapid expansion of wind power and solar PV that jointly account for 48% of total EU-28 power generation in 2050. Carbon intensive thermal power plants are projected to be replaced by RES, CCS and biomass-fired technologies. With regard to CCS, the EUCO projection takes into account acceptability issues and difficulties for licensing $CO_2$ storage sites and reflects scarcity of storage sites by assuming high storage costs. The EUCO policy scenario takes the view that in the long term, decarbonisation conditions will enable some degree of acceptance and deployment of CCS, however not in all EU countries.

The investment outlook in the electricity production sector is dominated by the massive development of variable RES, notably wind and solar PV, which jointly account for 68% of total EU power generation investment in the period 2016-2050 (Figure 22). Investment in nuclear both for extension of lifetime and new nuclear plants is also significant (185 GW). The investment requirements in gas-fired plants are relatively high in the decade 2030-2040, in contrast to the continuous decrease in their rate of use; in the EUCO policy context, gas-fired power plants complement expansion of variable RES and are mainly used for load balancing purposes. Investments are projected to be limited in biomass and coal-fired power plants and especially in hydro due to the limited capacity expansion potential in most EU countries.

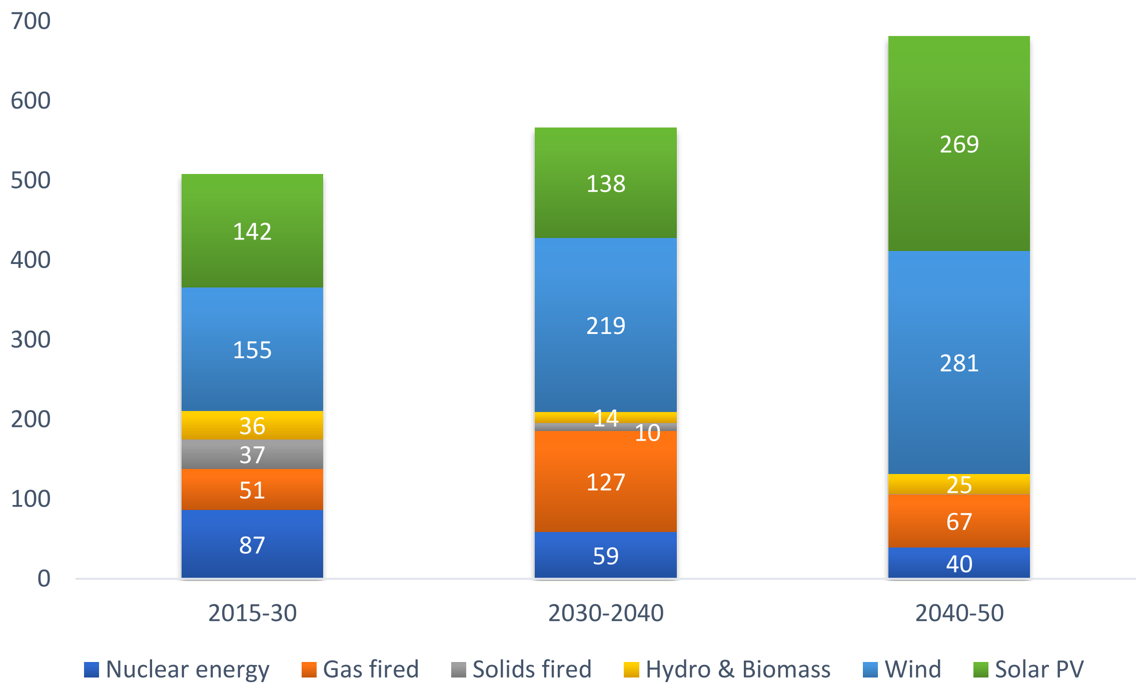



**Figure 22: EU Power capacity additions in 2015-2050 (in GW), Source: E3-Modelling calculations based on EUCO and Reference scenario, 2016**

# Employment impacts of alternative policy scenarios

## Factors influencing job impacts

The employment impact from low-carbon transition and switching to low-carbon generation sources (RES) depends on the mix of clean energy technologies chosen and characteristics of fossil fuel supply. Employment impacts of high RES development (in the context of EC Winter package, 2016) highly depend on a multitude of factors, the most important of which include:

- Labour intensity of RES and conventional power generation technologies; labour intensities in the entire chain of activities, including manufacturing, installation, fuel supply and O&M of power plants.
- Labour intensity of low-carbon options in road transport (biofuels and electricity) relative to oil products when employment in the entire chain of activities is quantified.
- Labour intensity and domestic content of manufacturing of energy technologies (especially for power generation); export potential of industries manufacturing power generation equipment
- Domestic content and labour intensities of fuel supply both for fossil fuels (coal, oil and gas) and for bioenergy forms (solid biomass, biofuels, biogas and waste)
- Projected energy system configurations, as intermittent RES (wind and solar PV) typically require higher capacity installations to produce the same amount of electricity as conventional thermal power plants
- Energy efficiency investment leading to job elimination in energy supply jobs, while creating jobs in the construction sector for building insulation and refurbishment
- Employment multiplier (indirect) effects in industries supplying equipment and services to renewable and conventional fossil fuel industries

| **Factor** | **Impacts on employment** |
|---|---|
| Investment in RES power generation technologies | Higher demand for workers in construction and in O&M (direct) and in supplying sectors (metals, equipment, engineering, machinery, services) |
| Reduction in demand for fossil fuels | Reduced jobs in the chain of activities in conventional energy supply sectors (extraction, refining, manufacture and sales of fossil fuels) |
| Increased demand for solid biomass and biofuels | Higher demand for agriculture workers to grow bio-crops and related feedstock and creation of jobs in related biomass conversion processes |
| Substitution of fossil fuels with RES technologies | Shift of employment demand from fossil fuels to RES technologies in all energy sectors (power generation, transport) |
| Development of RES upstream activities (innovation and manufacturing) | Creation of jobs in manufacturing of RES and in the supply chain providing materials, sub-components and services. Job elimination in conventional energy forms with secondary impacts in the value chain. |

| Factor | Impacts on employment |
|---|---|
| Transport decarbonisation | Increased employment in the production of biofuels and in the electricity sector (power generation and T&D). Lower employment in activities related to petroleum products (extraction, refining, gas stations) |
| Investment in buildings to improve insulation and thermal integrity | Increased demand for workers in construction, engineering and related services. Job elimination in conventional energy supply activities (oil refining, gas, transport, electricity production and distribution) |
| Increased electricity prices due to RES expansion | Reduction in real incomes of households affecting all production sectors (reduced demand for employment) |
| Higher ETS prices to achieve low-carbon emission targets | Lower employment demand in ETS industrial sectors due to losses in competitiveness. Switching from energy to labour in ETS sectors |
| Reduction in incomes due to higher prices of non-energy products | Reduced demand for employment in consumer-related sectors (e.g. services, equipment goods, trade) |
| Reduced import expenditures on fossil fuels | Re-direction of available resources to domestic activities; increased investment and employment in all economic sectors |
| Recycling of ETS revenues on social security contributions | Higher demand for employment in all sectors, mainly in consumer-related sectors. |

**Table 8: Factors influencing employment outcomes from RES expansion, Source: E3-Modelling**

## Methodological Approaches

Three broad approaches can be used to derive estimates for employment impacts of alternative policies: employment factors, the supply chain approach and Input-Output (I-O) models. The employment factor approach estimates the average number of jobs per unit of capacity installed or per unit of energy generated and combines them with energy system data to derive the total number of jobs. Factors are specific to technologies and stages/activities in the value chain. The supply chain approach maps out details of the supply chain for a technology and estimates costs for materials, labour and energy and profit margins in each supply chain link. Labour requirements in each stage are then aggregated to determine employment factors. The supply chain approach is used to estimate direct and indirect jobs. Input-output models project macro-economic impacts based on sectoral linkages across the entire economy and thus they can estimate direct and indirect jobs in all sectors. Macro-economic models (and econometric models) are built based on I-O tables but also include price-induced effects and supply constraints and are thus well-equipped to simulate direct, indirect and induced jobs. The current study uses the employment factor approach to estimate direct impacts from RES expansion by 2050, while the well-established CGE model GEM-E3 (Capros et al, 2013) is used to assess the total effects including both direct, indirect and induced impacts.

Input-output models are often used in studies exploring economic and employment impacts of energy and climate policies because they are transparent, they require a limited number of assumptions, are easily replicable and are built based on recent data from national accounts. On the other hand, I-O analysis uses several simplistic assumptions; namely fixed technical coefficients and fixed input proportions, i.e. the principles of homogeneity and proportionality. Fixed technical coefficients imply that the inter-industrial flows from industry i to industry j depend entirely on the output of industry j. Fixed proportions mean that industry j will use the same mix of inputs from all industries (and from primary factors like capital, labour and energy) as demand increases for industry j's output. Therefore, the production function of the I-O models is a Leontief minimization function, is homogenous and assumes constant returns to scale in contrast to CES production function assuming diminishing marginal returns. Technology is assumed to remain constant as output grows, while I-O models rarely represent clean energy producing sectors as separate sectors.

Therefore, I-O modelling is best suited to examine the current state of the economy and perform short-term projections, while macro-econometric and CGE models are especially used for medium and long-term analysis. CGE models consider technological improvements that change the input mix in production function and thus the factor proportions. In addition, the assumption of constant returns to scale of I-O models is relevant only for small changes in output levels. CGE models represent supply constraints in capital and labour markets that are important for the comprehensive macro-economic assessment of RES development policies in the long term. Finally, CGE models simulate substitutability of factors in the production function driven by changes in relative prices, as industries tend to substitute towards low-cost inputs.

The study uses a combination of a bottom-up approach to estimate direct energy supply jobs (based on labour intensities in each activity related to conventional energy supply and RES technologies) with a top-down approach based on CGE modelling with GEM-E3 to estimate employment impacts from RES expansion throughout the economy to 2050 (including direct, indirect and induced job impacts).

Studies based on Input-Output modelling have found positive employment impacts resulting from the expansion of renewable energy (Malik et al., 2014; Tourkolias et al, 2011, Garret and Peltier, 2016). A major drawback of previous I-O analyses is that industries producing renewable energy equipment and energy efficient products are not explicitly identified as industrial/manufacturing sectors in national accounts. On the other hand, conventional energy industries (including fossil fuels and electricity) exist in most national accounting systems. In the current study, a detailed disaggregation of industrial sectors producing solar PV equipment, wind turbines, electric vehicles, batteries and insulation materials from aggregate industries of I-O tables is performed incorporating an analytic breakdown of technology costs.

The GEM-E3 model (Capros et al, 2013) is a well-established CGE model that has been extensively used in major impact assessments of the EC to provide quantitative macroeconomic and employment analysis of energy and climate policies. Recently, an updated version of the model was used to estimate job impacts of the EC, Winter Package policy scenarios (E3MLab, 2016). GEM-E3 contains some innovative features that are important for the estimation of employment implications of the EU low-carbon transition, including:

#### Link with the EC Winter Package (EUCO projection) for EU countries and technology learning

Developing RES in all sectors implies substitution of imported fossil fuels, but also conventional fossil-fuel supply chains (e.g. coal mining, gas extraction, refineries, fossil fuel trade and others). The substituted value chains maintain non negligible shares in EU domestic employment and value added, especially in fossil fuel producing countries like Poland and Romania. The national-level context is thus important in job impact estimation from RES development. The analysis ensures full consistency of employment assessments with the evolution of the energy system by country until 2030 and 2050 (as developed for the EC winter package). The Reference 2016 scenario (EC, 2016) is used as the business as usual case against which the EUCO policy scenario is compared. The study includes RES deployment in all energy system sectors and their value chains (i.e. manufacturing of RES equipment, installation, production of biofuels and related feed-stock conversion).

The inclusion of endogenous learning mechanisms for clean energy technologies (learning by doing and learning by R&D) would lead to reduced costs for RES. The overall employment and economic impacts depend highly on the assumed technical progress for clean energy technologies driven by mass production, economies of scale and innovation.

### Incorporation of the financial mechanism in the CGE modelling

In general, RES technologies require higher upfront expenditures relative to fossil fuel technologies, but compensate (partly) by lower operating and fuel purchase costs. Renewables substitute fossil fuels (that are to a large extent imported in EU) by domestic activities required to manufacture and install RES, and thus bring additional jobs and value added to EU economies. The net effects of the low-carbon transition highly depend on RES costs; in case that RES costs are higher than conventional fossil fuels, then RES deployment would exert crowding-out effects on demand with consumers spending less for non-energy commodities and weaken the global competitiveness of trade-exposed energy-intensive industrial sectors (due to increased energy costs). Both mechanisms may counterbalance the direct and indirect positive effects of RES development on job creation, as other (non-related to energy) economic activities would experience decreased demand, exports and production.

Appropriate financing schemes for capital intensive investment in RES technologies can reduce crowding out effects. Despite the importance of financing low-carbon investment, this issue is generally neglected in the model-based climate policy assessment literature. An innovative aspect of the study is the use of the GEM-E3 model with a fully-fledged representation and modelling of the financial sector that has large implications for capital intensive clean energy investment. Assumptions for financing conditions have large impacts on employment estimations from RES expansion, as demonstrated in studies for the EC's "winter package" (E3MLab, 2016). The model-based analysis showed that the "loan-based" financing scheme[15] induces positive GDP and employment impacts largely due to the ease of financing that diminishes crowding-out effects from clean energy investment (mainly directed to RES expansion and energy efficiency improvements).

### Detailed representation of RES producing industrial sectors

GEM-E3 separates the sectors that manufacture clean energy technologies from general industrial sectors, and thus it represents the regional production and bilateral trade of RES-related equipment, namely for wind turbines, solar PV modules, CCS, electric cars, advanced energy-efficient appliances, ethanol and biodiesel. The collection and reconciliation of relevant data, evidence and information from available sources is critical for the analysis of exposure of EU RES supporting industries to foreign competition in terms of production costs, competitiveness and innovation. The comprehensive analysis of risks and opportunities for the EU RES manufacturing sectors deserves special attention and is an add-on to the existing literature.

[15] Assuming that firms and households can borrow in capital markets without facing increasing unit costs of funding.

### Update of employment data used in the GEM-E3 model

The survey of several studies demonstrates the existence of a large spread in reported employment factors, for manufacturing, installation and O&M activities associated with RES and the conventional energy activities. As described in chapter four, the employment data of energy supply and transport sectors (both fossil fuels and RES) for EU and its member states have been updated and significantly improved in terms of quality, technology representation and inclusion of the entire chain of related activities.

### Representation of the labour market

Induced employment impacts from RES development are driven by changes in costs and incomes of economic agents; studies using macro-economic models are inconclusive about the sign of induced job impacts with some models projecting net job creation (E3MLab, 2016, CAMECON, 2016), while others show job losses (Frondel et al, 2010). Many studies conclude that net employment effects of renewable energy expansion strongly depend on prevailing labour market conditions. In case that the economy already produces at its production possibilities frontier (natural unemployment rate) and RES require additional resources (capital and labour), prices of primary factors would tend to increase implying a crowding-out of other economic activities. In contrast, flexible labour market conditions can lead to substantial job creation, while additional production possibilities may arise via increased labour supply or higher productivity growth. Labour market policies should supplement RES expansion in order to take full advantage of the job creation potential induced by RES. Effective policies should be established to ensure an efficient transition to "low carbon" employment, in the form of measures to increase labour market participation and transform existing jobs with changes in skill requirements and job profiles.

## Direct employment impacts from RES expansion

Energy system transformation driven by high RES expansion would have profound implications for energy-related jobs in EU countries. In the winter package policy context, the EU energy supply and demand sectors will face fundamental changes during the next decades that will also affect employment levels and required qualification and skills. The quantitative analysis focuses on impacts from high RES expansion on direct jobs in energy supply and transport sectors and related activities. The "employment factor" methodology (assuming constant labour intensities in energy supply and RES-related activities to 2050) is used in combination with detailed energy system projections, based on the Winter Package projections (EC, 2016).

The analysis shows a moderate increase in direct energy supply and transport jobs in the Reference scenario from 3.3 million in 2015 to 3.6 million in 2050, while the share of energy jobs in total EU workforce would increase from 1.5% in 2015 to 1.8% in 2050 due to the declining EU labour force (EC Ageing Report, 2015). RES-related jobs (excluding manufacturing) are projected to increase from 595 000 in 2015 to 725 000 in 2020 driven by growing investment in wind and solar PV and higher production of solid biomass required to meet the binding EU RES target for 2020 (20% share in gross final energy demand). After 2020, the lack of further binding RES targets in the Reference scenario implies a reduction of RES jobs to 640k in 2030 due to the lack of sufficient investment especially in the power generation sector (Figure 23). However, in the longer-term investment in wind turbines and solar PV are projected to increase significantly driven by increasing ETS carbon prices, declining RES technology costs and replacement of RES installations that have reached the end of their lifetime. Thus, RES direct jobs are projected to increase to about 1 million in 2050. The low-carbon transition as quantified in EC, 2016 (Winter package policy scenarios) is projected to lead to a significant shift in energy sector employment away from conventional fossil fuels and towards renewable energy jobs. Employment in fossil fuel supply sectors is projected to decline substantially from 1.9 million jobs in 2015 to 900k in 2050, while direct RES-related jobs increase to about 1.65 million jobs in 2050, i.e. a 65% increase from Reference levels. Energy efficiency investment assumed in EC Winter Package policy scenarios would lead to job losses in energy supply sectors, but also would create jobs in construction, which are however not included in the study (reasons are explained in detail in chapter 4).

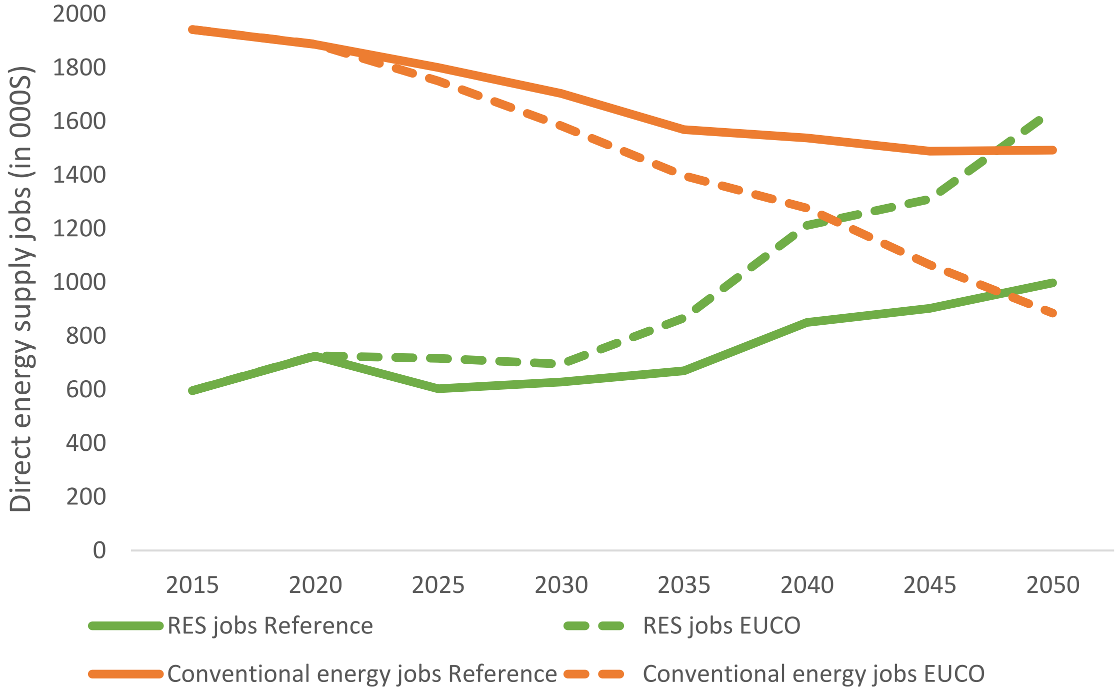



**Figure 23: EU direct jobs in conventional energy supply and in RES in 2015-2050 (in 000s), Source: E3-Modelling calculations**

The implementation of the EU winter package (EC, 2016) is projected to lead to a significant increase in RES employment, with RES jobs increasing to 1.65 million in 2050, out of which solar technologies and biofuels jointly account for about 1 million jobs (Figure 24). A constant increase is also projected for jobs in the construction and in O&M of wind farms (both onshore and offshore). Direct wind jobs are mostly located in the O&M of wind power capacities that amount to 520 GW in 2050, with 120 GW of them located offshore; solar PV is labor-intensive in the construction stage implying that 65% of cumulative solar PV jobs are created during the installation of solar PV modules. There is a large job creation potential in biofuels production after 2030, as advanced conversion technologies (Fischer-Tropsch, fast pyrolysis) mature and are massively developed leading to $CO_2$ reduction in the transport sector, especially in segments that cannot be electrified (heavy-duty trucks, aviation, navigation). Advanced lignocellulose-based biofuels create domestic jobs both in feedstock supply (as woody biomass is predominantly produced domestically in EU countries), in conversion processes and transport and in the final use (as liquid biofuels in road transport would use the same gas station infrastructure as petroleum products). On the other hand, a limited increase is projected for hydro-electricity jobs in the 2015-2050 period, as there is limited untapped hydro-electric potential in EU.

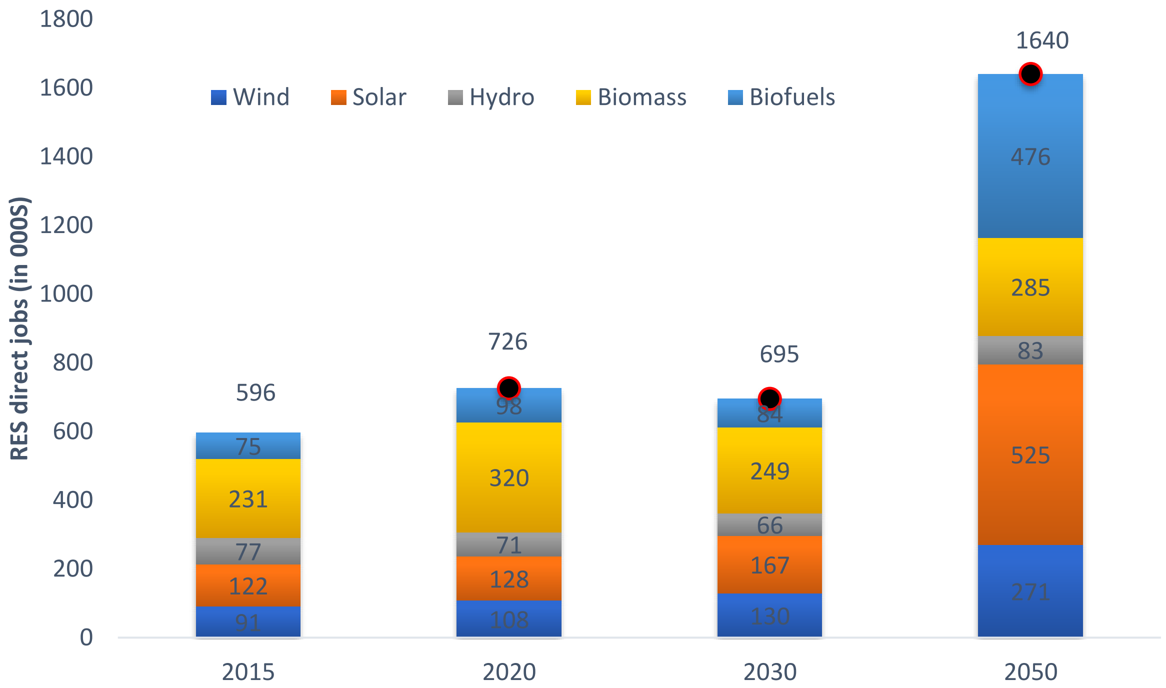



**Figure 24: EU RES direct jobs by technology in the EUCO scenario to 2050 (in 000s), Source: E3-Modelling**

Employment related to extraction and manufacturing of fossil fuels is projected to decrease following historic trends in all scenarios. The decrease would be larger in EUCO policy context compared to Reference, where fossil fuels continue to play a substantial role by 2050. Differences among scenarios materialize only after 2020, as energy system decarbonisation accelerates after 2020. Even in Reference, jobs in primary fossil fuel supply decline by 350 000 jobs over 2015-2050 (from 1.53 million in 2015 to 1.17 million in 2050). Jobs in oil and gas extraction decline in the Reference scenario driven by decreasing amounts of hydrocarbon extraction and limited reserves/resources in most EU countries. The EUCO scenario accelerates job losses in primary energy supply sector after 2030 leading to a reduction of 825 000 jobs from 2015 levels. Most job losses are projected to occur in coal mining as coal demand and production would strongly decline in the low-carbon context, while the emergence of transport electrification would lead to a large decline in consumption of oil products and hence to significant job losses both in retail fuel sales (gas stations) and in the refining sector (Figure 25).

It is worth noting that employment in the mining of solid fuels has been declining in EU in recent years reflecting the strong decline of the coal industry in most EU industrialised countries. According to LFS data, employment in the mining of coal and lignite has declined from 343 000 jobs in 2008 to 295 000 jobs in 2015 largely driven by growing mechanisation, substitution of human labour (Fischer-Kowalski, 2012) and reduced extraction of solid fuels as a response to climate policies.

The transition to a low-carbon energy-efficient economy would imply lower demand for jobs related to trade of fossil fuels (wholesale and retail trade). In case of a large-scale expansion of biofuels substituting refined oil products, the employment structure in retail sale of automotive fuels would not change drastically as biofuels are commonly mixed with petroleum products and use the same distribution system up to the point of end use (gas stations). On the other hand, transport electrification would imply a radically different paradigm in the automotive fuel sales sector, as jobs in gas stations would significantly decline and new jobs would be created in the electricity sector, namely in power generation, in electricity T&D and in battery recharging infrastructure for electric cars. Jobs in power production and in T&D of electricity used in electric cars are fully quantified in the analysis, while jobs that would be created in battery recharging infrastructure are not included as there are no comprehensive job estimates available.

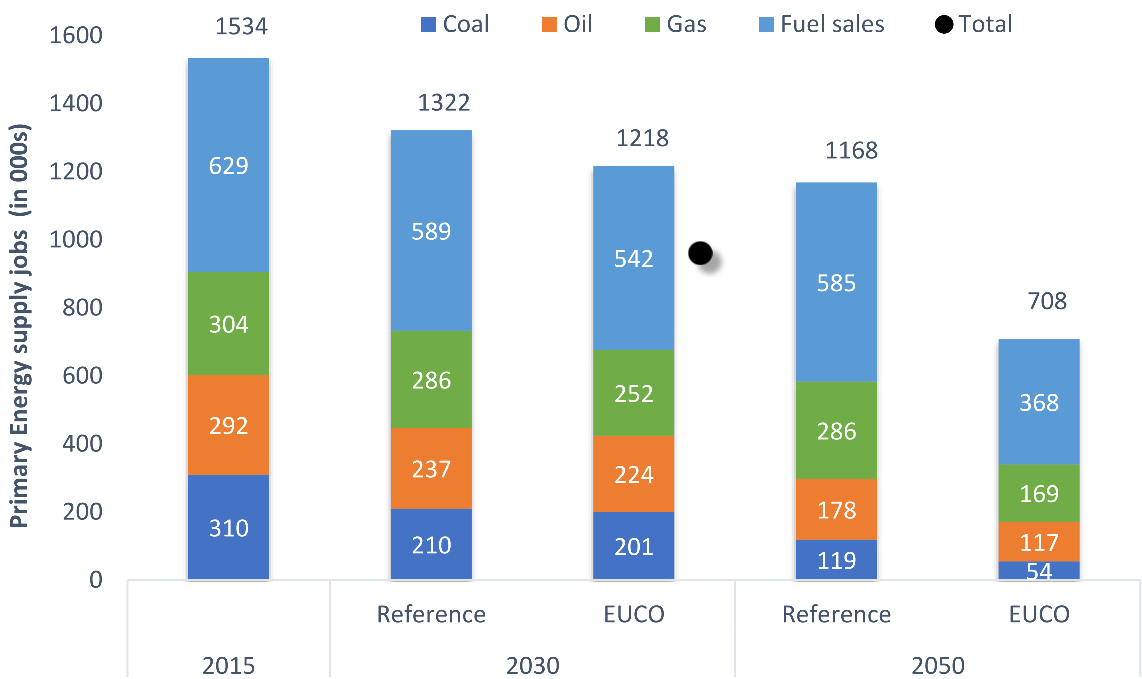



**Figure 25: EU direct jobs in primary fossil fuel supply to 2050 (in 000s), Source: E3-Modelling**

Jobs in the electricity sector are projected to increase from 1.4 million in 2015 to 1.9 million in 2050 in the Reference scenario driven by increased power requirements in all sectors and penetration of more labor-intensive RET (mainly solar PV and wind). High RES expansion in the context of the EC Winter Package leads to higher employment with electricity jobs increasing to 1.55 million in 2030 and to more than 2.3 million in 2050. The increase is driven by three factors, namely: (1) electrification of final energy mix, especially deployment of electric cars in road transport, (2) higher capacity and job requirements both in power plants and in electricity T&D induced by lower capacity factors of solar PV and wind and (3) higher labour intensity and domestic content of RES relative to fossil fuels that are substituted. Figure 26 shows that additional from Reference jobs are mostly created in the construction of solar PV plants and wind farms and in T&D of electricity induced by increased power capacities and increased grid requirements of intermittent variable renewable energy sources (wind and solar PV). The structure of electricity jobs is also projected to change drastically with the share of fossil fuels declining from 50% in 2015 to a mere 14% in 2050, while solar PV and wind will jointly account for about 56% of electricity jobs in 2050 (Figure 27); the share of nuclear-related jobs is projected to remain relatively constant up to 2050.

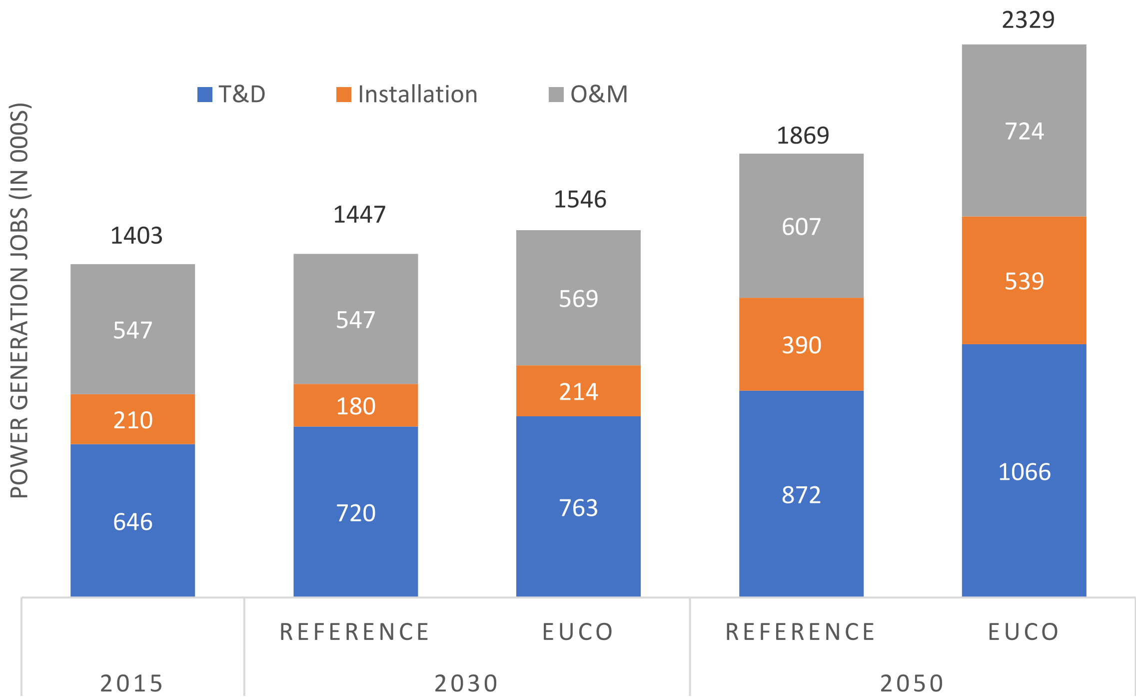



**Figure 26: EU jobs in the electricity sector to 2050 (in 000s), Source: E3-Modelling**

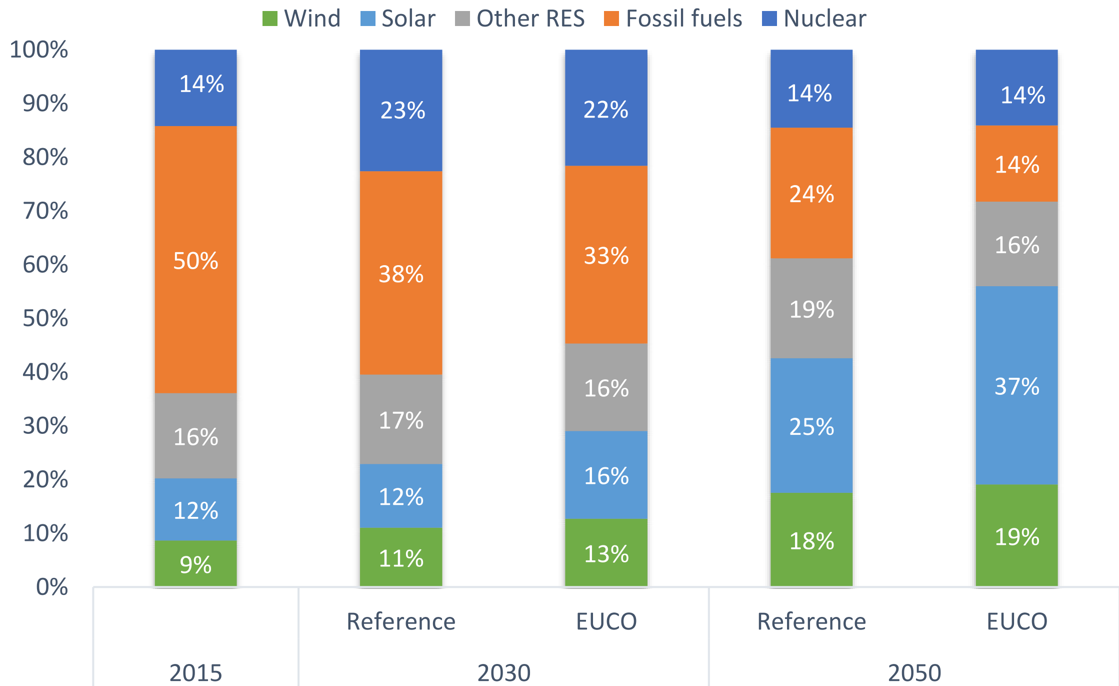



**Figure 27: Technology shares of electricity jobs in 2015, 2030 and 2050, Source: E3-Modelling**

## Jobs in the manufacturing of RES to 2050

Considering the competitiveness of the EU renewable energy manufacturing industry gives a mixed picture. While European manufacturers uphold key market positions in the wind power sector, keeping up to strong competition through steady innovation, EU companies only play minor roles in the manufacturing of solar PV panels (chapter 3). Germany has a leading role in the EU context in the production of wind turbines, electric cars, Li-ion batteries and PV modules. The main reasons for German dominance in clean energy production are its strong industrial sector, the transparent trade and investment system and the policy framework supporting clean energy deployment. Germany is highly committed to exports supported by labour market reforms that encourage employment of low-skilled labour, a highly-developed manufacturing capacity in machine tools, chemicals and cars, a strong national commitment to vocational education and the establishment of government-industry-university partnership. Other important clean energy manufacturers include Denmark and Spain (in wind turbines), Poland and the Czech Republic (in solar PV) and France, Italy and Sweden in manufacturing of electric cars. On the other hand, the production of biofuels and solid biomass is more equitably distributed across EU countries reflecting the local nature of the production of bioenergy products and related biomass feedstock.

RES technology exports would lead to additional activity and employment in the EU, mainly in countries that have established RES innovation and manufacturing activities and have developed vertically-integrated domestic supply chains (e.g. Germany and Denmark in wind turbine production). Based on the qualitative analysis of risks and opportunities for EU RES manufacturing industries (presented in chapter three of the study), alternative scenarios are designed to explore job impacts of RES manufacturing activities  to 2050. In order to develop the scenarios, lead market factors for EU clean manufacturing as illustrated in chapter three are used as a starting point. The main factors considered in the scenario design include current market shares in global production, lead market considerations and innovation potential, technology diffusion, historic developments and evolution of RES demand by region and technology. High uncertainties exist regarding the innovation dynamics, the regulatory system and the policy framework for the medium and long term, e.g. contrasting developments in climate policies (ambitious EU climate Policy framework for 2030 contrasting with the recent U.S. announcement of withdrawal from the Paris Agreement). In general, the dynamic outlooks and scenarios developed for EU RES manufacturing are consistent with the changes in the underlying drivers.

Two variants are examined with differentiated assumptions on the competitiveness of EU RES production industries. Scenario 1 assumes an optimistic outlook for EU RES manufacturing, with the EU maintaining its competitive advantage in the production of wind turbines. This implies that domestic EU turbine production meets expanded domestic demand for turbine installations, while EU companies continue to export turbines to non-EU regions satisfying about 22% of demand for wind installations in non-EU regions; the latter is calculated based on the New Policies Scenario of (IEA WEO, 2015). The scenario assumes accelerated innovation efforts by European companies that have already developed innovative, cost-efficient, commercially mature and competitive technological solutions (EurObserv'ER, 2016) and are in a position to exploit export potentials in rapidly growing markets outside the EU. In addition, EU wind component suppliers, research institutes, consultancies and turbine developers would reap significant benefits from the development of the global wind industry. In parallel, the EU is well-suited to lead the emerging wind-offshore market based on its current dominant position, the establishment of robust supply chains for turbine materials and components and accelerated innovation dynamics.

Regarding solar PV manufacturing, the “Optimistic” scenario assumes that European companies would continue to produce about 34% of the domestic solar PV market maintaining a constant import share at 2015 levels. This is based on the exploitation of emerging new business models based on solar panels combined with stationary batteries, in which German companies like Sonnen, Senec and E3/DC are already strong players. The relative revitalisation of the EU PV manufacturing industry can also be driven by product differentiation based on improved performance, reliability, and appearance, while the EU can become a lead market in building innovative integrated rooftop PV panels. However, the industrial analysis shows that Asian-based production of solar PV panels would remain dominant in the future, driven mainly by the lower production cost combined with the rapidly expanding market for PV installations in major Asian economies accounting for almost two-thirds of the global solar PV capacity additions up to 2025 (WEO, 2015). The emergence of solar PV production in Asian countries would depend on how quickly and at what cost will they be able to produce solar panels domestically.

<u>Scenario 2</u> assumes that the EU would lose its comparative advantage in wind turbine manufacturing due to the increasingly important role of developing countries, which rapidly build up their innovation systems, technological capabilities and manufacturing facilities combined with expanding RES domestic demand. This enables the consolidation of economies of scale leading to cost reductions and increased competitiveness of Asian-based companies, especially in China which is already at the technology frontier and is likely to experience robust demand growth (WEO, 2015). In parallel, high transportation costs for turbines prevent the continuation of EU exports and lead to lower EU exports of wind turbines to non-EU countries.

Figure 28 illustrates that the EU wind manufacturing industry can create additional jobs based on its strong leading position and innovation dynamics, even in scenario 2 in which the EU is assumed to lose market shares in global wind turbine production. In scenario 1, wind manufacturing jobs increase from 110k in 2015 to 210 k in 2050, while jobs also increase in PV manufacturing driven mainly by expanded domestic demand for solar PV installations The job creation potential in EU RES production industries can be even larger in case that non-EU regions adopt ambitious climate change mitigation policies and thus they would import a part of wind turbines from the EU.

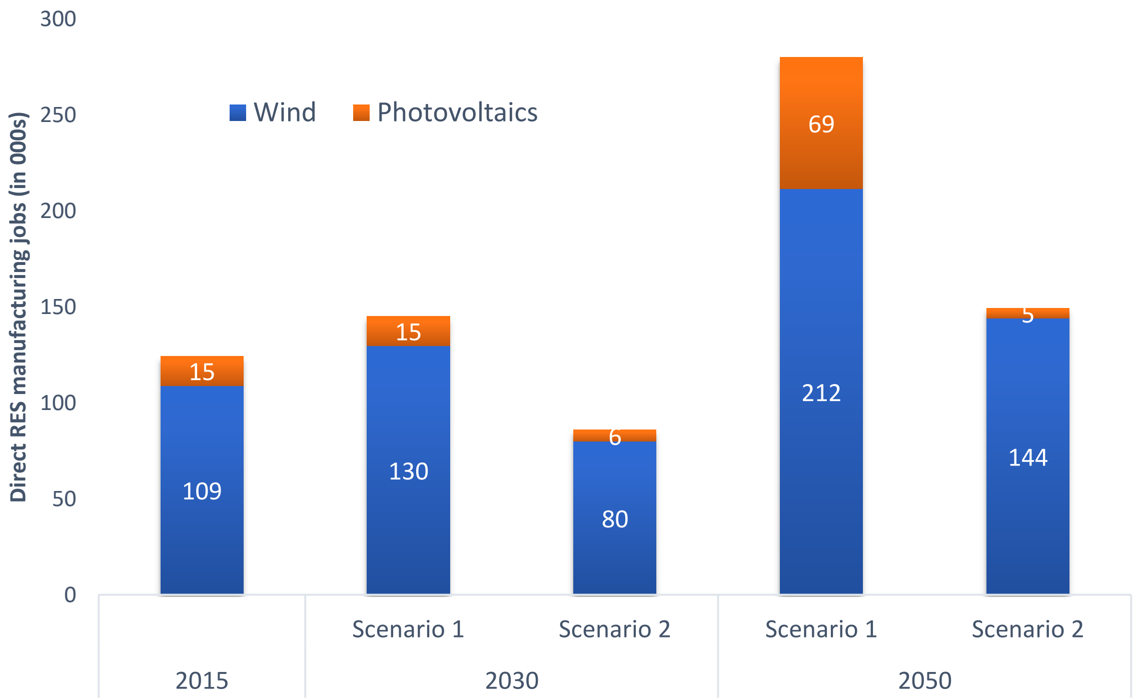



**Figure 28: Evolution of EU jobs in RES manufacturing to 2050, Source: E3-Modelling**

## Total employment impacts from RES expansion up to 2050

Achieving a low-carbon transition would require a major reallocation of capital resources from fossil fuel supply and transformation to clean energy technologies and energy efficiency. Capital reallocation would also have an impact on employment. However, the reallocation of jobs away from carbon-intensive industries is not expected to be particularly large, as these industries represent only a small share of total value-added and employment. Based on the bottom-up labour intensity approach, the study shows that the net job impact from RES expansion is positive in the entire period 2020-2050 (Figure 29) ; higher impacts are estimated for the longer term with the creation of 263 000 additional jobs in 2050 (relative to Reference levels). The net impact is very small in 2030, as the EUCO30 scenario assumes increased energy efficiency efforts in order to meet the target of 30% reduction in primary energy demand in 2030; this leads to job losses in energy supply sectors. Electricity jobs increase by about 460k from Reference levels in 2050 both in power plants (mainly in solar PV and in wind) and in transmission and distribution of electricity. The deployment of advanced biofuels in transport leads to about 270k additional jobs in the biofuel production sector, including feedstock supply, transport, conversion and in sales/distribution. On the other hand, the largest job elimination is estimated in the primary fossil fuel supply sector (mainly in coal mining and in petroleum refineries) and in fossil fuel sales with job losses of 240k and 220k respectively from Reference levels in 2050.

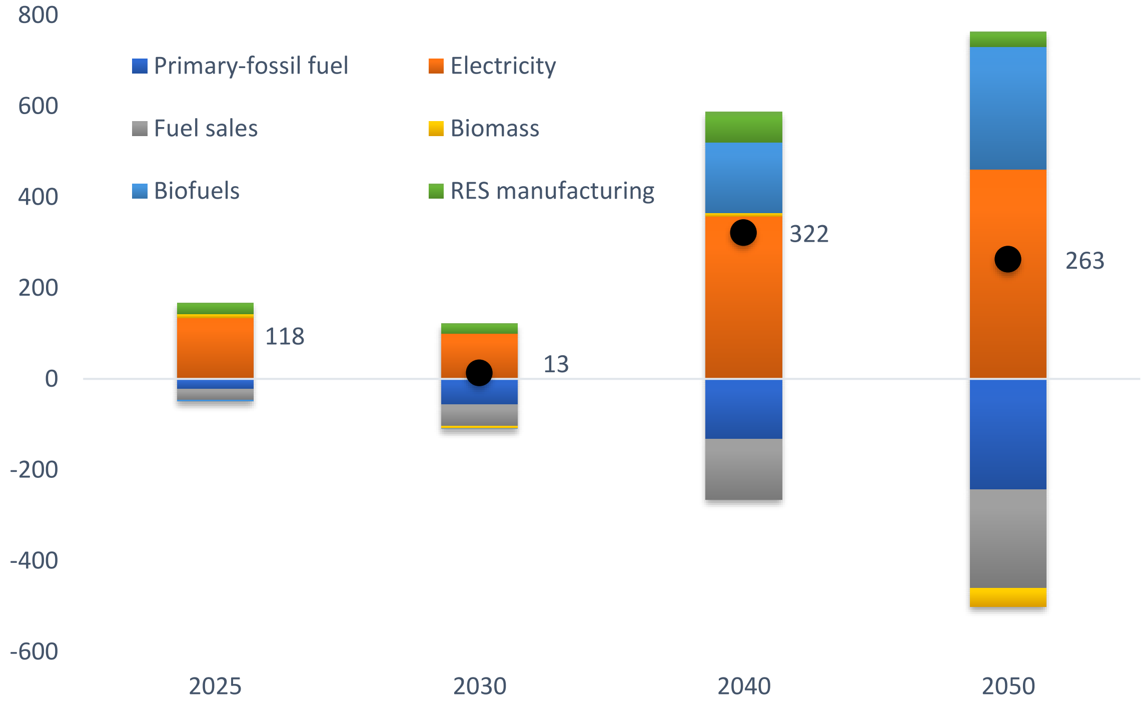



**Figure 29: Changes in employment by energy sector in EUCO policy scenario compared to Reference (in 1000 jobs), Source: E3-Modelling**

The GEM-E3 model is used to estimate total employment impacts from RES expansion. The model version used includes modelling of the financial sector, discrete representation of clean energy manufacturing sectors, endogenous learning mechanisms for RES technologies, updated employment data and detailed linking with fully-fledged energy system projections of the EUCO policy scenarios in the period 2015-2050. GEM-E3 assumes that agents (firms and households) can borrow in capital markets to finance investment in RES and energy efficiency without facing increasing unit costs of funding. Agents are modelled to annually pay back interest and principal of their loans at specific interest rates for a given period of time based on a reasonable debt to income ratio (E3MLab, 2016).

In general, total employment is driven by job-related multiplier effects[16] and interactions between sectors under the different policy-induced scenarios. Employment impacts depend on the respective labour intensity of the sectors delivering inputs to renewable energy and energy efficiency projects and that of the sectors negatively affected by the low-carbon transition (fossil fuel supply sectors). The share of domestically produced inputs to total inputs also matters. Net employment effects also depend on the extent to which wages will adjust to changes in labour demand, and on the availability of skill formation.

Since renewable energy and energy efficiency investment requires more labour relative to fossil fuel sectors, the low-carbon transition is expected to have positive impacts on EU employment (European Commission, 2016). GEM-E3 shows positive net employment impacts from low-carbon transition with largest job gains in 2050 projected in the electricity sector (+470k jobs from Reference), agriculture due to biofuels production (+277k from Reference) and in construction induced from increased investment in solar PV installations and in the refurbishment of buildings. The consistent integration of employment data and labour intensities in conventional energy supply and RES sectors in the GEM-E3 model has led to comparable results between the bottom-up (value chain) and top-down (based on CGE modelling) approaches.

Employment impacts of the EUCO30 policy scenario are projected to be positive, with the creation of 672 000 new jobs in 2030 relative to the Reference scenario. GEM-E3 projections are in line with the Impact Assessment accompanying the Energy Efficiency proposal and the EU Clean Energy Package (EC, 2016), which shows that the EUCO scenarios can lead to the creation of 400 000 to 900 000 new jobs in 2030 depending on underlying scenario assumptions. The employment estimation of the Energy Efficiency Directive is based on results of two macro-economic models, namely E3ME and GEM-E3, which have been frequently used for the economic assessment of energy and climate policies. There are important differences between the two models that arise from their theoretical foundations, underlying assumptions and respective structures. E3ME is a macro-econometric model, based on post-Keynesian demand-driven non-optimisation non-equilibrium framework; GEM-E3 is a CGE model based on supply-driven neoclassical economic theory and optimising behaviour of rational economic agents who ensure that markets always clear.

One of the key differences between E3ME and GEM-E3 models is related to the treatment of capacity constraints. GEM-E3 assumes that capital resources are optimally allocated in the economy, and a policy intervention to increase investments in a particular sector (e.g. RES and energy efficiency) would take place at the expense of limiting capital availability for other sectors ("crowding out" effect). On the other hand, E3ME allows for the possibility of non-optimal allocation of capital and thus the level of output can increase as a response to demand growth. This in turn means that decarbonisation policies in E3ME would tend to have positive impacts on the EU's economy and employment. In the current study, GEM-E3 assumes that firms and households can borrow in capital markets without facing increasing unit costs of funding, thus leading to reduced crowding-out effects. This enhances the comparability of GEM-E3 results on EU employment for 2030 with the macro-economic assessment of the Clean Energy Package.

[16] Multiplier effects refer to the economy-wide ripple effects stemming from an initial change in aggregate demand. The final impacts on the GDP level is higher than the initial change in aggregate demand, as the increased income results in more spending, more demand, which in turn leads to higher GDP, more income and so on.

Jobs in fossil fuel supply sectors and in energy intensive industries are projected to decline from Reference levels due to the introduction of ambitious climate policies including stringent ETS carbon pricing; job implications for services are limited due to their low energy and carbon intensity. A recent comprehensive modelling analysis by (OECD, 2017) confirmed that climate policies would result in employment increases in the energy efficiency and renewable energy sectors and declines in the fossil fuel supply and energy-intensive industrial sectors. The global job reallocation induced by ambitious climate change mitigation policies (summing up the creation and the elimination of jobs) is projected to represent about 1.5% of the total labour force by 2050; this share is projected to be higher in countries with strong growth of RES. We estimate that job reallocation induced by high RES expansion in EU in the low-carbon context represents about 1.4% of total EU labour force in 2050.

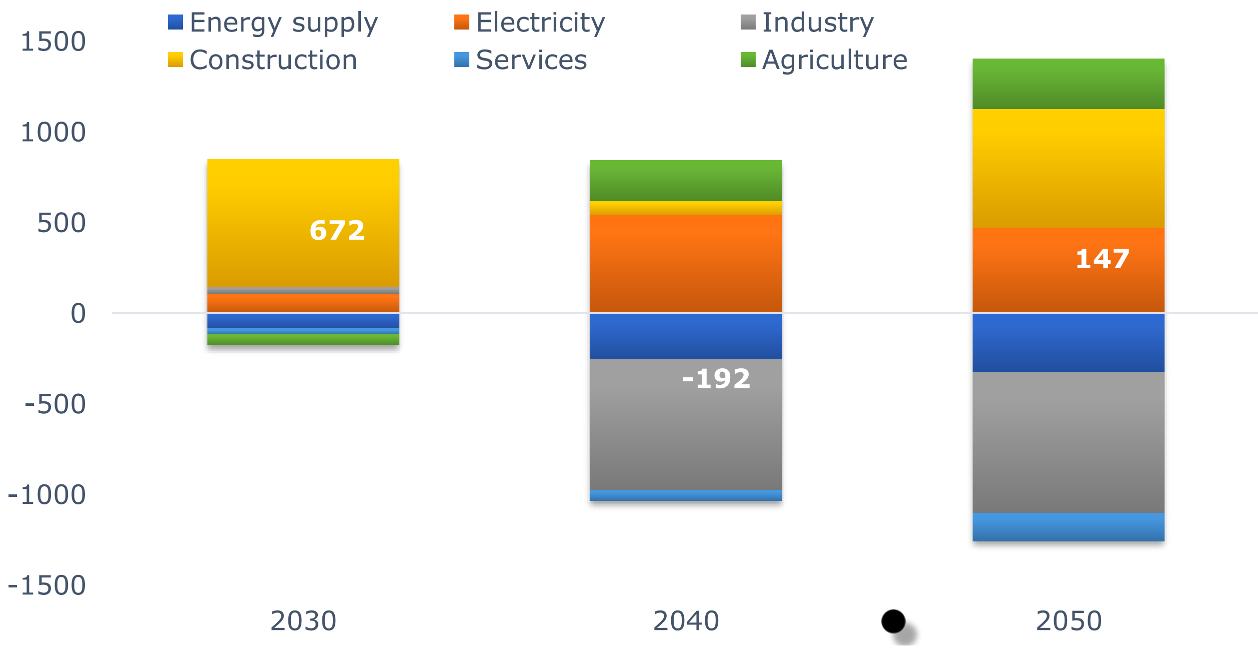



**Figure 30: Changes in EU employment by sector in EUCO policy scenario compared to Reference (in 000 jobs), Source: E3-Modelling based on GEM-E3 results**

Employment results of the EUCO policy scenario indicate the high importance of the GEM-E3 assumptions with regard to the financing mechanism and RES technology learning (E3MLab, 2016). In 2030 there are large positive job impacts triggered by increased investment in clean energy and energy efficiency and limited crowding-out effects, while in 2040 loans are paid back implying increased costs and leading to net job losses in the EU economy. In the longer term, GEM-E3 shows that positive effects from energy system restructuring with lower spending on fossil fuels counterbalance the negative job impacts in conventional energy supply sectors leading to the creation of 150 000 additional jobs relative to the Reference scenario in 2050.

## Conclusions/Key findings

High RES expansion is a key pillar towards the EU low-carbon transition as illustrated in the recent Winter Package proposals of the European Commission. Energy system restructuring towards clean energy technologies would have large economic and employment implications for the EU induced by a significant reallocation of jobs and activity away from fossil fuel sectors and towards RES. The study uses a bottom-up approach to estimate labour intensities (employment factors) in the entire chain of distinct activities related to RES and fossil fuels, including equipment manufacturing, construction and O&M of power plants. For fuel-based technologies (fossil fuels and biomass), fuel supply jobs are also estimated, including all related activities like fuel extraction or mining, fuel transformation (refining, bioenergy conversion and coke ovens) and distribution/sales of fuels.

We estimate that there are 3.3 million direct jobs in energy supply and transport in 2015 (i.e. 1.5% of total EU workforce), with RES industries representing about 700 000 of them. RES jobs are mainly generated in the biomass-related sectors as well as in the wind and solar PV sectors. The analysis shows that taking into account jobs across the entire value chain of related activities, renewable energy technologies are (on average) more labour intensive and have a higher domestic content relative to fossil fuels, both in power generation and in road transport. Solar PV and wind are more labour intensive in the construction stage implying high dependence on investment dynamics. Lower capacity factors of intermittent RES imply increased capacity requirements and jobs relative to fossil fuels to produce the same amount of electricity.

The EUCO policy scenario is based on EC, Winter package proposals and assumes high RES deployment substituting for fossil fuels; RES expansion leads to a significant increase in direct RES jobs to 830 000 in 2030 and to about 1.85 million jobs in 2050 representing about 0.9% of the EU labour force. However, job losses would occur in conventional energy supply sectors, especially in coal mining, refineries and retail sales of petroleum products in gas stations. The net employment effect of RES expansion is found to be positive leading to 260 000 additional jobs from Reference levels in 2050, with electricity and biofuels having the largest job creation potential. The growth in electricity-related jobs is driven by increasing power requirements, electrification of energy mix (including transport electrification) and expansion of high labour intensive RES technologies. In the EUCO policy context, conversion technologies related to advanced biofuels mature and are massively deployed after 2030 to decarbonise transport modes that cannot be electrified. This implies large growth in biofuel-related jobs, both in biomass feedstock supply (that is produced domestically in the EU) and in transport and conversion processes.

The bottom-up analysis based on employment factors is coupled with a model-based analysis with the GEM-E3 model in order to consistently evaluate overall job impacts from RES expansion in the entire economy by 2050. GEM-E3 results show that the low-carbon transition would lead to a reallocation of about 1.4% of EU jobs, with additional jobs created in electricity, agriculture (due to biofuels) and construction sectors (due to refurbishment of buildings). On the other hand, jobs are lost in fossil fuel supply sectors and in energy intensive industries. Assumptions about the financing scheme and RES technology learning are important for the estimation of overall employment impacts.

The consolidation of the leading EU position in wind turbines production and the establishment of domestic innovative clean energy solutions based on combinations of solar PV with stationary batteries would result in high activity and employment gains for EU RES manufacturing industries. However, the analysis illustrates that various factors can cause reduced competitiveness of EU wind and solar PV manufacturing industries, including: 1) contraction of domestic demand induced by gradual removal of support schemes, 2) grid-related integration challenges (e.g. curtailment), 3) emergence of oil companies with specific expertise in offshore applications and 4) losing market shares to low-labour cost competitors established in rapidly growing Asian markets as transportation costs for wind turbine equipment are significant. In order to maintain its leading position on clean energy innovation, the EU may need to adjust its R&D and innovation focus away from manufacturing and towards "creating new ideas and concepts". The European Commission (EC, 2016) has already formulated strategies and targets to exploit emerging clean energy export opportunities.

The study showed that there is no obvious one-to-one relationship between RES expansion and a net change in the number of energy supply jobs. The switch of investment from fossil fuels to low-carbon energy technologies may increase or decrease employment on a net basis, depending on the mix of technologies deployed, the domestic content of alternative energy sources, the time period and a series of modelling assumptions. Several studies have shown positive employment impacts of climate change mitigation policies for countries that are importers of fossil fuels and exporters of clean energy technologies, such as Germany and Denmark (Ragwitz et al., 2009, OECD, 2017). Our study confirms employment gains for the EU region that is a major net fossil fuel importer and an exporter of clean energy equipment (mainly wind turbines). However, the estimation of job impacts in countries with significant fossil fuel production or supply chain serving fossil fuel industries is more difficult, as net employment results are not obvious.

Energy system transformation towards renewable energy and electrified transport can bring major economic and environmental benefits, among which are an increased security of energy supply and reduced air pollution. Low-carbon transition and RES expansion can also lead to positive job impacts, especially in countries that have established sophisticated manufacturing industries, effective innovation systems and highly-qualified human capital. The mitigation of possible adverse side effects of RES expansion on labour market (mainly in low-qualified coal mining jobs) and the pursuit of social, economic and employment benefits from the transition to clean energy is important to maintaining the positive momentum of energy and climate policymaking in the EU.

# References


Bureau of Labour Statistics, 2017, Data available at: https://www.bls.gov/oes/current/oessrci.htm

AEBIOM (2015), Bioenergy: Fuelling Europe with jobs and innovation, October 2015

Organisation for Economic Co-operation and Development (OECD), Environment and Employment: An Assessment, Working Party on National Environmental Policy (Paris: 17 May 2004), p. 6

European Commission (2016), Impact Assessment Accompanying the Proposal for a Directive of the European Parliament and of the Council amending Directive 2012/27/EU on Energy Efficiency

Capros, P., Van Regemorter, D., Paroussos, L., Karkatsoulis, P., Fragkiadakis, C., Tsani, S., Charalampidis, I., Revesz, T., 2013. GEM-E3 Model Documentation, JRC-IPTS Working Papers JRC83177. Institute for Prospective and Technological Studies, Joint Research Centre.

REN21 (2017), Renewables 2017: Global status report, Paris, REN21 Secretariat

Cedefop (2013), Skills Forecasts (retrieved from http://www.cedefop.europa.eu/EN/about-cedefop/projects/forecasting-skill-demand-and-supply/skills-forecasts.aspx).

McKinsey Consulting, 2006. Wind, Oil and Gas: The Potential of Wind

Clean Energy Manufacturing Analysis Center-CEMAC (2016), Benchmarks of clean energy manufacturing

Global Agricultural Information Network, GAIN Report EU-28 Biofuels Annual 2016

Egenhofer, C. et al. (2013), Options for EU Climate Policy: Creating growth, jobs and competitive advantage in global market, Report for "#climate4growth" campaign, Centre for European Policy Studies, Brussels.

European Commission (1993), *The challenges and ways forward into the 21st century,* White
Paper on Growth, Competitiveness and Employment, COM(93) 700, ECSC-EECEAEC, Brussels/ Luxembourg

European Renewable Ethanol Association, ePURE (2016), Trade and Customs, Available at: http://epure.org/about/what-we-do/trade-customs/

EurObserv'ER. 2016. "The State of Renewable Energies in Europe", (chapter) Socio-economic indicators, 16th EurObserv'ER Report

EurObserv'ER. 2015. "The State of Renewable Energies in Europe", (chapter) Socio-economic indicators, 15th EurObserv'ER Report

EurObserv'ER. 2013. "The State of Renewable Energies in Europe", 13th EurObserv'ER Report

European Environment Agency. 2016. "Renewable Energy in Europe 2016: Recent growth and knock-on effects", (chapter) Renewable Energy Employment

European Commission (2016), "Clean Energy for all Europeans" – Winter package, Brussels

European Commission (2011), Energy Roadmap 2050, COM (2011) 885 final, Brussels

EUROSTAT (2017), Renewable energy in the EU, 43/2017 - 14 March 2017

Noailly J., Shestalova V. 2017. Knowledge spillovers from renewable energy technologies: Lessons from patent citations. Environmental Innovation and Societal Transitions, Volume 22.

International Energy Agency (2016), Medium-Term Renewable Energy Market Report 2016: Market Analysis and Forecasts to 2021

International Renewable Energy Agency-IRENA (2016), Renewable Energy and Jobs Annual Review 2016

International Energy Agency (2015), World Energy Outlook 2015

International Energy Agency (2017), World Energy Investment 2017

European Commission (2014), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A policy framework for climate and energy in the period from 2020 to 2030, European Commission, Brussels, 2014.

Fischer-Kowalski, M., W. Haas, D. Wiedenhofer, U. Weisz, I. Pallua, N. Possanner, A. Behrens, G. Serio, M. Alessi and E. Weis (2012), Socio-ecological transitions: definition, dynamics and related global scenarios, NEUJOBS State of the Art Report No. 6/D1.1 and Working Paper D1.2, Institute for Social Ecology, AAU, Austria/Centre for European Policy Studies, Brussels, April.

OECD, 2012. "The jobs potential of a shift towards a low-carbon economy". June 2012, Final report for the European Commission, DG Employment; 2012.

United Nations Environment Programme, UNEP (2008), Green Jobs: Towards Decent Work in a Sustainable, Low-Carbon World, UNEP and ILO, 2011

E3MLab, CE, EXERGIA, EY, Warwick, IER. 2013. "Employment Effects of selected scenarios from the Energy roadmap 2050", Technical report to DG-ENER.

E3MLab, 2016. "Evaluation of macroeconomic impacts of EUCO energy scenarios using the GEM-E3 model", Report to DG-ENER.

E3MLab & IIASA, 2016. "Technical report on Member State results of the EUCO policy scenarios", Report to DG-ENER.

Mario Ragwitz, et al. 2006. "The impact of renewable energy policy on economic growth and employment in the European Union", Final report of the EmployRES project, TREN/D1/474/2006

Vicki Duscha, Mario Ragwitz, Barbara Breitschopf, Wolfgang Schade, Rainer Walz, Matthias Pfaff, 2014, "Employment and growth effects of sustainable energies in the European Union", Final Report of the project "Support Activities for RES modelling post 2020" funded by the European Commission, DG Energy, under contract ENER/C1/428-2012.

Lehr, U., Lutz, C., Khoroshun, O., Edler, D., O'Sulllivan, et al. (2011), Renewably employed! Short and long-term impacts of the expansion of renewable energy on the German labour market.

Energy [R]evoLution: A Sustainable World Energy Outlook, Greenpeace International, 2015

Behrens, A., Coulie, C., Genoese, F., Alessi, M., Wieczorkiewicz, J. and Egenhofer, C. (2014), 'Impact of the Decarbonisation of the Energy System on Employment in Europe', CEPS Special Report: NEUJobs project

European Commission 2015, Energy Union Package: Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee, The Committee Of The Regions And The European Investment Bank, A

Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy, COM(2015) 80 final

European Commission 2017, fact sheet, Renewables: Europe on track to reach its 20% target by 2020, Brussels 1 February 2017

European Commission 2015, Commission Staff Working Document Impact Assessment, Accompanying the document proposal for a directive of the European parliament and of the council on the promotion of the use of energy from Renewable Sources (recast), Part 3, Brussels, 30.11.2016 SWD(2016) 418 final

European Commission 2009, Directive 2009/28/EC on the promotion of the use of energy from renewable sources, OJ L 140, 5.6.2009.

European Commission 2016, Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (recast)

Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Sophie Dupressoir et al., Climate Change and Employment: Impact on Employment in the European Union-25 of Climate Change and $CO_2$ Emission Reduction Measures by 2030, European Trade Union Confederation (ETUC), 2007

Foratom (2010), The socio-economic benefits of nuclear energy, Fact sheet, Brussels.

Nathani, C., C. Schmid, G. Resch and U. Lehr (2012), Methodological guidelines for estimating the employment impacts of using renewable energies in electricity generation. Annex 2: Country fact sheets. RE related gross employment in RETD member countries, Energy Economics Group (EEG)/ Fraunhofer ISI/Rütter

Bell, C. (2012), Energy Efficiency Job Creation: Real World Experiences, ACEEE White Paper, American Council for an Energy-Efficient Economy

Pikas, E. et al. (2015), "Quantification of economic benefits of renovation of apartment buildings as a basis for cost optimal 2030 energy efficiency strategies", Energy and Buildings, Volume 86,

IRENA, 2011, IRENA working paper: renewable energy jobs: status, prospects & policies. Abu Dhabi: International Renewable Energy Agency; 2011

E3MLab, 2016, Technical report on Macro-economic Member State results of the EUCO policy scenarios, December 2016

OECD (2016), OECD Business and Finance Outlook 2016, OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264257573-en

US DOE (US Department of Energy) (2017), U.S. Energy and Employment Report, US Department of Energy, Washington D.C.

Ayee, G., Lowe, M., & Geref, G. (2008). Manufacturing Climate Solutions. Carbon-Reducing Technologies and U.S. Jobs. Chapter 11. Wind power: Generating electricity and employment.

Cambridge Econometrics CAMECON 2016, E3ME Modelling of the EUCO policy scenarios, December

Enrica De Cian et al, “European-Led Climate Policy Versus Global Mitigation Action: Implications on Trade, Technology, And Energy”, Climate Change Economics Volume 04, Issue supp01, November 2013

Frondel M, Ritter N, Schmidt CM, Vance C. (2010) Economic impacts from the promotion of renewable energy technologies: the German experience. Energy Policy 2010; 38:4048–56

Garrett-Peltier, Heidi, 2011. Creating a Clean-Energy Economy: How Investments in Renewable Energy and Energy Efficiency Can Create Jobs in a Sustainable Economy. Lambert Academic Publishing, Saarbrucken, Germany.

Garrett-Peltier, Heidi, 2016. Green versus Brown: Comparing the employment impacts of energy efficiency, renewable energy and fossil fuels using an input-output model, Economic Modelling

Creating a Clean-Energy Economy: How Investments in Renewable Energy and Energy Efficiency Can Create Jobs in a Sustainable Economy. Lambert Academic Publishing, Saarbrucken, Germany.

Tourkolias C, Mirasgedis S. (2011) Quantification and monetization of employment benefits associated with renewable energy technologies in Greece. Renew Sustain Energy Rev 2011; 15: 2876-86

International Renewable Energy Agency, 2012a. Solar Photovoltaics. Renew. Energy Technol.: Cost Anal. Ser.

International Renewable Energy Agency, 2012b. Wind Power. Renew. Energy Technol.: Cost Anal. Ser.

Malik, A., Lenzen, M., Ely, R., Dietzenbacher, E., 2014. Simulation the impact of new industries on the economy: The case of biorefining in Australia. Ecol. Econ. 107, 84–93.

Pollin, R., Garrett-Peltier, H., Heintz, J., Chakraborty, S., 2015. Global Green Growth: Clean Energy Industrial Investments and Expanding Job Opportunities. United Nations Industrial Development Organization and Global Green Growth Institute, Vienna and Seoul

Bloomberg New Energy Finance (BNEF), 2013. Sustainable Energy in America: 2013 Factbook. BNEF.

Tegen, S., Hand, M., Maples, B., Lantz, E., Schwabe, P., Smith, A., 2013. 2011 Cost of Wind Energy Review. NREL Technical Report NREL/TP 5000-56266. National Renewable Energy Laboratory, Golden, CO.

Black and Veach (2012), Cost and performance data for power generation technologies, Prepared for the National Renewable Energy Laboratory

Chung D. et al (2016), U.S. Photovoltaic prices and cost breakdown: Q1 2015 Benchmarks for Residential, Commercial and Utility-scale systems, NREL Technical Report (2016)

Wei, M., S. Patadic and D. Kammen (2010), “Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US?”, Energy Policy, Volume 38, Issue 2, February 2010,

Van der Zwaan BCC, Cameron L, Kober T., Potential for renewable jobs in the Middle East. Energy Policy 2013; 60: 296–304.

Cameron L, Van der Zwaan BCC, Employment factors for wind and solar energy technologies: A literature review, Renewable and Sustainable Energy Reviews 45 (2015), 160-172

European Commission (2012), Exploiting the employment potential of green growth, SWD (2012) 92 final, Brussels.

Rutovitz, J. and S. Harris (2012), Calculating global energy sector jobs: 2012 methodology, prepared for Greenpeace International by the Institute for Sustainable Futures, University of Technology, Sydney

Rutovitz, J., Dominish, E. and Downes, J. (2015). Calculating Global Energy Sector Jobs: 2015 Methodology Update, Prepared for Greenpeace International by the Institute for Sustainable Futures, University of Technology, Sydney

International Renewable Energy Agency-IRENA (2016), Renewable Energy and Jobs Annual Review 2016

Behrens, A., Coulie, C., Genoese, F., Alessi, M., Wieczorkiewicz, J. and Egenhofer, C. (2014), 'Impact of the Decarbonisation of the Energy System on Employment in Europe', CEPS Special Report: NEUJobs project

Hiroki Hondo, Yue Moriizumi (2017) Employment creation potential of renewable power generation
technologies: A life cycle approach, Renewable and Sustainable Energy Reviews, 79 (2017), 128-136

T. Ronzon, S. Piotrowski, R. M'Barek, M. Carus, A systematic approach to understanding and quantifying the EU's bioeconomy, *Bio-based and Applied Economics* 6(1), 2017

National Renewable Energy Laboratory, 2014. PHOTOVOLTAICS model: Release Number: PV3.24.14. In Jobs and Economic Development Model (JEDI).

National Renewable Energy Laboratory, 2015. WIND model: Release Number: W07.08.15. In Jobs and Economic Development Model (JEDI)

Transport and Environment, 2016, Electric vehicles in Europe 2016- Approaching Adolescence

Cleantechnica 2016, Top EV Battery Producers (2015 vs 2014 Top 10 List), March 2016, Available at: https://cleantechnica.com/2016/03/26/top-ev-battery-producers-2015-vs-2014-top-10-list/

CEMAC (2016) Clean Energy Manufacturing Analysis Centre, 2015 Research Highlights, March 2016

CEMAC (2016) Clean Energy Manufacturing Analysis Centre, Benchmarks of Global Clean Energy Manufacturing

Chung D., Elgqvist E., Santhanagopalan S. (2016) Clean Energy Manufacturing Analysis Centre, Automotive Lithium-Ion Cell Manufacturing: Regional Cost Structures and Supply Chain Considerations, Technical Report NREL/TP-6A20-66086

Future Market Insights (2015), Global Lead Acid Battery Market, Available at: http://www.futuremarketinsights.com/infographics/Global_Lead_Acid_Market.pdf

Earth Policy Institute (2013a), Data available at: http://www.earth-policy.org/indicators/C47

Earth Policy Institute (2013b), Data available at: http://www.earth-policy.org/indicators/C49

Fraunhofer Institute for Solar Energy Systems ISE, Photovoltaics Report, Freiburg, 2016, see: https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdfhttp://www.ise.fraunhofer.de/de/downloads/pdf-files/aktuelles/ photovoltaics-report.pdf

Fraunhofer Institute for Solar Energy Systems ISE, Photovoltaics Report, Freiburg, December 2012, Available at: http://www.ise.fraunhofer.de/de/downloads/pdf-files/aktuelles/photovoltaics-report.pdf

JRC, 2015, Perspectives on future large-scale manufacturing of PV in Europe, JRC Science and Policy report

Navigant Consulting company, "International wind energy development: World Market Update", various editions used (2009, 2010, 2011, 2012, 2013)

Navigant Research, 2015, "World Wind Energy Market Update 2015"

Stark, Camila, Jacquelyn Pless, Jeff Logan, Ella Zhou, and Douglas Arent. 2015. Renewable
Electricity: Insights for the Coming Decade. Joint Institute for Strategic Energy Analysis. Golden, CO: NREL. http://www.nrel.gov/docs/ fy15osti/63604.pdf

Ernst & Young, Solar Power Europe (2015), Solar Photovoltaics Jobs & Value Added in Europe

James T., Goodrich A., 2013, Supply chain and blade manufacturing consideration in the global wind industry, NREL

## GETTING IN TOUCH WITH THE EU

### In person

All over the European Union there are hundreds of Europe Direct information centres. You can find the address of the centre nearest you at: https://europa.eu/european-union/contact_en

### On the phone or by email

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

– by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),

– at the following standard number: +32 22999696 or

– by email via: https://europa.eu/european-union/contact_en

## FINDING INFORMATION ABOUT THE EU

### Online

Information about the European Union in all the official languages of the EU is available on the Europa website at: https://europa.eu/european-union/index_en

### EU publications

You can download or order free and priced EU publications at: https://publications.europa.eu/en/publications. Multiple copies of free publications may be obtained by contacting Europe Direct or your local information centre (see https://europa.eu/european-union/contact_en).

### EU law and related documents

For access to legal information from the EU, including all EU law since 1952 in all the official language versions, go to EUR-Lex at: http://eur-lex.europa.eu

### Open data from the EU

The EU Open Data Portal (http://data.europa.eu/euodp/en) provides access to datasets from the EU. Data can be downloaded and reused for free, for both commercial and non-commercial purposes.

Publications Office
of the European Union