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Techno-Economic study on the potential of European Industrial Companies regarding Europe's Green Deal

Final report

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Abstract

The study provides theoretical as well as case-study based evidence for the potential of European industries to become carbon neutral and provide job security and growth in the EU. The study identifies, maps, and analyses Global Innovation Networks, i.e. networks between industry and other actors that facilitate innovation, and their role in making the European Green Deal a success. The study also presents the main current policy context in place in the EU, China and the U.S., e.g. regulatory and financial frameworks, and identifies the main drivers and barriers for investing in technologies relevant for Europe's Green Deal. In addition, a concise policy toolbox for Research & Development & Innovation (R&D&I) policies supporting technologies relevant for Europe's Green Deal is discussed. It moves beyond the current European, national, regional and sectoral policy instruments and mixes of policies based on the insights obtained throughout the whole study. The findings offer an important knowledge base for devising new and additional policy instruments.

Executive Summary

The study is situated in the context of the European Green Deal and provides theoretical as well as case-study based evidence for the potential of European industries to become carbon neutral and provide job security and growth in the EU. The study identifies, maps, and analyses Global Innovation Networks, i.e. networks between industry and other actors that facilitate innovation, and their role in making the European Green Deal a success. After identifying three Green Deal priority areas – industry (including specifically chemistry and steel), energy and mobility – and two transversal technologies – batteries and hydrogen –, the study presents findings for each of these areas.

We start by reviewing the R&D&I competitiveness per Green Deal priority area. The focus lies on the assessment of R&D&I competitiveness in five main geographical regions – the EU, the U.S., Japan, China and 'RoW' (Rest of the World) along the Green Deal priority areas industry, energy and mobility, and the two transversal technologies batteries and hydrogen.

We first explore the industry sector[1] as they are one of the main emitters of greenhouse gases. Hence, the decarbonization of the industrial sector is crucial. In line with the goals of the European Green Deal, this transformation should simultaneously maintain economic performance and job security. Regarding the regional distribution of top R&D investors in the industrial sector, the EU is well positioned. Inside the EU, top R&D investing companies are especially centred within Germany. Chinese companies are also strongly represented among the top R&D investing companies. Zooming in on R&D investments, the EU has leading positions both in terms of total R&D investments (country level) and in terms of R&D intensity. Although in the past being on a relatively low level, R&D investments of Chinese companies have recently strongly grown both on regional and company level.

Zooming in on the steel sector, total funding is highest for EU start-ups. At the same time, mean funding per company is highest for Chinese start-ups (double the EU level), indicating that highly innovative enterprises are well positioned in China.[2] Over all geographic regions, the number of start-ups in the steel sector is relatively low compared to other sectors, indicating high barriers to market-entry. Also, interferences between highly policy-relevant sectors, especially key enabling technologies (KET) were identified within the steel sector. In the chemical sector, interferences mainly with the biotech sector were found. In this sector, start-ups in the US received the highest amount of funding, both on regional and firm level, and appear most frequently in the database. The regional concentration of funding within the chemical sector in the EU is lower than in other sectors analysed (e.g. steel). Japanese start-ups operating in the chemical sector are not included in the database.

We then explore the energy sector as the EU has the largest share of top R&D-investing companies operating in this sector. Furthermore, total R&D investments are highest in the EU, whereas mean R&D expenditures per company are highest in the US and China. In both the US and China, start-ups in the energy sector receive higher amounts of funding than in other world regions. Further findings suggest that companies in China and RoW are to a large degree active in the conventional energy sector whereas in EU or US, for instance, the share of companies active in the renewable energy sector is growing. Yet, operational profits are still higher for companies in the conventional than in the sustainable energy sector. The high and continuously growing number of start-ups operating in the energy sector indicates lower market barriers than in the steel sector, for instance. Linkages between the energy sector and KET (especially biotechnology and nanotechnology) and key and emerging software technologies (primarily IoT and AI) have been identified in the analysis of innovative tech start-ups, which indicates synergy effects between the energy industry and the highly policy relevant areas.

Next, we explore the mobility sector as top R&D-investing companies in this sector are spatially regularly distributed on a regional level. Yet the inner-EU analysis gives a high concentration of actors in specific countries, such as Germany that is home to a clear majority of the European companies. Both total R&D investments and mean R&D expenditures per company are highest in the EU, with strong growth rates. The US and Japan also record high expenditures for R&D. Chinese companies recently increased their R&D intensities indicating large growth rates. Yet, in terms of funding, US mobility start-ups received the highest amount of funding in total, followed by Chinese start-ups, which received the highest sums per company.

[1] In some cases, the study analyses the industry sector on deeper sublevels, mainly the chemical and steel sector.

[2] Analysis based on Crunchbase database (2020).

New foundations of tech start-ups show an immense positive trend, indicating a market with high potential for shareholders. Further analyses of mobility tech start-ups reveal linkages to highly policy relevant areas, notably key and emerging software technologies (mainly IoT and AI).

Finally, we zoom in on cross-sectional technologies, more specifically on hydrogen and batteries as they are indispensable for the sustainable transformation of all three identified Green Deal priority areas (industry, energy, mobility). Analyses of current and emerging tech start-ups operating in the hydrogen sector imply a young market still gaining in importance. US start-ups receive the largest share of overall funding, followed by EU companies on both macro and firm level. Links to operations in policy relevant fields, such as KETs, key and emerging software technologies and advanced manufacturing technologies are also limited. The number of start-ups operating in the battery sector has highly and continuously increased during the past years, indicating a high growth potential for this sector. Again, US start-ups receive the largest share of overall funding, whereas Japanese start-ups receive the highest amount of funding per company.

Another aspect of the study is to obtain key insights from GINs and R&D&I ecosystems. The study uses various quantitative and qualitative analyses to identify main relevant companies active in Global Innovation Networks (GINs) in the three Green Deal priority areas industry, energy and mobility. These main relevant companies are of particular interest due to their role as large R&D investors: they invest in start-ups, help smaller firms to grow by purchasing their innovative products, control supply and distribution chains, and often collaborate with public research institutions and universities. For increasing the validity of the results, the study focusses additionally on some smaller companies. In depth information on the involvement of large R&D investors as well as smaller companies in Global Innovation Networks (GINs) was mainly obtained from interviews but triangulated against other results at each step of the study to generate a comprehensive picture and to increase validity.

The study presents ten case studies on Global Innovation Networks (GINs) focussing on technologies connected to sustainability and the goals of the EU Green Deal. The results show that actors are typically involved in more than one Global Innovation Network. MNEs tend to be members in more networks than SMEs and “younger” companies. Most GINs addressed have a geographic centre in the EU or Europe. At the same time, the networks’ geographical scope and the diversity of actors is variable and seems to a certain degree correlated with the number of actors involved. In some cases, being located in the EU is seen as an enabler for the related technology concerning the aim to become carbon-neutral and the demand for “green” technologies. The choice of cooperation partner highly depends on the respective company’s core business, specialization and capabilities. Different types of actors tend to have different roles within a given Global Innovation Network and a high degree of diversity within the network is seen as beneficial by the actors involved. The study also identifies common reasons for being organized in an R&D&I network, such as the joint development of new ideas and the access to relevant knowledge or the formation of new partnerships. Technologies that are developed within these networks are often closely linked to the members’ usual fields of activity. In general, network members expect growth in the sectors related to the technologies in question. This expectation is conditioned by policy conditions pushing the demand for “green solutions” and the resulting current growth of related markets. Yet, although being organized in a GIN is in part a strategic benefit due to the spread and reduction of risks, R&D&I projects are often accompanied by high risks. Thus, it is necessary to complement the existing policy framework with supportive enabling instruments.

Next, the study discusses the main current policy context in place in the EU, China and the U.S. and identifies the main drivers and barriers for investing in technologies relevant for Europe's Green Deal.

The political sustainability framework in the EU is driven by the European Green Deal[3] and its ambitious aim to boost Europe´s competitiveness based on cutting edge innovation in a broad sense. The long-term goal of the new growth strategy is to make Europe the first carbon neutral continent by 2050. This entails the need for structural transformation and crosscutting policy support towards competitive sustainability. Compared to other regions, the EU policy focus of the Green Deal enabling industrial competitiveness and

[3] The European Green Deal. COM/2019/640 final. Brussels: European Commission. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN

structural transformation is unique. Thus, EU companies and their participation in GINs will play a central role in the transition to a more environmentally friendly path while at the same time competing on a global level.

The US innovation system is characterized by a strong focus on private sector innovation and decentralized innovation. Innovation in firms, especially in highly innovative start-ups, plays a crucial role in the US innovation activities. Since January 2021, a Green New Deal seeks to reduce greenhouse gas emissions, create high-paying jobs, ensure that clean air, clean water and healthy food are basic human rights, and end all forms of oppression. Just recently, President Biden issued a number of executive actions addressing climate change, for instance rejoining the Paris Agreement and a global pact to reduce emissions.

The Chinese innovation system is characterized by strong, centralized control by the government. In contrast to Europe, workers' actors do not play an active role in the innovation systems of the US and China. China just recently introduced its 14th 5-year plan 2021-25 that presents an opportunity for China to link its long-term climate goals with its short- to medium-term social and economic development plans. In addition, China's commitment to achieving carbon neutrality by 2060 has set a direction for its economy but requires ratcheting up ambition on its near-term climate policy. The new plan covers six key areas of energy development, including the construction of eight large-scale clean energy "bases", coastal nuclear power, electricity transmission routes, power system flexibility, oil-and-gas transportation and storage capacity.

The study also classifies barriers and enabling factors for R&D&I policies supporting the sustainable transition into three categorical instruments: regulatory instruments, economic and financial instruments and soft political instruments. Insights from a literature review and expert interviews show that in the context of sustainable transformation of the industry, regulations are seen as having negative impact on conventional business, such as the EU ETS which increases the price for CO_2 leading to less competitiveness which impacts the business model. At the same time, an appropriate regulatory framework is the cornerstone of the new Industry Strategy for a green and competitive EU industry and can lead to benefits for sustainable and transformative sectors and technologies. The existing funding instruments and financial guidelines are seen as beneficial for the transformation towards a sustainable economy. Yet it is suggested to improve the dialogue between all relevant stakeholders, such as firms and political decision makers regarding the development towards a climate neutral industrial sector.

Finally, the study developed a policy toolbox. There are three classic categories of policy instruments in the field of innovation and industrial policy: (1) regulations, (2) economic and financial instruments, and (3) soft instruments. The tradition is that they are discussed separately which is not the best approach when looking on new instruments regarding Europe's Green Deal. These new instruments are quite often 'three in one' which means that they consist of regulations, economic, and financial instruments, and soft instruments. This phenomenon can be found for instance in Public Private Partnerships like SPIRE or Fuel Cells and Hydrogen Joint Undertaking (FCH JU). It can be also found in innovation alliances like the European Battery Alliance or the European Clean Hydrogen Alliance. Anticipation-based innovation and industrial policy instruments ('three in one') linked with the European Green Deal related technologies can be used, even if they are still vague in the initial phase, to systematically design job profiles, qualification requirements and employment opportunities. Regulations are seen as having negative impact on conventional business but can lead to benefits for sustainable and transformative sectors. Regulation can increase competitiveness, however the speed and agility of policies in the EU is seen as too slow. The interviewed companies of various sizes and from different sectors do not report a general funding gap. Existing financial guidelines and funding instruments are seen as beneficial for transformation towards a sustainable economy. Soft instruments like the improvement of dialogue between all stakeholders and involvement of all relevant actors are seen as beneficial for a stronger innovation network.

1 Introduction

1.1 Background of the study

The objective of this study is to provide theoretical as well as case-study based evidence for the potential of European industries to become carbon neutral and provide job security and growth in the EU, which is defined as a key priority in the European Green Deal following declining job prospects and the industries' burden on the environment. Accordingly, this study identifies, maps, and analyses **Global Innovation Networks and their role in making the European Green Deal a success.** The study encompasses the following major tasks:

- Identifying key industries which are working towards carbon efficiency and/or employment security on a granular level.
- Assessing the role of corporate actors in GINs in terms of efficiency, productivity, and employment by separating economic from technological actors as well as separating technology producers from users.
- Identifying barriers to the development of the role of Europe in GINs.
- Proposing a policy toolbox for strengthening European R&D&I and their capabilities in developing technologies which cater to the European Green Deal.
- To provide a comprehensive and exhaustive view of the matter, the study feeds on theoretical and empirical findings from Global Innovation Network (GIN) studies relating to Global Value Chains (GVCs), Regional Systems of Innovation (RSI) theories, and the institutional systems approach among others, while also addressing economic aspects weighing in, such as infrastructure, labour market conditions, reliability of communication systems, and trade policy climates with other regions.
- Milestones for this study will be the identification of relevant R&D investors and related actors in GINs and national/regional innovation systems, their analyses, interviews with key industry players, and lastly a policy toolbox facilitating the European industries' implementation of the European Green Deal.

The European Green Deal represents a paradigm shift in European politics that is designed to lead the change towards making the European economy digitalised and environmentally sustainable. The long-term goal of the new growth strategy is to make Europe the first carbon neutral continent by 2050. The intermediate goal is to decrease greenhouse gas emissions by 55% by 2030. This entails the necessity of efforts in Research & Development & Innovation (R&D&I) that will eventually shape EU policy and have a direct impact on industry and civil society. The growth strategy includes a timeline for guiding documents to be published between 2020 and 2023 (European Commission, 2019d). A central document represents the proposal for a European Climate Law, published in March 2020 (European Commission, 2020d).

The European Green Deal is the ambition of the next European Commission to make Europe the first carbon neutral continent by assessing energy-intensive industries and how they can be reshaped. In its first draft and after public consultation, the European Green Deal sets to make the European economy carbon neutral, restore biodiversity, and provide more reliable job security. Partially through a €1 trillion injection into various actors in the European Industry, facilitated by the Sustainable European Investment Plan and justified by the current investments in non-sustainable practices, the European Green Deal outlines that it wants to reach its goals through targeted investments in various aspects of society and new legislation in line with the 3 goals (von der Leyen, 2019), European Commission, 2019e, 2019f).

FDI and local investments into R&D&I are crucial to innovations which have the potential to lead to carbon-neutral industry practices and while their effectiveness varies from region to region, they are the first trigger for innovation.

Innovation is identified by theoretical and empirical research as being a crucial driver of job growth in high skilled labour and as being the only viable investment option leading to environmentally friendly technologies, which are two goals the EC wishes to reach with the European Green Deal (European Commission, 2019, Moser & Feiel, 2019, Johnsen & Ennals, 2011).

The OECD attributes a key-role to GINs as a crucial policy and research tool to lead the change towards what the European Green Deal highlights as carbon-neutral industries and job-prospect rich economies. Furthermore, the OECD stresses the importance for European industries to engage in GVCs and allocate subsidies and investments into research leading to expertise in various industries (OECD, 2017). As GVCs are becoming more fragmented than in the early 2000s and productions stages are becoming smaller and more geographically dispersed, the accurate assessment of GVCs and GINs and their relation to national and regional innovation systems is paramount to policy decisions aimed at catering to the European Green Deal (Dosso, Potters & Tübke, 2017). Consequently, collaborations between actors of different stages of GVCs increase out of necessity, making a policy understanding of innovation systems and networks increasingly important as well. Protectionist measures are believed to be a limitation to advances in R&D&I and Europe's ability to engage in relevant GVCs. The shift from closed to open innovation is identified as a capacitator for GINs (Huawei, 2018).

Global Innovation Networks are networks of industry actors and other stakeholders such as academia and public institutions that facilitate and/or promote innovation. Their value becomes apparent when they allow an understanding of e.g. firms' relocation decisions or their choice of public-private partnerships. GINs provide a comprehensive understanding of innovation drivers and hampers. GINs allow for a historical as well as projective analysis of companies' locational, operational, and strategical choices and their position in GVCs (Herstad et al., 2014; Dosso, Potters & Tübke, 2017). Unfortunately, comprehensive and actionable research of how GINs can contribute towards a greener economy are lacking.

As a majority of R&D investors are MNEs, this study focuses on large companies in favour of smaller firms. Additionally, large firms have a bigger impact than SMEs as they are active in several countries simultaneously and can potentially broaden the scope to address the whole ecosystem. As mentioned previously, an understanding of their respective roles in the GINs will give better insights into what current market trends and practices are and how they fit into the ambitions of the European Green Deal.

Europe is undergoing major transitions, each of which has wide-ranging implications on its own. As such, digitisation reforms employment and transfers jobs from obsolete sectors to new sectors. Digitisation further influences consumers' expectations and gives niche interest groups a voice to be heard, which has direct implications for industries in Europe and beyond. The transition towards a carbon-neutral economy and environmentally sustainable society, and the fact that industries are expected to implement circular economy strategies while also accounting for planetary boundaries affects the way R&D&I is conducted and invested into, beyond affecting job prospects as the digitisation transition does as well. The EC foresees that the transition to a carbon-neutral economy will create 1.2 million new jobs, in addition to 12 million new jobs expected to result from the other transitions mentioned (European Commission, 2019f; Adler et al., 2019). If European job growth and carbon net-neutrality are at the core of the ECs plans, it will be relevant to provide a mapping of key players in GINs and make sure that they are anchored in Europe. Furthermore, providing an overview of European MNEs and what function they accomplish in their respective GVC will give a grounded base for the design of policy tools. This is because companies placed at the higher value-added functions of GVCs have more leeway and capacity for job-growth in high-skilled positions than companies that are active at the lower end (European Commission, 2019e).

Based on the aforementioned developments in European industries and the targets set within the European Green Deal, this study aims to provide insights into the way large (and some smaller) firms operate in and engage with GINs, who the stakeholders are, and finally the actions undertaken by private actors towards environmental sustainability.

1.2 Objectives of the study

The European Green Deal identifies seven policy areas that cover the European ambition to become carbon neutral by 2050. This project will zoom in on a subset of the European Green Deal priority areas, including clean energy, sustainable industry, sustainable mobility, as well as hydrogen and batteries as two key technologies. The rationale for the selection of these priority areas is three-fold:

Contribution to Green Deal objectives: The Green Deal targets, among others, clean energy, sustainable industry and sustainable mobility. Together, the sectors of energy, industry and mobility are responsible for 87% of emissions in the EU-28 (as of 2019). Industrial processes and product use accounts for 8% of total greenhouse gas (GHG) emissions, whereas transport accounts for 25% and fuel combustion (excluding transport) for energy accounts for 54% (Eurostat, 2019). Seeing the overall emissions, these areas also have a great potential, through key innovations, to make positive contributions to emissions reductions.

Innovativeness: Highly innovative sectors, such as those depicted in the Strategic Value Chains (SVC) of the Important Project of Common European Interest (IPCEI) are linked to key enabling technologies, technological breakthroughs or disruptive innovation. The sectors of energy, mobility and industry have been leading the innovation wave related to low carbon and circular innovation, also within the framework of the SVC, with many examples already present in their works.

Competitiveness: The selected areas are positioned within global value chains, where it is particularly interesting to analyse the EU's competitive position as compared to key global players such as China and United States.

1.3 Structure of D4.1

This study provides a summary of all activities, findings and conclusions of the entire project. The report includes after this short introduction (Chapter 1):

- Chapter 2: details the study approach and the methodology used in the project;
- Chapter 3: provides a characterisation and assessment of Global Innovation Networks (GINs) along the Green Deal priority areas industry, energy and mobility;
- Chapter 4: provides a summary of the policy context and the policy toolbox that was developed as part of this study;
- Chapter 5: provides a brief conclusion;
- A list of all references.

2 Study approach and methodology

In the following, we present our approach as well as the methodology applied for the empirical work.

2.1.1 Approach

Figure 1 sketches the overall approach of this project including the different tasks, results and deliverables.

As a first step, **Deliverable D1.1** offered a concise review based on desk research (in the web, scientific literature, industry and company documents), to provide an enhanced picture of techno-economic developments in terms of R&I competitiveness of companies regarding Europe's Green Deal, including a comparison with international competitors. As part of the analysis of this deliverable, we have presented five Green Deal priority areas, namely energy, industry, mobility, hydrogen and batteries. The deliverable has also identified a broad set of properties and testable assumptions as a base for positioning the study in its context and for developing the subsequent approach of company and stakeholder identification.

Deliverable D1.2 laid out the methodological approach to identify and assess R&D&I competitiveness of companies and stakeholders regarding Europe's Green Deal (Task 1.2). Furthermore, the deliverable proposed an approach for the description and measurement of selected GINs and their R&D&I and economic competitiveness over time (Task 1.3).

In **Deliverable D2**, the methodology and approach to the data and for the identification of the main relevant companies and actors proposed in the previous step have been applied (Task 2.1). Furthermore, we characterised/measured the selected GINs/ecosystems and assessed their relative positioning, providing insight on main sector/technology specificities (Task 2.2). Finally, the findings from Tasks 2.1 and 2.3 have been validated and missing information have been completed by collecting additional information through interviews with managers in companies, industrial organizations, associations and other experts, as well as the screening and text mining of Corporate Responsibility reports (Task 2.3).

Deliverable D3 provided a concise description of the main current policy context in place (e.g. regulatory and financial frameworks) allowing to address the main drivers and barriers for investing in technologies relevant for Europe's Green Deal (Task 3.1). Furthermore, it presented a concise policy toolbox for R&D&I policies supporting technologies relevant for Europe's Green Deal (Task 3.2).[4]

The present **final report** summarises the findings of the preceding tasks and deliverables, including the policy toolbox and describing potential ways forward for supporting specific technologies (Task 4.1, **Deliverable D4.1**). Finally, the information resulting from the proposed methodology and used for the analysis has been collected and delivered in a dataset format (Task 4.2, **Deliverable D4.2**).

[4] Note that the present Deliverable 1.2 outlines the methodology to be applied in Deliverable 2, but not the methodology for Deliverable 3.

Figure 1: Overview of project tasks, results and deliverables

Tasks	Results	Deliverables
Task 0: Kick off Month 1	Common understanding of objectives and approach	
Task 1: Propose methodology and approach for the study Months 1-2	Coherent framework on how to identify key actors, GINs as well as their competitiveness	**D1.1**: Report on review and positioning summarising state of the art and literature **D1.2:** Report on proposed methodology
Task 2: Analyse R&D&I competitiveness in GINs and ecosystems Months 2-11	Presentation of main actors relevant for European Green Deal, their embeddedness in GINs and their global competitiveness	**D2**: Report on the stakeholders, GINs and ecosystems
Task 3: Policy context and policy toolbox Months 7-11	Outline of current policy context for European Green Deal, options for EU industrial and R&D&I policies	**D3**: Policy context and toolbox: Report developing and describing a policy toolbox
Task 4: Final report and data Months 11-15	Report summarising the results and dataset allowing replication	**D4.1**: Final report **D4.2:** Replication datasets

Source: VDI TZ

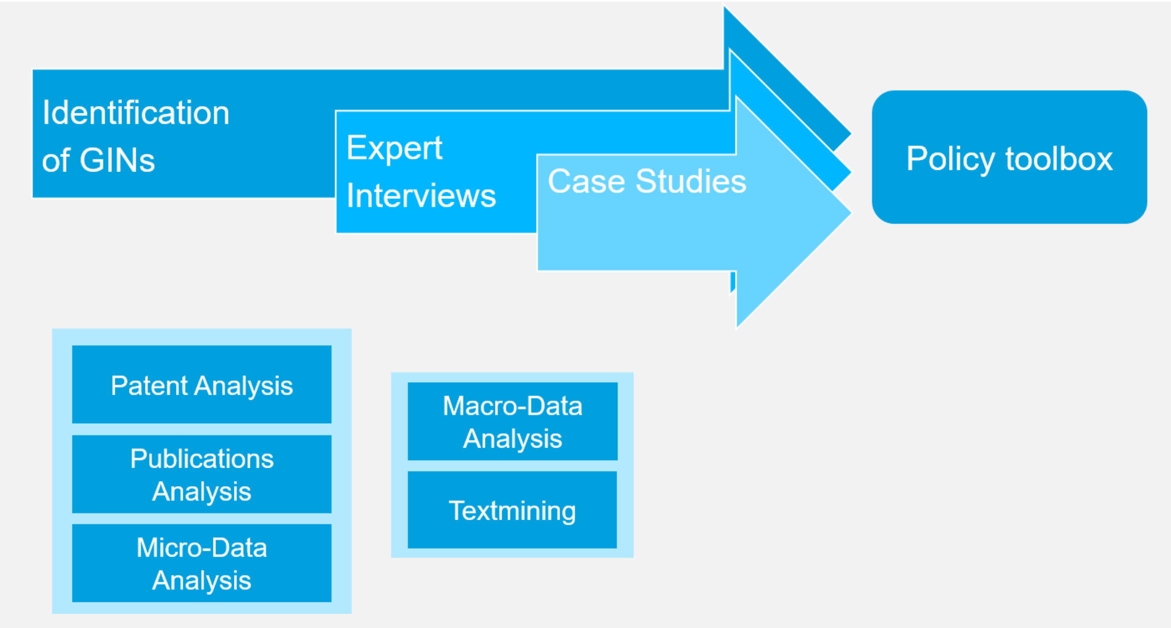
2.2 Methodology

The central aim of the methodology was to offer a coherent framework on how to identify key actors and GINs relevant to Europe's Green Deal. Furthermore, the methodology provided a framework to describe and measure the identified key actors, their embeddedness in GINs as well as their R&D&I and global economic competitiveness.

The applied methodology combined various different approaches – both of quantitative and qualitative nature – in a systematic way (see Figure 2). By combining different methods into a systematic mix-methods approach, we could leverage the advantages of each approach, thereby generate a more holistic selection of and view on companies and stakeholders, and finally derive conclusions with a higher robustness and explanatory power.

To identify relevant GINs, companies and stakeholders, we built on exploratory interviews, patent and publications analyses, text mining as well as micro- and macro-data analyses. To describe and measure GINs in terms of their R&D&I and global economic competitiveness, we additionally relied on expert interviews. The results were then combined in case studies on ten selected GINs.

Figure 2: Visualization of the methodological approach.



Source: VDI TZ

In the following, we present selected results from the patent and publication analyses as well as the textmining.

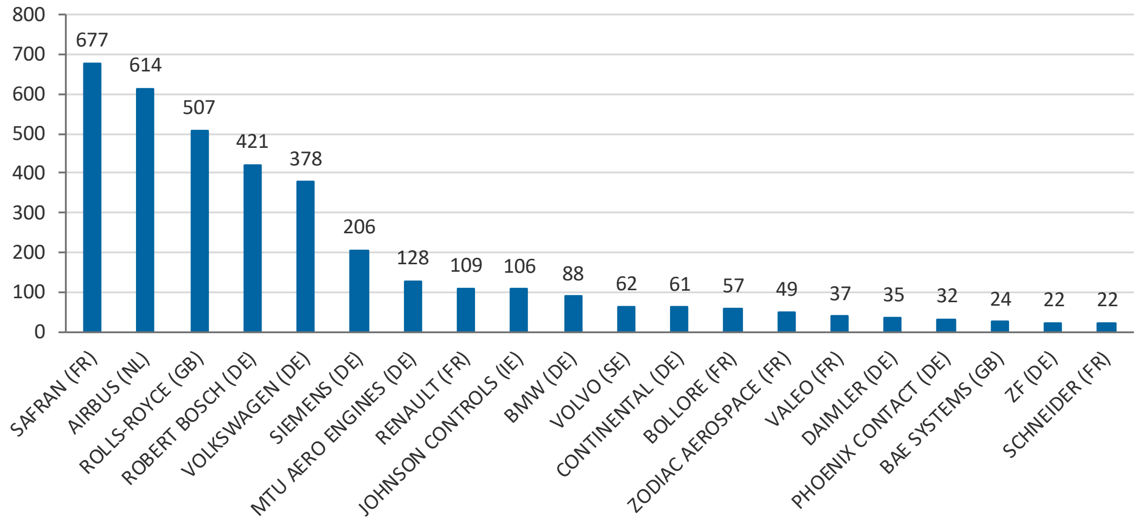
2.3 Patent analysis

The patent analysis served several goals: First, it allowed to identify companies having registered green patents, indicating R&D&I activities in fields relevant to Europe's Green Deal. Second, when comparing companies and sectors, patents are an indicator of companies' respective R&D&I competitiveness. Finally, considering co-patenting, i.e. patents registered by more than one company and/or organisation, offers the possibility to identify innovation networks (GINs).

We built on a detailed classification of green patents classes provided by the OECD (OECD 2016 and Haščič & Migotto 2015). For each of the five Green Deal priority areas, we compiled a list of all registered patents from the PATSTAT database. More details on the methodology of selecting relevant patent classes can be found in Deliverables D1.2 and D2. In total, we identified almost 20,000 green patents in the priority area “mobility”, around 11,000 patents for the energy sector, and between 2,600 and 5,100 for the remaining technologies (chemicals, steel, batteries and hydrogen).

For each of the Green Deal priority areas, we compiled a rank list of the top-20 European patenting firms by number of green patents (see Figure 3 for the mobility sector)[5]. This was used to identify relevant large stakeholders with strong activities in the area of green patenting.

Figure 3: Top-20 European patenting firms by number of green patents (mobility sector)



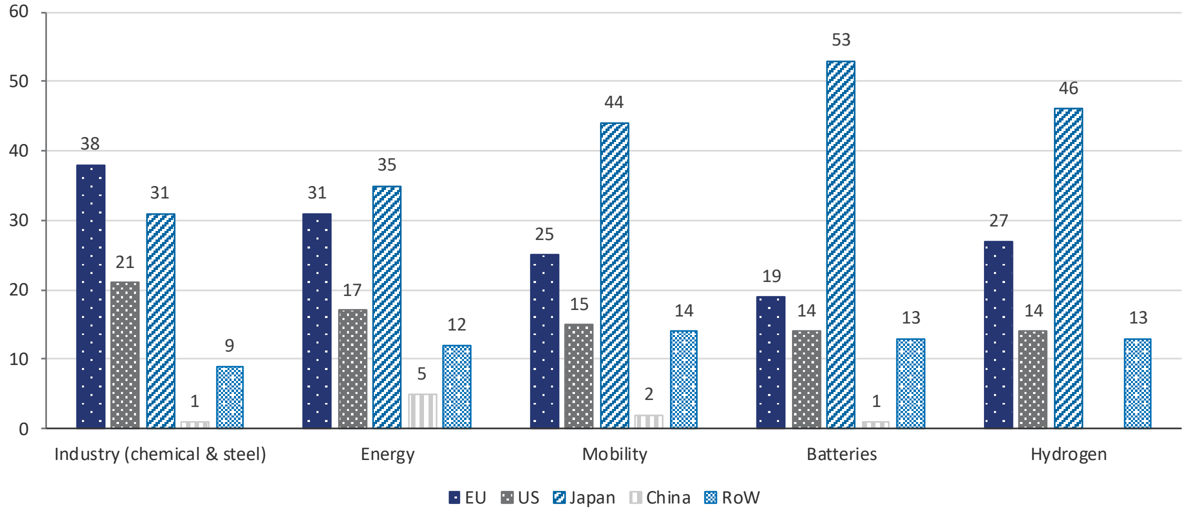
Source: VDI TZ

We also analysed the regional distribution across world areas – EU, US, Japan, China and Rest of the World (RoW) – of the top-100 patenting firms by Green Deal Area (see Figure 4). This analysis was used as an indicator of the relative positioning in terms of global competitiveness.

[5] More details and figures for the other sectors can be found in Deliverable D2.

Figure 4: Number of firms among the top-100 patenting firms by Green Deal area and world region

Source: VDI TZ



The total number of patents, among the top-100 patenting companies in all Green Deal areas, is 29,562 of which 9,292 (about 31 percent) are registered by companies head-quartered in Japan, 7,223 (about 24 percent) belong to companies headquartered in the US, followed by 5,815 (19 percent) patents from European firms and 277 (0.94 per-cent) from Chinese companies. The remaining part (about 23.5 percent of all patents among the top-100 patenting companies in the identified Green Deal Areas) can be allocated to the aggregate of other countries, RoW.

The summary of the results shows that firms headquartered in Japan, lead the ranking in both top-100 patenting firms regarding all of the considered Green Deal priority areas as well as the ranking for, in descending order, batteries, hydrogen, mobility and energy. Especially in the first three named sectors, Japanese firms are strong competitors in terms of their patent activities, compared to firms headquartered in the EU. This indicates that Japanese firms active in those areas, are strong in R&D&I compared to firms headquartered in other areas. Only in the industry sector, EU companies are performing better than Japanese firms in terms of their patent activities. EU companies which are active in both areas, steel and chemicals, are strongest compared to other regions, in terms of innovative output.

Additionally, we compiled a list of noticeable co-applicants.[6] Patent co-applications can – after triangulation with additional analyses, especially company publications – be considered as indicators for potentially existing GINs. In sum, in the mobility and batteries sector, patent co-application between European, Asian and US firms seems to appear quite frequently. Furthermore, taking all identified sectors into account, one of the co-applicants often is a prominent research institution, such as the French CEA and CNR or the German Max-Planck-Gesellschaft, while the other co-applicant is a major industrial player.

2.4 Publication analysis

The publication analyses served two goals. First, we focussed on identifying the top-30 global companies and their scientific publications in the COR&DIP database. Secondly, we zoomed in on the overall scientific publications carried out by the top-20 EU players, also looking at their overall investments in R&D. This two-step approach allowed us to support the decision-making on the case study stakeholders selected, which are predominantly EU companies, while leaving room to detect important players for the internationally oriented part of the in-depth case studies and company analysis.

[6] The number of patent co-applications is generally rather low, signifying that a quantitative analysis would be here of only limited additional value.

Our approach was performed based on the COR&DIP database, that contains information on the R&D&I activity and IP assets (i.e., patents) of the top 2000 corporate R&D performers worldwide, as well as bibliometric data. Counts of scientific publications are from Elsevier's Scopus® database. Relying on the so-called All Science Journal Classification (ASJC) and departing from the Green Deal priority areas (energy, industry, mobility, hydrogen and batteries), we were able to identify the most relevant scientific fields for the European Green Deal.[7, 8]

The analysis then **zooms in on the top-20 European players** in order to support the selection of European centric case studies. For this, we present, in addition to the publication activity, the relationship with the **overall R&D investments** for these players.

Companies such as Volkswagen (DE), are recurrent, and particularly evident due to high amounts of R&D investments in the indicated period, however the number of publications is not particularly high by comparison to the specialists in the field. Despite comparable small R&D investments, Royal Dutch Shell (GB/NL) stands out as a player with particularly high number of publications, especially in the area of energy-related publications, as well as hydrogen-related publications. In industry, Umicore (BE) and Siemens (DE) show significant numbers of publications alongside Eaton Corporation (IE) and Robert Bosch (DE). In the area of mobility-related publications, companies such as Thales (FR), Volkswagen (DE) and Daimler (DE) are evidently active compared to the remainder, however BMW (DE) and Renault (FR) are also present in the top-20. In addition, in the area of hydrogen-related publications, BASF (DE) and Royal Dutch Shell (GB/NL) together with L'Air-Liquide (FR) are also evident players in the list, with the latter with comparably lower R&D investments. Overall, the results present companies that have both the practice to publish in scientific journals and do so also in the relevant classified areas that can be associated with the Green Deal and hence the proposed companies can be considered as particularly active in innovation and interesting to explore further in the further analysis of the GINs.

2.5 Textmining

The aim of the text mining was to verify and complement findings resulting from the other analyses. We used the UN's Sustainable Development Goals (SDGs) as basis and matched corporate reports against SDGs to answer the question of how much topics covered by the SDGs are reflected in the company reports. To this end, we applied a bag-of-words approach.[9] To focus on SDGs which are of especially high interest to JRC, we concentrate on the following SDGs:

SDG8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all,

SDG9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation,

SDG12: Ensure sustainable consumption and production patterns, as well as

SDG13: Take urgent action to combat climate change and its impacts.

[7] Certain ASJC subfields were not able to sufficiently capture the typical key players associated with the field, as the granularity of the ASJC field does not match well with the scope of the Green Deal priority area. In the area of hydrogen, several companies appear that do not seem to have a direct link to hydrogen. Similarly, batteries are related to ASJC subfields on materials and chemistry, however this is not to say that the publications detected in this area are exclusively dealing with battery technology development.

[8] For more detail, see Deliverable 2.

[9] The bag-of-words method is frequently used in text mining, natural language processing and document classification. It signifies that all cleaned words – i.e. conjugations and declinations being removed – occurring in a document are put in an unsorted "bag" or, in more technical terms, a document-term matrix, where their occurrence is counted. Inside this "bag", only their (relative) frequency matters, while the order of words does not. To implement the text mining, we used R (especially the quanteda package for text mining, see Benoit et al. 2018, as well as the tidyverse collection of R packages, see Wickham & Grolemund 2017).

As a text base for each of the chosen SDGs, we used the "Progress & Info" texts for the years 2016 to 2019, as well as the presentation of targets and indicators for each SDG, as provided on the official UN website[10]. As a text base for the company reports, we opted for analysing annual reports instead of sustainability reports.[11] We selected a large set of companies in each of the three main Green Deal priority areas (industry, mobility and energy), including in total more than 120 annual company (sub-) reports.

Both SDG texts and company reports were cleaned and analysed using the quanteda package for R (Benoit et al. 2018). Cleaning included the removal of stopwords and stemming.

To match SDGs against company reports, we calculate Cosine similarity between normalized document-term matrices. Cosine similarity is a measure of similarity frequently used for text mining and takes into account the frequency with which words appear in each text document.[12] Normalization accounts for varying document lengths.

1. As a first step, we analysed which of the chosen four SDGs appear more prominently in the corporate reports. To answer this question, we compared the distribution of Cosine similarities for each SDG across all documents and industry sectors. **SDG8 (economic growth) is the SDG most reflected in the company reports** (median Cosine similarity of 0.27). This is not surprising, as company reports mostly deal with economic activity and economic growth. **SDG13 (climate change) is the SDG least reflected in the company reports** (median Cosine similarity of 0.22), while SDG12 (consumption and production, median Cosine similarity of 0.26) and SDG9 (infrastructure and industrialization, median Cosine similarity of 0.23) rank in the middle. The results could be interpreted as a first (though weak) indicator that climate change mitigation, central to Europe's Green Deal, still needs to seize a more prominent relative place in companies' annual reports and business agendas.

2. As a second step, we analysed the extent to which the reflection of the selected SDGs in the company reports varies by industry and world region. For this end, we focussed on companies with headquarters in the EU, the US and Japan, as company reports of companies located elsewhere (China, RoW) often differ considerably in their structure and language.

Reference to SDGs is somewhat lower in the mobility sector than in the industry and energy sectors. In the industrial sector, within the EU the similarity is highest for SDG12 (consumption and production) and SDG8 (economic growth). This indicates that commercial success is an important target for companies, especially in direct comparison to the other SDGs. In the EU energy sector, SDG8 (economic growth) and SDG12 (consumption and production) are highest compared to other world regions, but still comparatively lower compared to the industry sector.

[10] All texts published on https://sustainabledevelopment.un.org/sdg8; https://sustainabledevelopment.un.org/sdg9; https://sustainabledevelopment.un.org/sdg12; https://sustainabledevelopment.un.org/sdg13

[11] Sustainability and/or responsibility reports focus by their very nature on issues related to sustainable development. This circumstance makes it difficult to assess the importance companies attribute to sustainability relative to other issues (such as financial and other performance indicators, important achievements and future plans of the company etc.). By looking at annual reports instead of sustainability reports, it becomes possible to assess the relative weight attributed to sustainability.

Furthermore, annual reports compared to CSR / sustainability reports follow specific reporting standards. The International financial reporting standard (IFRS) is used as accounting standard for consolidated financial statements within the EU, the United States Generally Accepted Accounting Principles (US-GAAD) are foundation in the US. Therefore, company reports follow specific rules regarding necessary content and their structure which simplifies their comparison with one another, especially regarding the identification of consistencies regarding the SDGs.

[12] For an excellent explanation of different similarity measures, see https://towardsdatascience.com/overview-of-text-similarity-metrics-3397c4601f50

3. In a third step, we examine temporal developments in the reference to SDGs in company reports.[13] **Reference to SDGs has increased over time** for all considered SDGs except for SDG8 (economic growth), which remains, however, the SDG most reflected in the company reports. Especially reference to SDG12 (consumption and production) and SDG13 (climate change mitigation) has increased over the recent years. An increase can be generally seen as positive in terms of the relative weight attributed to sustainability. It remains important to keep in mind, however, that the analysis is only based on texts (i.e. companies' own statements, which are easier to adjust to changing expectations of the audience) and not company activities. Triangulation with other analyses reflecting company activities (e.g. patent and Scoreboard analysis) remained therefore central.

4. Finally, we analysed which EU companies have reports that reflect the selected SDGs most. A number of companies that appear in the top were also ranked high in the patent analysis – this was a factor considered for the selection of the case studies.

[13] To make a valid comparison, we only apply within-company comparisons, meaning that we compare earlier reports with the most recent reports from the same company. Using this approach allows us to take into account varying reporting tradition across companies.

3 Characterisation and assessment of Global Innovation Networks (GINs) along the Green Deal priority areas

Global Innovation Networks are networks of industry actors and other stakeholders such as academia and public institutions that facilitate and/or promote innovation. Their value becomes apparent when they allow an understanding of e.g. firms' relocation decisions or their choice of public-private partnerships. GINs exist within their Global Value Chains (GVCs), where R&D&I processes are becoming more and more widely dispersed, and this dispersion is occurring more and more quickly (Dosso, Potters, & Tübke, 2017).

GINs provide a comprehensive understanding of innovation drivers and hampers. GINs allow for a historical as well as projective analysis of companies' locational, operational, and strategical choices and their position in GVCs (Herstad et al., 2014; Dosso, Potters & Tübke, 2017). Unfortunately, comprehensive and actionable research of how GINs can contribute towards a greener economy are lacking, and hence this study aims to tackle this research gap.

Following this definition, we propose to define key building blocks of the GINs related to the Green Deal. These also served as key elements to select the case studies, including the following:

- Background information
- Characterisation of the networks and involved actors[14]
- Key enabling technologies and technological maturity
- Potential for growth

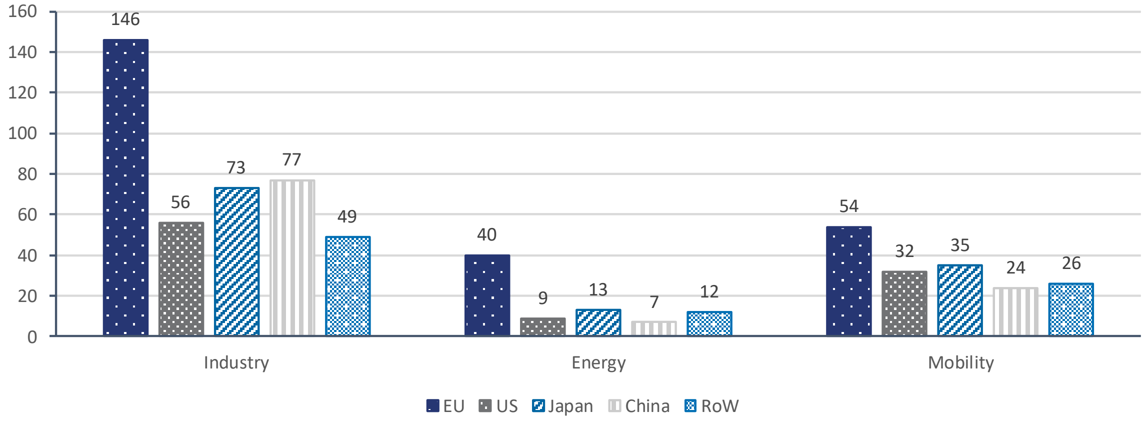
Thereafter, we provide detailed information on the GINs we interviewed and their potential to contribute to the Green Deal. Here, we will first focus on the specific technologies the networks are performing R&D&I in, before focussing on a more macro level of GINs and their potential to contribute to the Green Deal.

The following chapter aims to state both literature and empirical based evidence on the economic competitiveness of actors in the three identified **Green Deal priority areas** industry (steel and chemistry), energy and mobility on both regional and company level. Further, we will merge this information with insights obtained from ten case studies that are based on interviews we conducted with experts in the Green Deal priority areas. We also identified two **cross-sectional technologies** with the potential to accelerate the carbonisation of the European industry, that are integrated with the Green Deal priority areas: hydrogen and batteries. Hydrogen is produced within the energy sector and is used as source of energy by the mobility and the industrial sector. Vice versa, the industry is a producer of batteries that are used for energy storage in the energy and mobility sectors

The development of new technologies, sustainable or conventional, is linked to R&D&I efforts of the respective actors (Dernis, et al., 2015). Hence, analysing the distribution of companies that are investing the largest sums of R&D depicted in the EU Industrial R&D Investment Scoreboard provides a first indication on the distribution of R&D investments per Green Deal priority area and per region (Figure 5).

Figure 5: Number of companies in the Scoreboard by region and Green Deal priority area

[14] Results are based on expert interviews and desk research complementing information on specific networks. The results therefore provide only additional information and limited generally valid conclusions for the specific Green Deal priority areas.



Source: VDI TZ based on 2019 EU industrial R&D investment Scoreboard

As seen in Figure 5 most companies (with a sum of 401) operate in the industrial sector, followed by the mobility sector (171 firms) and the energy sector (81 companies). Most companies are EU firms (1,147 out of 3,288 in total) in both Green Deal priority (240 out of 653 companies) and other areas (the latter not illustrated here), showing a clear EU dominance in the industrial and especially in the energy sector.

The following chapters provide detailed information on the competitiveness of innovation activities and innovative competitiveness in the three Green Deal priority areas and the cross-sectional technologies. The analysis focusses on consistent indicators both on input and output level, such as R&D investments and patenting activities (Dernis, et al., 2015). To complement the results, we add analysis-based results on additional sources such as investment data in small companies based on the Crunchbase[15] database and supplement the results with insights from the case studies.

3.1 Industry

Background

The industrial sector takes third place in terms of EU GHG emissions in 2018, following the energy supply and transport sector (European Energy Agency, 2019). Hence decarbonizing the industrial sector by simultaneously maintaining job security is an important issue in transforming the industry. Within this sector, we identified two main subsectors, namely steel and chemicals, that are important actors in both contributing to EU GDP and EU CO_2 emissions. Due to data gaps, some of the analyses presented in the following provide results on an aggregated level, industry, while other analyses focus on both subsectors (chemistry and steel). In 2015, the steel sector directly emitted 190 and chemistry emitted 128.4 CO_2 eq. emissions in the EU (see Figure 6).

High energy consumption is a main contributor to the industrial sector´s high emissions level. So-called **Energy-Intensive Industries (EIIs)** are responsible for 15% of Europe's overall GHG emissions. To decarbonise these EIIs, funding and market creation remain important factors to support innovation activities forwarding the transformation.

Generally, the decarbonisation of EEIs involves the adoption of the following emission reduction pathways:

- Energy efficiency and process integration
- Switching to **alternative fuels** and feedstocks with a high greenhouse gas abatement potential (hydrogen, biomass, etc.)
- Electrification
- Hydrogen-based-processes

[15] https://www.crunchbase.com/

- Carbon capture, utilisation and storage (CCUS)
- Recycling, materials efficiency and circular economy
- Adoption of **industrial symbiosis** techniques, with a higher valorisation of waste streams and material efficiency

Figure 6: Evolution of GHG emissions across selected EIIs and the EU as a whole

Direct CO_2-eq emissions	**1990**	**2005**	**2015**
Chemicals[3]	325.1	212	128.4
Fertilizers4 [ammonia+nitric acid] (included in chemicals)	*76*	*66*	*28*
Steel[5]	258	232	190
Cement[6]	163	157	105
Refining[7, 8]	122	143	137
Pulp and paper[9]	39.9	43.2	32.7
Ceramics[10]	26	26	17
Non-ferrous metals and ferro-alloys[11]	52.3	31	17.8
Lime[12]	25.9	23	19.4
Glass[13]	*28*	*20*	*18.1*
Total	**1,040**	**887**	**665**
EU28 (excl. LULUCF)[14]	**5,650**	**5,220**	**4,319**

Source: VUB-IES, 2018

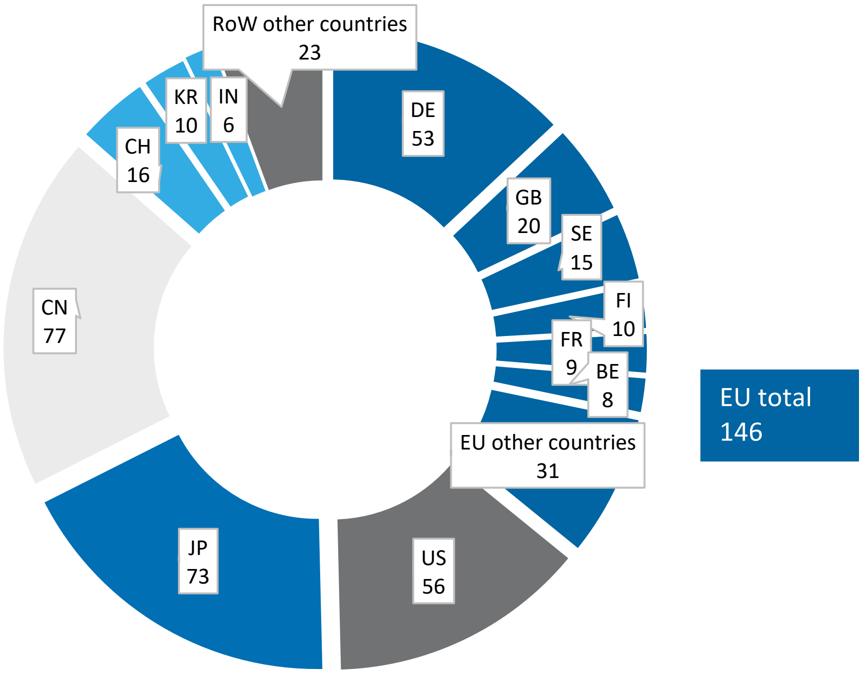
Looking at the overall value added for the economy, it can be seen that within the EU-27 the most important manufacturing sectors are machinery and equipment, motor vehicles, trailers and semi-trailers, food products, fabricated metal products and chemicals and chemical products (Eurostat, 2017). The zero-pollution action plan of the Commission aims to reduce harming substances in air water and soil. Specific measures will address micro-plastics and pharmaceuticals, as well as **chemicals**, with the launch of a new chemical's strategy for sustainability and a toxic-free environment.

To identify the growth potential of the industrial sector[16] and derive competitive positions both on regional levels, we provide results on the regional distribution of the number of companies active in this sector. The 2019 EU Industrial R&D Investment Scoreboard lists the top-2500 R&D investing companies worldwide. Of these 2500 companies, 401 are operating in the industrial sector. Together the EU, that accounts for one third of all companies in this sector in the Scoreboard, and the US with 56 companies in total, share 50 percent of the companies in the industrial sector (Figure 7). More specific, 50 percent of the top R&D investing companies in this sector can be assigned to the EU and US market. The regional distribution of companies within the EU is highly concentrated on a few major actors located in Western Europe, mainly Germany but with the UK and Sweden following. Chinese (77) and Japanese companies (73) are strongly

[16] Due to data restrictions for some analyses aggregated results of the industrial sector will beprovided. For other analyses, we were able to analyse the chemical and steel sector separately.

represented in the industrial sector as well. Regarding spatial distribution of highly R&D investing companies, the EU has a good competitive position but regions like China and Japan are important actors as well.

Figure 7: Number of Scoreboard companies by country, Industry



Source: VDI TZ based on 2019 EU Industrial R&D investment Scoreboard

Characterisation of the networks and involved actors

Based on prior analyses, we identified relevant companies in the industrial sector that are powerful actors in their individual sectors. We were able to conduct interviews with three MNEs. Two of them are operating in the chemical sector and a third company is a Global materials technology and recycling company.[17]

Both **chemical companies** are headquartered within central Europe, France and Germany, and are active in many networks. The project-based networks consist of either nine partners from six different countries (of which five are EU countries, see

Figure 8: Graphical illustration of the Global Innovation Network, MNE 2

Source: VDI TZ, based on interviews and additional research. EU member states (EU27) in blue. For a better overview there is just one line per country even though in practice there are usually several actors involved on the country level.

Figure 9: Graphical illustration of the Global Innovation Network, MNE 3

Source: VDI TZ, based on interviews and additional research. EU member states (EU27) in blue. For a better overview there is just one line per country even though in practice there are usually several actors involved on the country level. Grey line indicates USA.

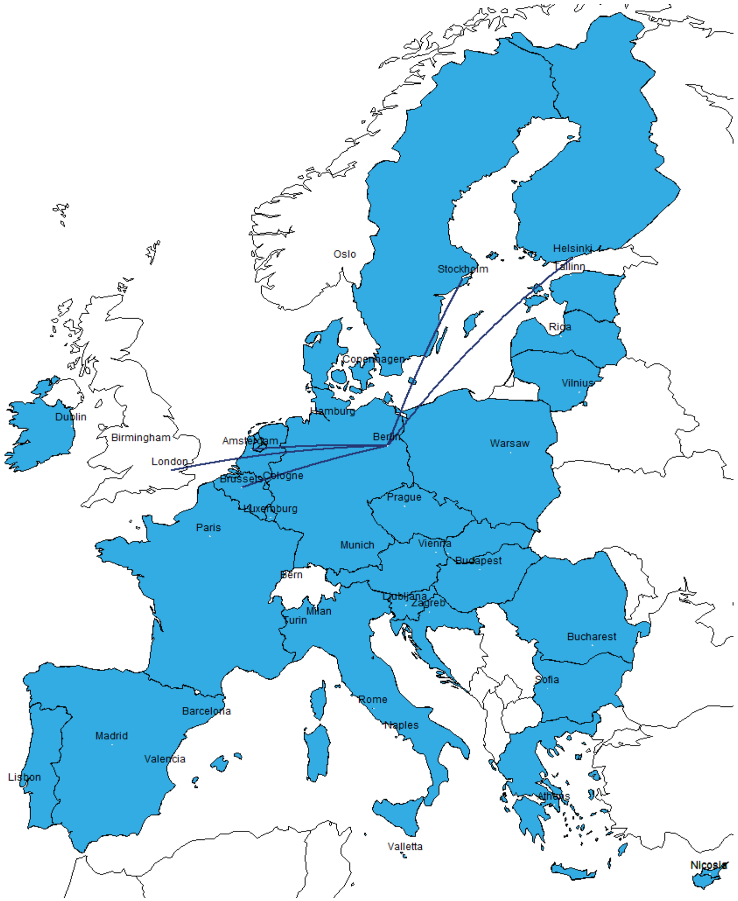
[17] Although the focus in this chapter is mainly on chemicals and steel, it was unfortunately not possible for us to schedule an interview with outstanding steel companies. Instead, in this sub-chapter the focus is on chemicals as well as materials and recycling.

) or ten partners from nine different countries (of which eight are EU countries, see Figure 9). The networks include profit entities as well as RTOs and universities in one case. Stakeholders in these networks usually combine the diversified knowledge and skill set, that is crucial for R&D&I processes in the chemical fields. Here, one stakeholder e.g. does basic research whereas other stakeholders contribute with theoretical background and simulation as well as field experimentation. More specifically, large companies contribute with broad knowledge, network structure, logistics and resources, whereas SMEs contribute with more specialized and in-depth knowledge concerning specific tasks. In general, high diversity in a network is seen as a benefit. The interviewee themselves, for instance, provides knowledge and resources in the hydrogen sector.

The Global **materials technology and recycling company** (Figure 10) has its headquarters in Belgium and has a large focus on sustainable technologies. Innovative activities here are based on a mix of in-house expertise and networks. Exemplary for an essential network in the material and recycling sector is the European Institute of Innovation and Technology (EIT) Raw Materials[18], that is established in so-called co-location centres (CLCs), which are regionally organised innovation hubs. The network brings together 317 actors from 33 European countries, of which 28 are EU members. The financial resources are built on funding through the institute as well as membership fees of stakeholders, who can in turn apply for specific projects. The composition in this network is highly diverse, spanning from universities to large companies operating in the materials sector. Which member is working at which project highly depends on the topic and the skill set of stakeholders. By participating in this network, larger companies have access to collaborations with RTOs and SMEs. Latter are included to transfer projects that have reached higher TRL level into start-up activities and support the start-up phase of companies, whereas RTOs contribute by basic research in their specified focal point (such as mining or recycling, for instance). In general, being organized in this network helps to address cross-cutting questions (primary supply / mining, material science, use and energy efficiency, recycling, social dimension, etc.), and is hence important for promotion and development of recycling and materials topics.

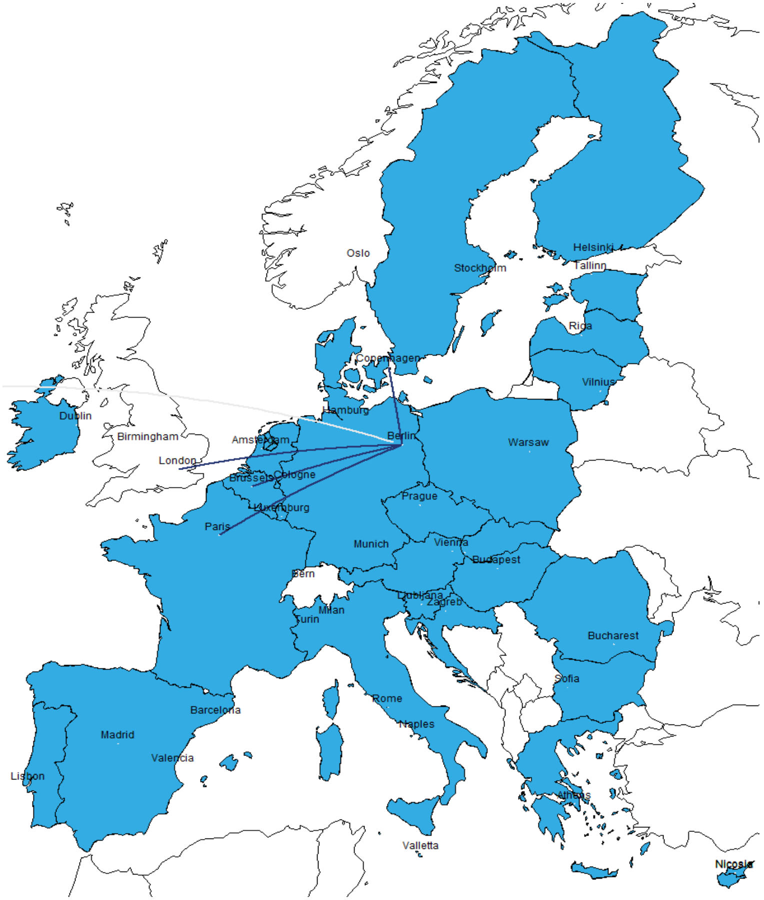
[18] https://eitrawmaterials.eu/

Figure 8: Graphical illustration of the Global Innovation Network, MNE 2



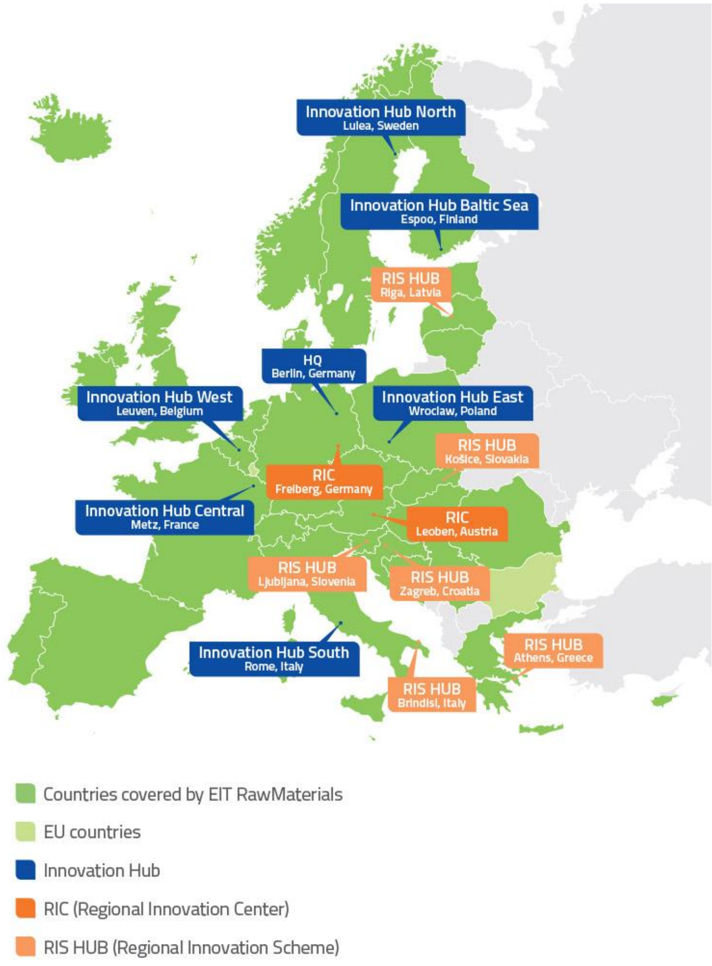
Source: VDI TZ, based on interviews and additional research. EU member states (EU27) in blue. For a better overview there is just one line per country even though in practice there are usually several actors involved on the country level.

Figure 9: Graphical illustration of the Global Innovation Network, MNE 3



Source: VDI TZ, based on interviews and additional research. EU member states (EU27) in blue. For a better overview there is just one line per country even though in practice there are usually several actors involved on the country level. Grey line indicates USA.

Figure 10: Graphical illustration of the Global Innovation Network, MNE 4



Source: EIT Raw Materials, https://eitrawmaterials.eu/about-us/

Key enabling technologies and technological maturity

Relevant technologies and solutions that can help decarbonize specific sectors in the EIIs are listed in Figure 11. In both analysed subsectors, biomass solutions, the use of green hydrogen and the industrial transformation from linear towards circular industrial economy play key roles in decarbonising these sectors. Additionally, Carbon Capture and Storage (CCS) is regarded a promising technology in decarbonising the steel production.

Figure 11: Key decarbonisation solutions by sector

Sectors	Key solutions
Iron and steel	Green hydrogen, CCS, biomass, circular economy
Chemicals and petrochemicals	Biomass, green hydrogen, circular economy
Aluminium	Electrification, circular economy
Cement and lime	CCS, circular economy, renewable energy and waste

Source: IRENA, 2020

Analyses of tech start-ups active in the **steel sector** allow to draw conclusions about interfaces with highly policy relevant industries that can lead to synergy effects. Based on data from the Crunchbase database, we identified 225 enterprises operating in the steel sector. This relatively small number of start-ups implies high capital intensity and high fixes costs that act as market barriers. Seventeen steel start-ups (7.56 percent) are also active in policy relevant fields:

- 12 in KETs (9 in advanced materials, 2 in biotech, 1 in nanotech)
- 4 in advanced manufacturing technologies (all 3D-printing)
- 1 in key and emerging software technologies (Quantum computing).

The largest focal point can be found in the KET area, especially within advanced materials, and advanced manufacturing technologies. One example for a start-up that connects the technologies of bio- and nanotech with the steel sector is a supplier for instruments whose work will help enabling sustainable chemistry production to production plants and laboratories, e.g. in the steel industry.[19]

According to the Strategic Forum on Important Projects of Common European Interest (2019), for the **chemical sector** to transform into a low CO_2-emissions industry, technologies on each link of the value chain must be adjusted, namely

- input level: use of alternative carbon feedstock like CO_2 and waste and use of electricity
- production process: use advanced processing and new technologies such as chemical valorisation of CO_2, chemical waste recycling, use of PtH and PtC technologies
- outputs: low carbon chemicals, plastic from a circular economy / recycled plastics or e-chemicals and e-fuels

[19] Information obtained from company description in the Crunchbase database.

Furthermore, the future of the chemicals industry in Europe is strongly intertwined with the future of hydrogen technology (European Chemical Industry Council, 2019).[20]

Both steel and chemistry are part of the EIIs, but feature different structures. In contrast to the steel sector, chemical tech start-ups appear almost twice as often (431 times) in the Crunchbase database than steel enterprises. Matching these with start-ups also operating in the identified policy relevant fields indicates 96 companies active across the board. This corresponds to 22.3 percent of the start-ups indicating high synergy effects between the chemical and other sectors, namely:

- 93 start-ups in KET (66 in Biotech, 15 in advanced materials, 12 in Nanotech)
- 2 start-ups in Key and emerging software technologies (one in AI, one in IoT)
- One start-up operating in advanced manufacturing technologies (3D-printing)

With 22.3 percent of tech-ups also operating in highly policy relevant fields, the chemical sector has the highest share of all Green Deal priority areas. Further, a clear intersection with KET, especially Biotech solutions, exists. These quantitative results strengthen the outcomes obtained by the literature analysis, mainly that biobased solutions in the chemical sector play a crucial role in the transformation. This trend is already taking place in the areas chemical start-ups are operating in. As example one start-up listed in the Crunchbase database is, among other fabrics, using resin as a feedstock for the polymer industry, combining biobased, alternative feedstock with the plastics industry.

Potential for growth

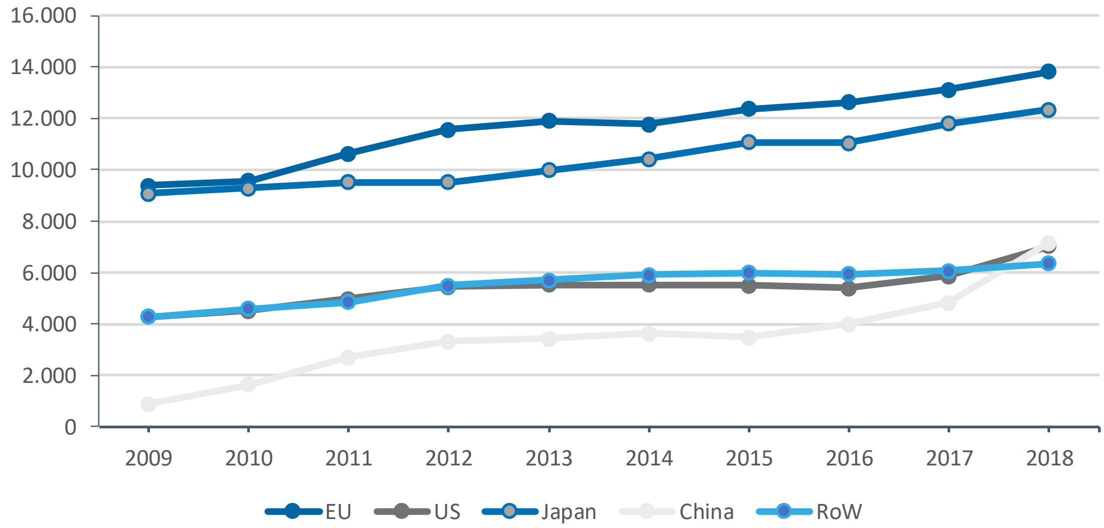
To identify the growth potential of the industrial sector, we cross-check results of innovation indicators of both input level, such as R&D investments and number and trend of employees, and output level such as the number of patents granted in the industrial sector. We will then continue to add information on the trend of newly founded tech start-ups operating in the chemical and steel sector.

To get information on the distribution of top-100 **patenting** firms in the industrial sector, we searched the PATSTAT database. Among these top patenting firms in the industrial sector, EU companies are most frequent (38 firms), followed by Japanese (31 firms) and US (21) companies. Nine firms have their headquarters in RoW, whereas only one of the top-patenting companies in the industrial sector is a Chinese company. EU companies which are active in the industry sector are strongest compared to other regions, in terms of patents, i.e. innovative output.

The EU Industrial R&D investment Scoreboard registers data on the **R&D investments of companies**. For the industrial sector analysed here, numbers of R&D expenditures on country level and company level as well as data on R&D intensities will be presented. Figure 12 graphically shows the regional distribution on total R&D investments for the relevant world regions identified; EU, US, China, Japan and other countries (aggregated as RoW here). A comparison of all areas regarding their temporal development shows that the total R&D investment in the industrial sector has been (slightly) increasing between 2009 and 2018. On country level, total R&D investment is highest in the EU, followed by Japan. The US and Japan show investment rates on a regional level, whereas Chinese companies invested only a fraction of the spending of other regions back in 2009, but increased their investment by the factor 6.7 by 2018 and overtook the US and Japanese R&D investments in 2018.

[20] More detailed information provided in chapter 3.4 of this deliverable: Cross-sectional technologies.

Figure 12: Total R&D investment by region, Industry (in EUR Mio.)

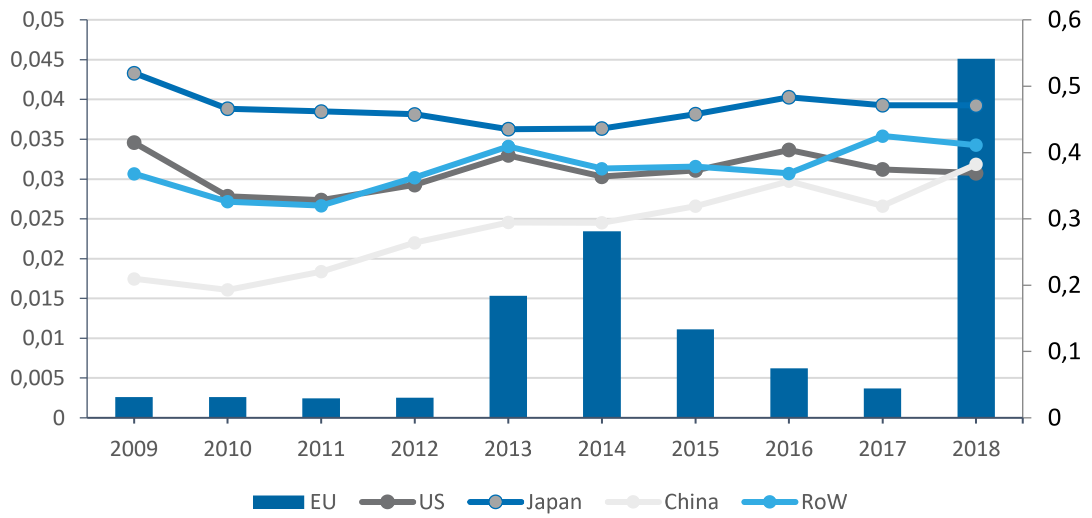


Source: VDI TZ based on 2019 EU Industrial R&D investment Scoreboard

Unlike total R&D investments, mean R&D investments were calculated by aggregating the total R&D investments in the industrial sector in shares of number of companies listed in this sector. Adding information on mean R&D investments gives information on the competitive position of regions on a company level. Analysing the industrial sector´s mean R&D expenditures in demonstrates that Japan has the highest shares on company level, followed by the RoW, the US and the EU afterwards. Again, China had the lowest account in 2009 but shows an increasing trend and almost reached the EU level in 2018. On average, Japanese top R&D investing companies in the industrial sector invested about 124 Mio. EUR in 2009 and increased this amount to 169 Mio. EUR in 2018, whereas an average Chinese Scoreboard company in this sector spend 26 Mio. EUR on R&D in 2009, which more than tripled in 2018, exhibiting 93 Mio. EUR.

The **R&D intensity** (Figure 13) was calculated by dividing the total R&D investment by net sales for each region and sector. The second highest dispersion of all Green Deal priority areas in terms of R&D investments can be found in the industrial sector, ranging from China showing the lowest R&D intensity in 2010 to the EU in 2018. Similar to total and mean R&D investments, Chinese companies have strongly increasing trends in their R&D investments, whereas Japan, RoW and the US showed a stable, slightly volatile trend. Except for the EU, all other main regions followed similar trends in their R&D intensities between 2009 and 2017, indicating regionally spanning trends in the industrial sector. EU companies in the industrial sector have the highest R&D intensity, followed by Japan (with a maximum of 0.043 in 2009), the aggregate RoW (with a maximum of 0.035 in 2017), the US and China.

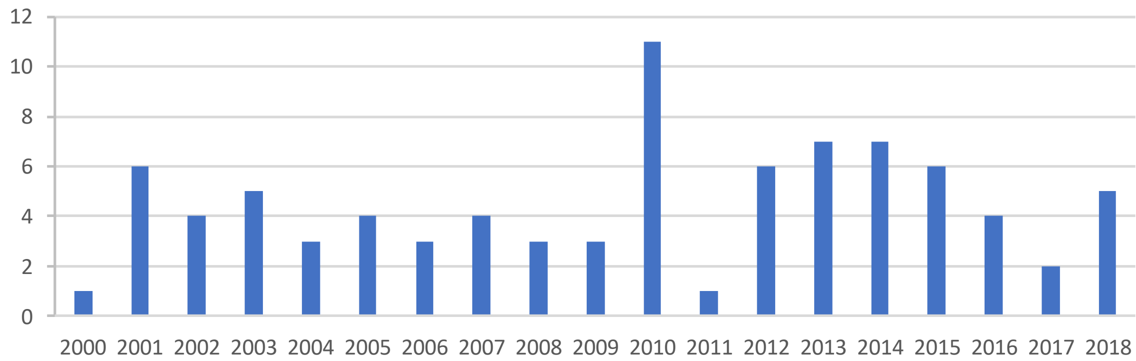
Figure 13: R&D intensity by 5 main regions, area industry (shares)



Source: VDI TZ based on 2019 EU Industrial R&D investment Scoreboard. Lines (here US, Japan, China and RoW values) belong to the left-hand axis, bars (here EU values) to the right-hand axis.

The development of newly funded start-ups allows to draw conclusions on the relevance of specific sectors. Further, it can provide implications on the level of competition and give indications on market barriers, e. g. due to high fixed costs.

Figure 14: Number of foundations per year, steel sector



Source: VDI TZ, based on Crunchbase Database (2020)

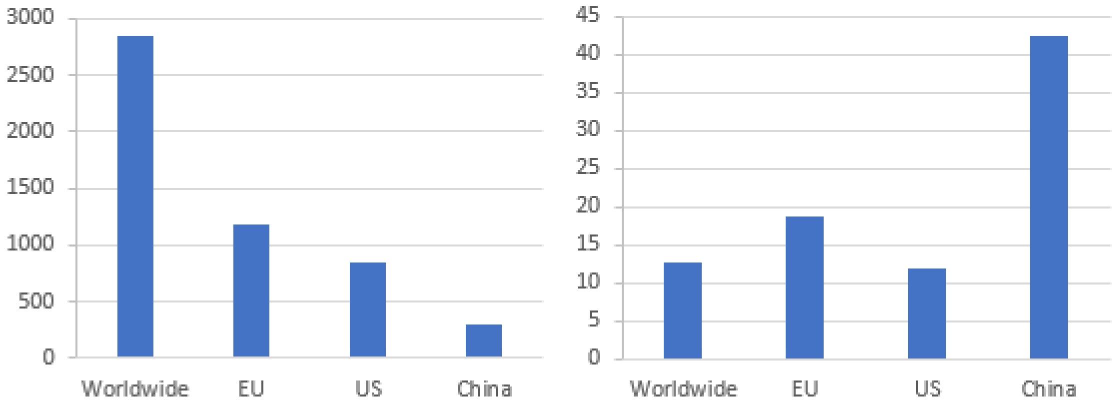
About one third of all companies in the **steel sector** have been founded between 2000 and 2008 (Figure 14), according to queries of the Crunchbase database[21]. The number of new start-ups was highest in 2010, in the aftermath of the financial crisis. Compared to other sectors, the total number of companies as well as the number of recently founded companies is relatively low, indicating high market-entry barriers (e. g. high fixed costs) exist in the steel market.

According to the Crunchbase database, the total amount of funding (worldwide) in the steel sector adds up to 2.85 Billion USD, of which EU tech start-ups in total received the largest amount, followed by the US and China, indicating the EU is well positioned. On a company level, on the other hand, Chinese companies on average receive by far more funding. To transform young and small start-ups to value-generating

[21] Here and in the following analyses based on the Crunchbase database, we consider only companies for which data is available. Hence, there exists a reporting bias which has to be considered.

companies and to bring innovative ideas into the market, it is necessary for start-ups to receive enough capital. Average amounts per company are an informative key figure and future performance indicator.

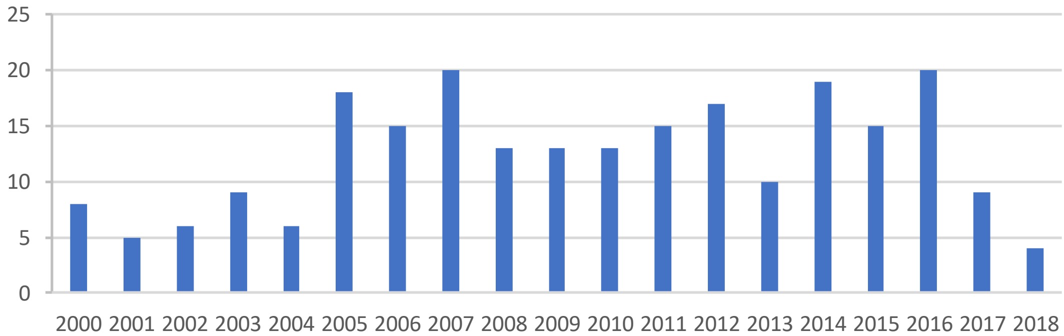
Figure 15: Total and average amount of funding (Mio. USD), steel sector



Source: VDI TZ, based on Crunchbase database (2020)

Contrary to the steel sector, the number of start-ups operating in the chemical sector listed in the Crunchbase database equals 431 and is significantly higher, indicating lower market barriers compared to steel. 55 percent of these companies are younger than 20 years (Figure 16), showing an increasing, but volatile trend that reveals increasing competition within the chemical sector.

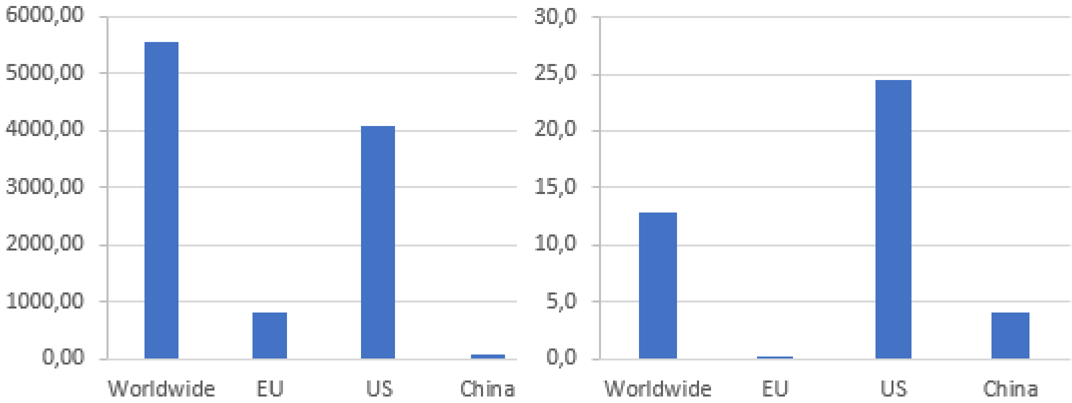
Figure 16: Number of foundations per year, chemical sector



Source: VDI TZ, based on Crunchbase database (2020)

As to funding, US companies receive significantly high amounts of funding on both regional and company level, acquiring more than two thirds of worldwide funding in chemistry.

Figure 17: Total and average amount of funding (Mio. USD), chemicals sector



Source: VDI TZ, based on Crunchbase database (2020)

In terms of patenting and total R&D investments on an aggregated country level, the EU has a strong competitive position in the **industrial sector**. The analysis of R&D intensities gives similar results on company level. Accordingly, Japan is also a strong competitor, when taking these indicators into account. Analyses on company level give different results, indicating that there are few companies with strong research interests in Japan and RoW, respectively. Zooming in at the **steel sector**, the EU is well positioned on a regional level, but Chinese companies are financially well equipped and can be strong competitors. Further, the relatively low number of companies indicates high market barriers due to high fixed costs (powerplants, machinery etc). US start-ups have a better standing in the **chemical sector**, receiving the most funding.

3.2 Energy

Background

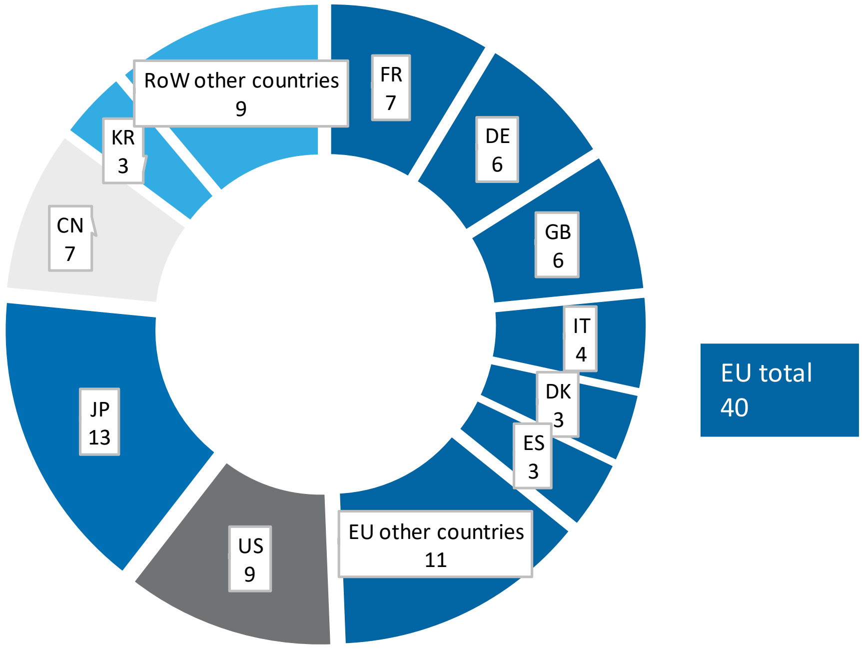
Energy has a key role in transforming the current economic system into a sustainable system and thus is an important sector. Energy is essential in daily life, and due to an ever-increasing global population, coupled with global economic growth, the demand for energy is constantly increasing. Based on a report of the European Technology and Innovation Platform on Strategic Networks and Energy Transition (ETIP SNET), the energy system can be broken down into energy generation (supply), and energy consumption (demand), which is accompanied by energy networks (infrastructure) to transport and store energy (ETIP SNET, 2018).

Relating to the energy sector, the **European Green Deal** includes the **following actions to be undertaken** in order to make its ambitions reality:

- Interconnect energy systems and better link / integrate renewable energy sources to the grid
- Promote innovative technologies and modern infrastructure
- Boost energy efficiency and eco-design of products
- Decarbonise the gas sector and promote smart integration across sectors
- Empower consumers and help Member States tackle energy poverty
- Promote EU energy standards and technologies at global level
- Develop the full potential of Europe's offshore wind energy
- End subsidies for fossil fuels

Global changes in energy production and demand will have a significant impact on geopolitics and industrial competitiveness. Referring to this, the regional distribution and the actors´ current strength and future developments are important indicators.

Figure 18: Number of Scoreboard companies by country, Energy



Source: VDI TZ based on 2019 EU Industrial R&D investment Scoreboard

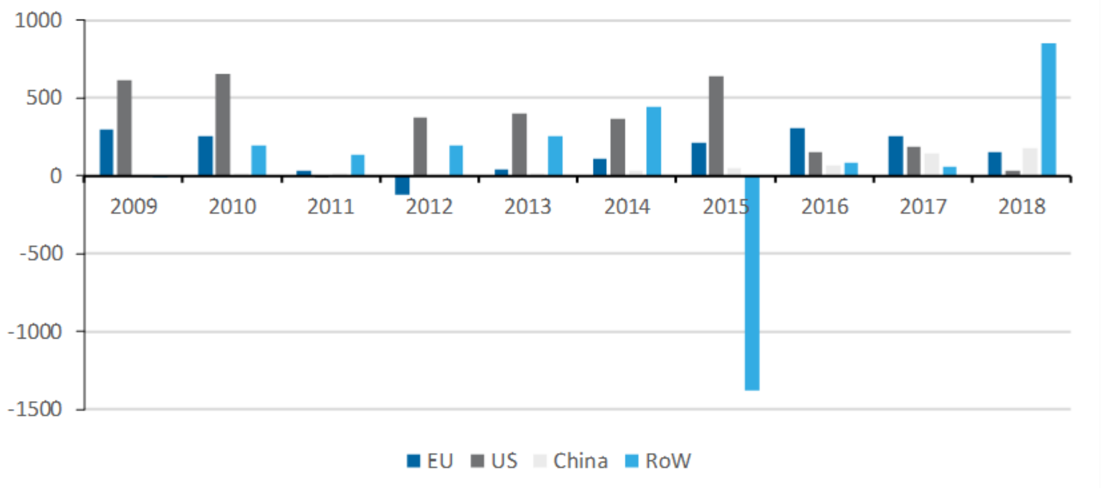
In the selection of top-2,500 R&D investing companies depicted in the EU Industrial R&D investment Scoreboard, important energy companies are distributed as seen in Figure 18. 81 energy companies are in total listed in the EU Industrial Scoreboard. Compared to the other sectors this figure is relatively low which indicates high market barriers due to high fixed costs. Almost 50 percent are European companies, followed by Japan, the US and China. The inner-European distribution of companies in the energy sector is relatively equally distributed: No regional clustering within this sector can be found.[22]

For the energy sector, we have been able **to compare conventional and non-conventional electricity and energy**.[23] This approach allows to draw conclusions about chances and opportunities regarding the Green Deal and sustainability. Operating profit indicates how well companies, and on aggregated level a whole industry, can use their core operations to generate revenues. Analyses show profits are higher for conventional (Figure 20) than for green energy (Figure 19). The US generates the highest mean operational profit in the renewable energy sector (3,418 Mio. EUR between 2009 and 2018), followed by the EU (1,526 Mio. EUR), RoW (822 Mio. EUR) and China (520 Mio. EUR), which equals 6,288 Mio. EUR of operational profit in total. In direct comparison, the mean operating profit in the conventional energy sector is more than twice as high (14.8 Billion EUR).

[22] Regional clustering of specific industries might be due to historical reasons, endowment of factors of production, infrastructure or further reasons that can lead to economies of scale or different things. Regional clustering (up to a certain degree) often leads to comparative advantages of companies within these areas, in contrast to companies outside these clusters (Hill and Brennon 2000).

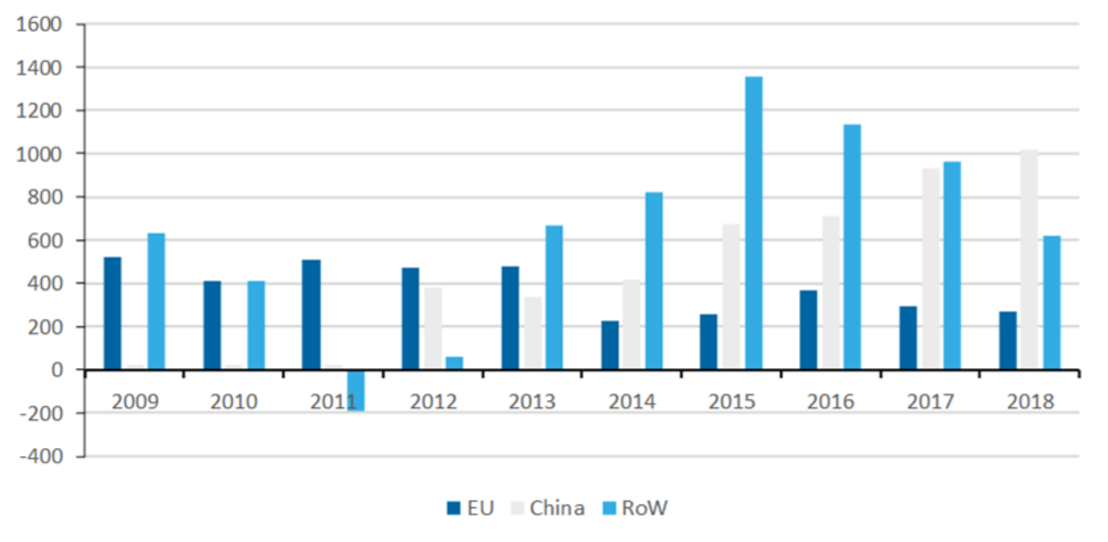
[23] The selection is based on the Industry Classification Benchmark (ICB, see FTSE Russell 2019) included in the scoreboard. The ICB branch itself is built up on "Alternative Energy" (ICB branch 0580), "Renewable Energy Equipment" (ICB branch 0583), "Alternative Fuels" (ICB branch 0587) and "Conventional Electricity" (ICB branch 7535).

Figure 19: Mean operating profit, alternative energy and renewable energy equipment sector, in Mio. EUR



Source: VDI TZ based on 2019 EU Industrial R&D investment Scoreboard

Figure 20: Mean operating profit, conventional energy, in Mio. EUR



Source: VDI TZ based on 2019 EU Industrial R&D investment Scoreboard

EU operating profits in the conventional sector have decreased over time. Contrary, operating profits generated by Chinese companies and companies headquartered in RoW have increased their profits over time. During the observed time period, Chinese companies have increased their average operating profit from 24 Mio. EUR to 1,021 Mio. EUR by about 4,000 percent.

Characterisation of the networks and involved actors

Based on previous analyses, we identified four relevant energy companies with whom we conducted interviews. In order to get highly diverse results, we identified both an SME headquartered in Central Europe and MNEs based in Europe and Northern America.

The European energy SME relies rather on strong ties with an OEM in order to organise innovation activities. The OEM itself is directly involved in Global Innovation networks. Where existing legislation does not outline particular rules towards circularity or emissions reductions, the OEM is the decision maker. For the specific energy SME interviewed, collaboration in research related GINs involves typically the OEM, the company and a Research and Technology Organisation (RTO) who can help with the research-specific aspects and developments.

Whereas the SME is just starting to be present in Global Innovation Networks (GINs), MNEs in the energy sector are typically operating in multiple R&D&I networks. Internal and external R&D&I networks can exist within one company, depending on the skill set and resources available inhouse versus the opportunities of the collaborating externally.

The R&D&I networks´ diversity is high. The energy companies interviewed are operating in multiple networks depending on their specialization within the energy sector. In the energy sector, R&D&I networks are often regulator-based and typically very established. The reasons for energy companies to become involved in these types of networks are very diverse. On the one hand, being organized in these types of organizations can be based on strategic decisions. On the other hand, membership in larger consortia as Hydrogen Europe or BBI JU eases engagement with other stakeholders and thus partnership formation or to follow key developments on an EU level as well. On a lower TRL (technology readiness level) often RTOs are involved to perform basic research.

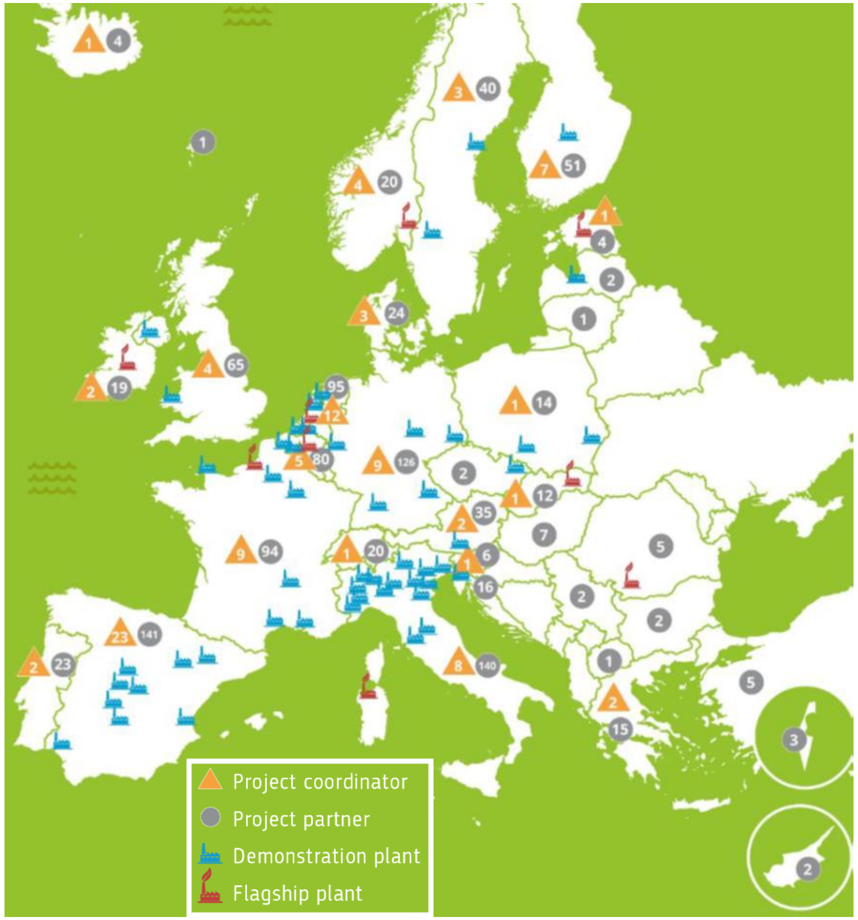
On a spatial level, the networks´ scope is also very diverse and to a certain degree correlated with the number of actors involved. The composite company for instance, is included in a GIN that involves the European company itself, the OEM and an RTO, all situated in different countries, in this case in Europe. The OEM is likely involved in other GINs such as WindEurope[24] (Figure 21). Other networks like Hydrogen Europe consist of a larger and more diverse group of members, industry, research and national associations, in Europe (like BBI JU, see Figure 22) and also neighbouring countries.

[24] https://windeurope.org/

Figure 21: Graphical illustration of the Global Innovation Network, SME 2

VDI TZ, based on interviews and additional research. EU member states (EU27) in blue. For a better overview there is just one line per country even though in practice there are usually several actors involved on the country level.

Figure 22: Depicting the BBI JU GIN: Location of BBI JU projects, partners, demonstration plants and flagship plants



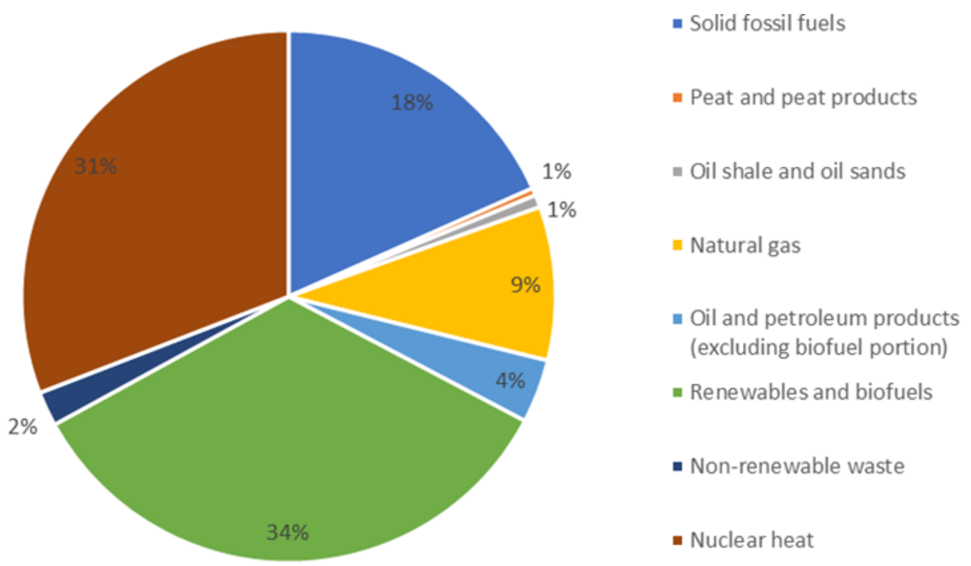
Source: BBI JU, 2020

Key enabling technologies and technological maturity

In order to implement the energy transformation from fossil fuel based to sustainable energy within established energy companies, these companies now diversify their portfolio to become broad energy companies, e.g. deploy activities on batteries and alternative biomass subjects, hydrogen, among others.

In 2018, the share of renewable energy (and fuels) of the total amount of energy produced in the EU was still relatively low, compared to the EU target (see Figure 23).

Figure 23: Share of EU energy production by source, 2018



Source: Eurostat, 2020b

Transforming the established energy system from fossil-based energy towards sustainable produced energy therefore demands the development of further disruptive technologies. According to the Strategic Energy Technology Plan (so-called SET Plan), the five prioritised renewable technologies are wind energy, solar photovoltaics (PV), ocean energy, geothermal energy, and concentrated solar power (CSP) (European Commission, 2020h). Key areas for technological developments in the energy sector are identified by the SET and include integrating renewable technologies in the energy systems, reducing costs of technologies, new technologies and services for consumers, resilience and security of energy systems, new materials and technologies for buildings, energy efficiency for industry, competitiveness in global battery sector and e-mobility, renewable fuels and bioenergy, carbon capture and storage and nuclear safety (European Commission, 2020f).

Above listed literature-based results are reaffirmed by data from the Crunchbase database containing information on tech start-ups. We identified 12,911 energy companies in total, of which 577 companies that are also active in policy relevant fields, which equals a share of 4.5 percent.[25]

- The majority of them is operating in the KET field. Within this area, 203 enterprises operate in biotechnology, 45 in industrial nanotechnology and 38 in advanced materials
- The KET field is followed by key and emerging software technologies (286 enterprises), of which 157 companies are operating in IoT followed by AI (94 firms), quantum computing and embedded systems in decreasing order

[25] The chemical sector, batteries and steel present a higher share of companies with policy relevant fields, indicating higher synergy effects. The mobility and hydrogen sector have lower shares compared to energy.

- 36 companies are using advanced manufacturing (3D-printing)

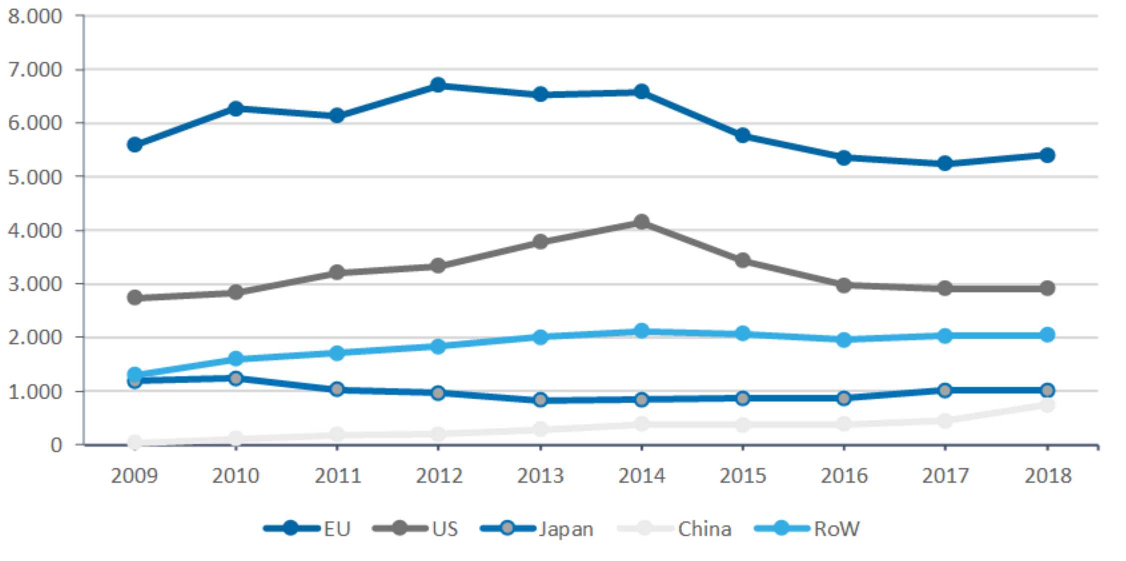
Potential for growth

The growth potential of a certain sector and / or region can in parts be monitored by analysing output indicators, e. g. the number of patents as a proxy, or indicators that aim to monitor the input, such as R&D investment.

Regarding the number of firms among the top-100 **patenting** firms in the energy sector, the EU ranks second behind Japan. In total, 31 out of the 100 top green patenting firms having headquarters in the EU, whereas 35 out of the top-100 patenting firms are headquartered in Japan. The US and the area RoW follow with 17 and 12 companies among the top 100-patenting firms, respectively. This signifies that Japanese top innovative firms are strong competitors in terms of their patent and hence R&D&I activities compared to firms headquartered in the EU.

Analyses of **R&D investments** based on the 2019 EU Industrial R&D investment Scoreboard provide evidence on the R&D competitiveness of specific regions in the energy sector.

Figure 24: Total R&D investment by region, Energy (in EUR Mio.)



Source: VDI TZ based on 2019 EU Industrial R&D investment Scoreboard

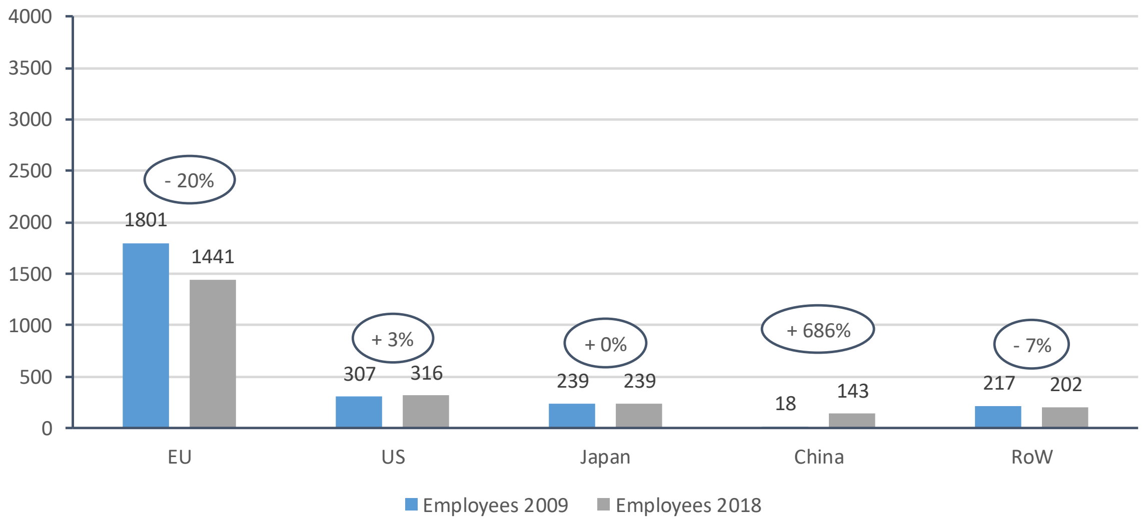
Between 2009 and 2018 the **total R&D investment** in the energy sector is constantly highest within the EU, followed by the US, the aggregate RoW, Japan and finally China (see Figure 24). The latter and the aggregate RoW are the only regions demonstrating a positive trend in total R&D expenditures on country level, whereas the EU´s and the US´ total R&D investment reveal a decreasing trend since 2014. Considering the whole energy sector, the rising markets China and RoW increase their efforts whereas the established markets EU and US show decreasing trends on country level.

On company level, the US has the highest **average R&D investment** per company with a maximum value of 385 Mio. EUR in 2014, followed by the aggregate RoW. The EU ranks third with a mean investment of 151 Mio. EUR between 2009-2018. China is the only country with an increasing trend in mean R&D expenditures raising their mean investment from nine Mio. EUR (2009) to 106 Mio. EUR (2018) almost reaching the EU level in 2018 (135 Mio.).

Considering the entire time frame, US companies show the highest **R&D intensity** in the energy sector. China follows with a total R&D intensity of 0.2 considering the complete time span, whereas The EU ranks third (0.15 in total). RoW (0.14) and Japan (0.07) follow in descending order, exhibiting decreasing trends.

Chinese companies show an increasing trend in R&D intensities from 0.01 in 2009 to almost 0.03 in 2018 while the EU has a varying, slightly increasing trend.

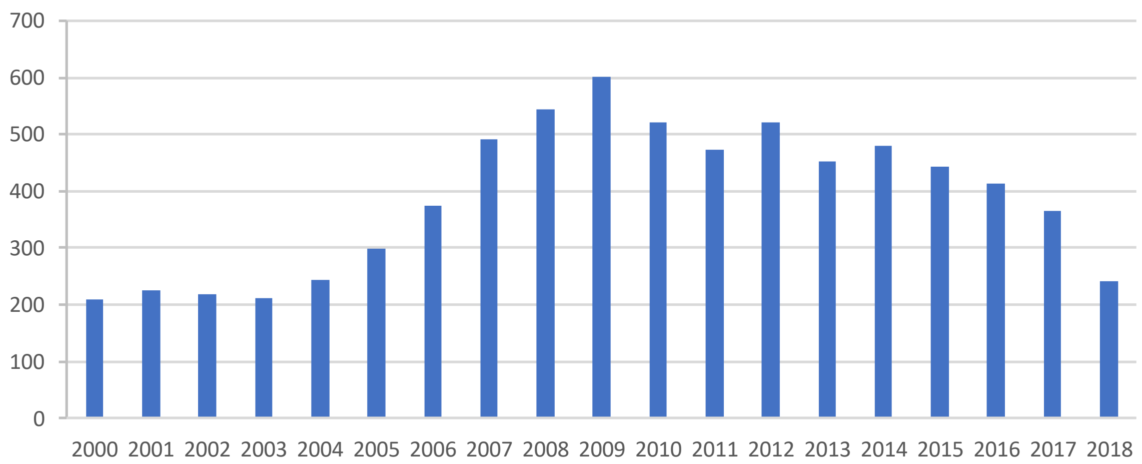
Figure 25: Number of employees employed by companies from 5 main regions, energy sector (in thousands, change)



Source: VDI TZ based on 2019 EU Industrial R&D investment Scoreboard

The number of employees (displayed in Figure 25) employed by EU energy companies dropped by 20 percent and for RoW companies by seven percent between 2009 and 2018. US companies recorded a slight increase (3 percent), whereas Chinese energy companies increased their labour force in the by almost 700 percent. The total number of employees employed by Chinese Scoreboard companies in the energy sector still only amounts to about one third of EU employees in the energy sector in 2018, based on the industrial Scoreboard.

Figure 26: Number of foundations per year, energy sector

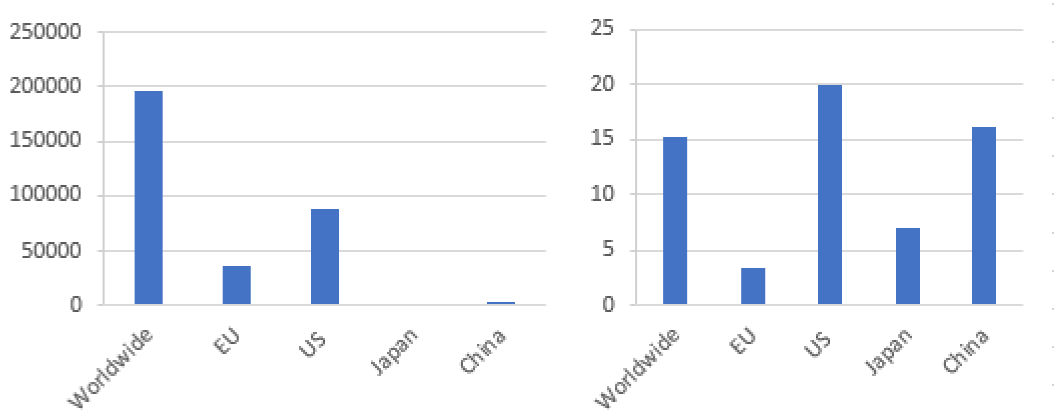


Source: VDI TZ based on Crunchbase Database (2020)

In total, 7,322 of the 12,911 energy tech-start-ups listed in the Crunchbase database (i.e. 56 percent) have been founded between 2000 and 2018. Also, a clear trend can be detected: Being constant from 2000 to 2003, the number of worldwide annual founding almost tripled from 2003 (211 start-ups) to 2009 (602 business creations), which simultaneously increased the competition in the energy market. From 2009 onwards, the number of new companies entering this sector decreased.[26]

The funding on both country and company level is highest for US start-ups operating in the energy sector. Chinese companies, although receiving a relatively low total amount of funding, generate high capital inflows from investors on company level. Hence, Chinese and US start-ups are strong competitors in the energy area.

Figure 27: Total and average amount of funding (Mio. USD), energy sector



Source: VDI TZ, based on Crunchbase database (2020)

In the overall energy sector, the established regions US and EU still have a strong competitive position in terms of R&D&I. Lately, other regions like the aggregate RoW and especially China are catching up, both in terms of R&D spending and increasing their labour force in the energy sector. One important issue in the energy area is the type of energy produced. Alternative energy and renewable energy equipment will become increasingly important in the future. China and RoW lately increased their profits in conventional energy (Figure 27), whereas the US and EU generated higher profits from sustainable energy businesses (be it direct production or primary and intermediate products).

3.3 Mobility

Background

The mobility sector includes services of transporting goods and people, when vehicles and infrastructure are used to enable this movement. Overall, the transport sector has roughly 675 billion EUR Gross Value Added (GVA) and accounts for 5 percent of the GVA in the EU-28 in 2017. In the EU, **transport accounts for 25 percent of GHG in the EU-28** and thus transformations in this sector are key to unlocking the potential of the European Green Deal (Eurostat, 2019). Within the mobility sector, CO_2 emissions are highest for passenger vehicles, followed by other road transport using freight vehicles, aviation and shipping (International Energy Agency, 2019d).

To support and accelerate the decarbonization within the mobility sector, **transformations will need to be made for all modes of transport**, including supply infrastructure and demand in order to effectuate the required emissions reductions while at the same time promoting the digital transition (European Commission, 2019a; European Parliament, 2020). Key elements of sustainable mobility for the European

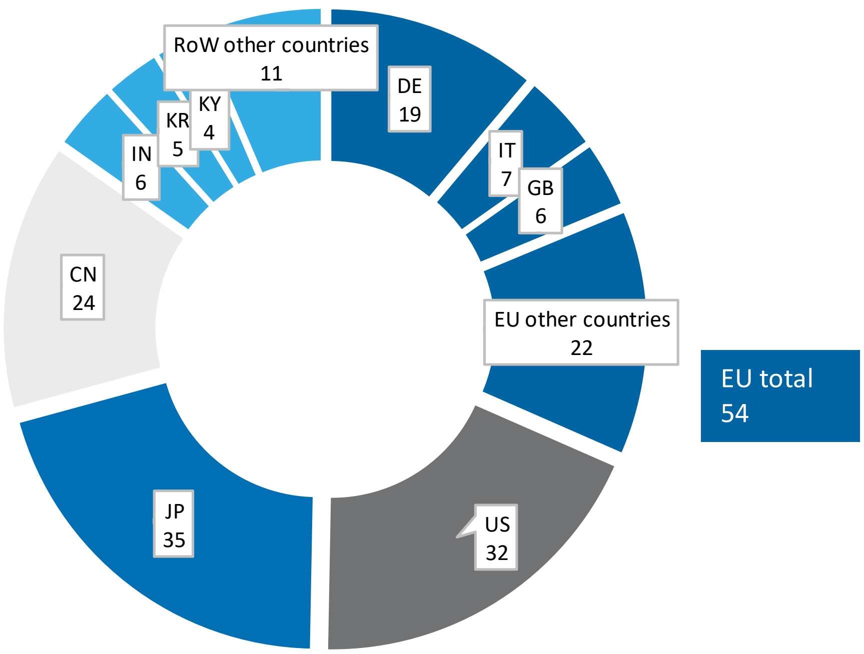
[26] On the one hand, impacts of the financial crisis must be considered. On the other hand, the data on more recent years must be interpreted with caution since younger companies are often relatively small and therefore not yet sufficiently well known that they are included in the Crunchbase database. Data on company foundations in recent years can therefore be downwards biased. This restriction holds for the analysis of all Green Deal priority areas analysed here.

Green Deal include zero- and low-emission vehicles in connection with the manufacturing industry sector and sustainable alternative fuels such as advanced biofuels.

The automotive industry remains one of the most important economic sectors in the EU, employing 2.6 million people in the EU-28 in 2017 (European Commission, 2019c). The development of the electric car stock by region and technology shows a relatively constant growth across world regions, with a slightly larger proportion of growth for China as compared to the remaining world regions (International Energy Agency, 2019d). Considering the importance of the automotive industry in the EU, it will be important for European companies to follow the transition to electric mobility in order to retain their competitive position globally.

Results from the EU industrial R&D innovation Scoreboard 2019 show the actual regional distribution of companies in the mobility sector in 2018 (Figure 28). Most companies (54) are headquartered in the EU. The regional distribution of companies within the EU is highly concentrated on a few major actors located in Western Europe. Almost one third of the EU companies in the mobility sectors are German companies, followed by Italian firms (7) and UK firms (6 companies) whereas the remaining EU enterprises are spread across a variety of EU countries. The EU itself is followed by Japanese companies (35), US firms (32) and China (24).

Figure 28: Number of Scoreboard companies by country, Mobility



Source: VDI TZ based on 2019 EU Industrial R&D investment Scoreboard

Characterisation of the networks and involved actors

Based on various analyses, three noticeable companies in the transport sector were identified and interviewed. These are a German SME and a German MNE as well as one Swedish MNE[27]. The German SME is part of an industrial consortium that produces synthetic fuel based on hydrogen and carbon (obtained from CCU, carbon capture and utilization) for the aviation sector. The German MNE is, among others, part of a network that performs project-specific R&D&I regarding the diversification of power trains in the area of

[27] A Chinese enterprise is one of the main owners of this MNE. Based on our desk research, this Chinese enterprise is not involved in the Global Innovation Networks the MNE analysed in this research study is part of.

e-mobility. The Swedish company is also active in different projects, including a project regarding the distribution and acceleration of hydrogen powered trucks throughout Europe.

The reasons for the interviewed companies in the mobility sector to become involved in GINs instead of developing the above-named technologies otherwise were for instance:

- the mobility sector being a highly competitive area, making it necessary to join forces with different actors in the field,
- diverse skill sets, strategic knowledge as well as financial instruments and material equipment,
- strategic aspects including the aim to diversify,
- the possibility to try out new things and reduce the (financial) risk, due to spreading among different actors,
- the establishment of new research partnerships and new business relationships that can evolve from funded projects,
- as well as networks being important tools in technological and social innovation processes as they help bring different companies and ideas together to learn from each other and foster an innovation-friendly environment.

Research networks for instance help speeding up the transition towards electric mobility and hydrogen fuelled vehicles by providing a larger "lobby".

In some cases, the inclusion of a specific actor is important. Some projects are for instance only funded if academia is included in the project team. Furthermore, MNEs benefit from innovative ideas, niche knowledge or transfer performance from SMEs as well as basic research in materials or on societal impacts of the innovations conducted by academia. In return, MNEs often provide access to markets and liquidity, specific engineering skills, employee training and recruiting benefits as well as hands on R&D and sharing expertise. In larger networks, OEMs often are important actors as well, since they often bundle results.

Figures 29 to 31 display the networks´ geographical distribution. The networks´ geographical scope is variable and seems to a certain degree correlated with the number of actors. The more actors involved, the higher the probability that non-European members are included in the network. The network displayed in Figure 29 consists of four European members (two EU members), of which two are SMEs which provide the necessary technology, an investment company focusing on cleantech investments[28] and an MNE that contributes to the project by its engineering and project execution competences.

A contractual Public Private Partnership (cPPP) can be seen in

Figure 30. Due to the international scope and the high differentiation in the type of actors, this network can be characterized as GIN. Its members work and co-operate on sustainable motor vehicles. They are headquartered in many countries within the EU. Actors from European non-EU countries are involved as well.[29] Besides industrial corporations, research organisations and universities are taking part. Contrary to the first mobility network, this network includes 84 members in total of which 42 are industrial members (16 OEMs) and 33 can be assigned to the academic sector. Its members are headquartered in 19 different countries, of which 17 are European countries and two actors are headquartered in the US and Japan, respectively.

The third mobility network is a project-based private research consortium assembled in December 2020, consisting of industry partners from Germany, the Netherlands, Italy and Austria (depicted in Figure 31), centred in Sweden. With the help of each project partner, the research consortium aims to establish a market with a favourable framework for efficient hydrogen transport. To achieve this, the companies plan to work together with legislators and policymakers of several countries and on EU level.

[28] Crunchbase (2020)

[29] Although the headquarters of some of the actors are located outside Europe, as illustrated in Figure 30, only parts of the companies located in the EU are involved in the network.

Figure 29: Graphical illustration of the Global Innovation Network, SME 1

Source: VDI TZ, based on interviews and additional research. EU member states (EU27) in blue. For a better overview there is just one line per country even though in practice there are usually several actors involved on the country level.

Figure 30: Graphical illustration of the Global Innovation Network, MNE 1

Source: VDI TZ, based on interviews and additional research. EU member states (EU28) in blue. For a better overview there is just one line per country even though in practice there are usually several actors involved on the country level. For details see description below this figure. Grey lines represent Japan and the USA.

Figure 31: Graphical illustration of the Global Innovation Network, MNE 8

Source: VDI TZ, based on interviews and additional research. EU member states (EU28) in blue. For a better overview there is just one line per country even though in practice there are sometimes several actors involved on the country level.

Key enabling technologies and technological maturity

Similar to the other sectors, transformation processes in the transport sector will be accompanied by **technological change going beyond decarbonisation**, including digitalisation, Internet of Things (IoT), as well as individualisation and mass-customisation. Mobility specific big data, integration of modes of transport, including new shared mobility services, autonomous driving and Mobility as a Service (MaaS) instead of ownership has the potential to reshape the mobility sector (Arthur D. Little, 2018). Relevant technologies prioritised in the EU's Strategic Transport Research and Innovation Agenda´s Roadmaps are for instance: electrification, alternative fuels, vehicle design and manufacturing, connected and automated transport, infrastructure, network and traffic management systems, and smart mobility and services (European Commission, 2017a). Other key solutions listed by the International Renewable Energy Agency (IRENA) that support the decarbonisation of key emitters in the transport sector include electrification, hydrogen, biofuels and synfuels (IRENA, 2020).

These literature-based results can be cross-checked using quantitative methods. The Crunchbase database contains information on funding rounds and investments with a focus on start-ups active in technological sectors (Dalle et al., 2017). Of the 1,075 start-ups active in the mobility area, 39 enterprises are also operating in highly policy relevant areas, equalling a share of 3.63 percent. Compared to other Green Deal priority areas (especially Industry and Batteries), this share is relatively low. The synergies are as follows:

- 32 start-ups in key and emerging software technologies (23 in IoT, 8 in AI, one in embedded systems)
- 5 in KETs (2 in nanotechnology, 3 in advanced materials)
- 2 in advanced manufacturing technologies (3D-printing)

These numbers indicate interceptions between the mobility sector and key and emerging software technologies. As can be seen from the analysis, both qualitative and quantitative results showed interaction points between mobility and IoT and AI.

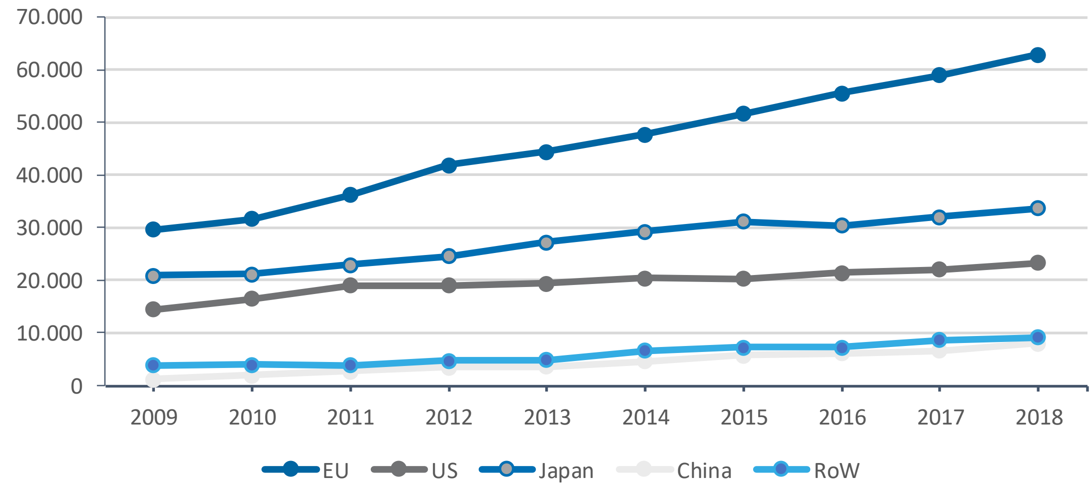
Potential for growth

The growth potential of mobility can, to a certain degree, be monitored by the analysis of certain innovation indicators. On the output level, we focus on results from the patent analysis to analyse companies´ R&D&I competitiveness regarding the European Green Deal.

Analyses of the PATSTAT database identified almost 20,000 green **patents** in the Green Deal priority area mobility. The regional distribution of the top-100 patenting firms in the mobility sector is concentrated: 44 of the companies are headquartered in Japan, followed by 25 companies headquartered in the EU. Both the US and RoW rank similarly regarding their patenting activities in the mobility sector. Only two Chinese companies are listed among the top - 100 mobility patenting firms.

The analysis of **total R&D investments** per region based on the 2019 EU Industrial R&D investment Scoreboard provides input indicators per region. Figure 32 gives the temporal development of total R&D investment in the Scoreboard between 2009 and 2018. In direct comparison to both other Green Deal priority areas, the total R&D investment is highest in the mobility sector and still following a positive trend. The total R&D investment of EU Scoreboard companies has more than doubled between 2009 and 2018. Total R&D investments are highest for the EU, followed by Japan, the US, RoW and China. On a country level, the EU is most competitive in terms of total R&D investment.

Figure 32: Total R&D investment by region, mobility sector (in EUR Mio.)

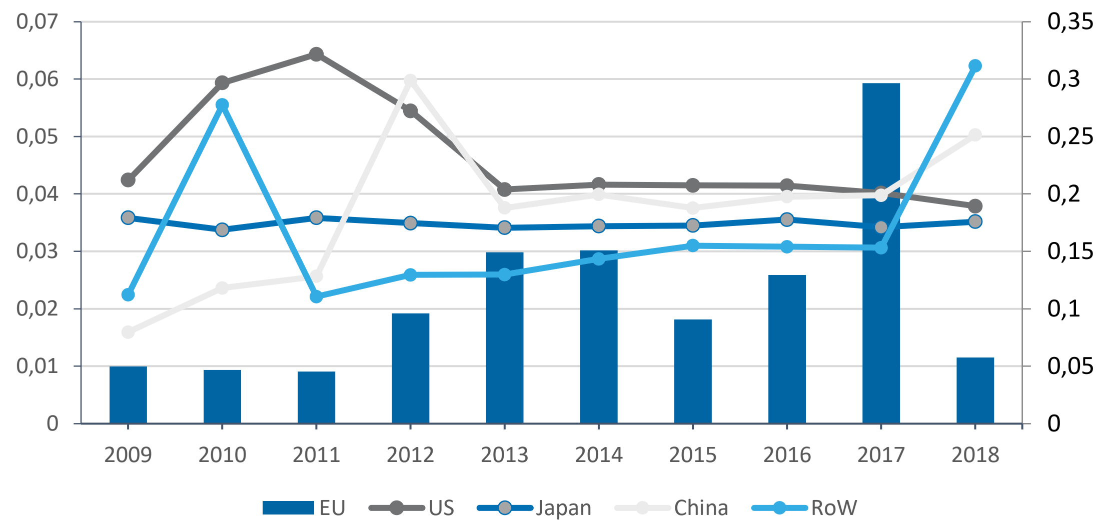


Source: VDI TZ based on 2019 EU Industrial R&D investment Scoreboard

Similar to total R&D investment, EU companies in the Scoreboard have the highest amount of **mean R&D expenditures** (total R&D expenditures in shares of the number of companies), followed by Japan and the US. The R&D intensities, calculated as total R&D investment per net sales, are highest for the EU as well, reaching a maximum share of almost 0.3 in 2017.

The EU has the highest R&D investments per net sales in the mobility sector, reaching a maximum with a share of almost 0.3 for the year 2017. Adding up all shares for each world region (between 2009 and 2018) indicates that US companies are ranked second in terms of R&D intensities (0.46 in total), followed by China (0.37 in total), Japan (0.35) and RoW (0.335). Showing diverging trends from 2009 to 2013, all considered world regions show similar developments from 2013 to 2019. This indicates global trends in the mobility sector. In total, China and RoW show a general, significant increase in **R&D intensities** between 2009 and 2018, while the other regions show no clear (EU), a stagnating (Japan) or a decreasing trend (US) in terms of R&D intensities.

Figure 33: Total R&D investment by region, mobility sector (shares)



Source: VDI TZ based on 2019 EU Industrial R&D investment Scoreboard

The **number and trend of employees** in specific sectors in general and relatively compared to other sectors is an indicator of the competitiveness of a sector regarding the production factor labour. A high number of employees as well as an increasing workforce is an indicator for a well developing industry.

Figure 34: Number of employees employed by companies from 5 main regions, mobility sector (in thousands, change)

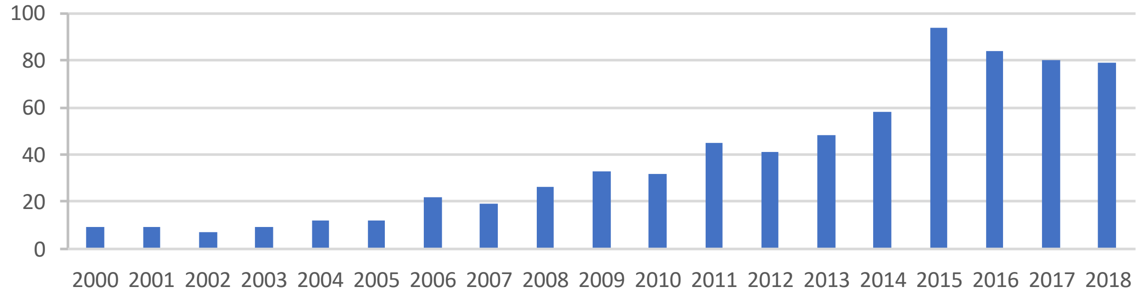
Source: VDI TZ based on 2019 EU Industrial R&D investment Scoreboard

In general, Scoreboard companies active in the mobility sector had in total the highest number of employees (Figure 34, for all regions compared and for both 2009 and 2018) as well as the largest increases, compared to the industrial and the energy sector. In both 2009 and 2018 European enterprises in the transport sector employed most workers with a maximum workforce of almost 3.4 million employees in 2018, followed by Japan (almost 2 million employees), the US (approx. 1.3 million), China (approx. 0.99 million) and RoW (0.55 million employees in 2018).[30] The total number of employees is key to the present competitiveness of a sector. Contrary the growth rate of employees indicates a sector´s and / or region´s growth potential. RoW mobility companies registered the highest increase by almost 200 percent, while Chinese mobility companies increased their number of employees by 150 percent. Established regions that already have a strong labour force, namely the EU, Japan and the US, have lower growth rates.

The EU Industrial R&D investment Scoreboard lists companies that invest the largest sums in R&D in the world. In contrast, the Crunchbase database lists innovative tech **start-ups** and provides data on the amount of funding the start-ups receive. Figure 35 gives the development of newly founded companies in the mobility sector.

[30] These numbers only represent the number of employees in the mobility sector employed by companies that are listed in the EU Scoreboard and does not illustrate the total number of workers in a specific region.

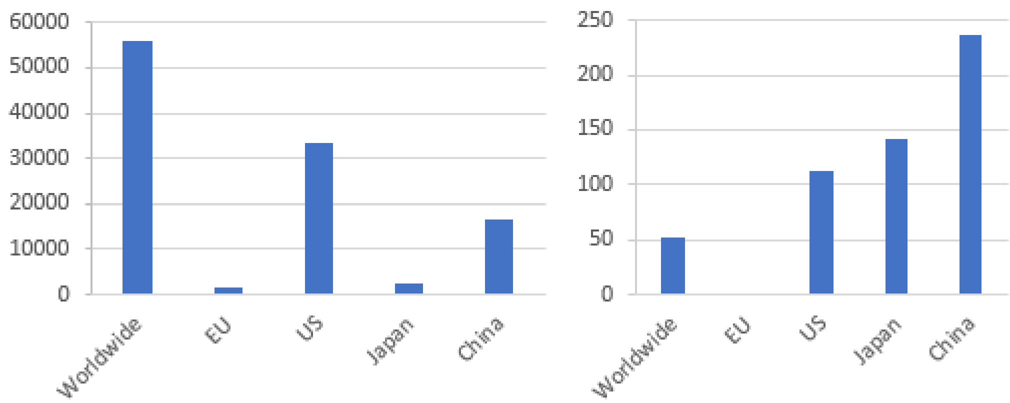
Figure 35: Number of foundations per year, mobility sector



Source: VDI TZ, based on Crunchbase database (2020)

Between 2000 and 2018, 719 start-ups were founded in the mobility sector, which results in a share of 68 percent of start-ups younger than 20 years. Furthermore, there is a clear trend in the number and development of start-up founding activities in this sector. Beginning with 9 foundations in 2000, the number of start-ups almost nine folded by 2018 (79 start-ups), following an almost steady increase. This indicates that the mobility sector represents a very promising, uprising market with the potential to achieve high profits.

Figure 36: Total and average amount of funding (Mio. USD), mobility sector



Source: VDI TZ, based on Crunchbase database (2020)

Building on data from the Crunchbase database, we find that start-ups in the mobility sector (Figure 36) received about 60 Billion USD of **total funding**, of which major parts were received by companies headquartered in the US (about 34 Billion USD) and China (about 17 Billion USD). Japanese and EU start-ups received significantly less investments. On EU level, companies from the UK received most (554 Million USD), followed by Germany (382 Million USD) and Sweden (229 Million USD). Adding information about **mean funding** shows that on company level, Chinese start-ups are highest-ranking (237.5 Million USD per company), followed by Japanese (141.5 Million USD) and US start-ups (112.5 Million USD). EU start-ups received only a fragment of this (1.12 Million USD per company). Relating this information to the numbers of start-ups per region implies that there are a few Asian companies that display strong competitors to companies in the US and especially in the EU. In terms of funding European start-ups have a relatively weak market-position.

3.4 Cross-sectional technologies – Hydrogen and Batteries

Background

Batteries and hydrogen have the potential to support and accelerate the decarbonisation and transformation of sectors with high emissions. In sectors where full electrification is not possible, such as the mobility and transport sector for instance, the use of **hydrogen** represents an alternative. Also, the future of the chemicals industry in Europe is strongly intertwined with the future of hydrogen technology. Hydrogen can be 'grey' (sourced from fossil-based technologies), 'blue' (from natural gas where CO_2 is stored or re-used) or 'green' (from renewable energy). Both 'blue' and 'green' hydrogen are considered as low-carbon solutions. **Batteries** can also act as catalyst for the transformation of the mobility sector and enable transformations in industrial processes to lower CO_2 emissions and at the same time support the energy system.

Characterisation of the networks and involved actors

Hydrogen and batteries are classified as cross-sectional technologies within this study and hence were not subject to the case studies themselves. Due to high interceptions with the industry, mobility and energy sectors, both key technologies have indirectly been addressed within the case studies.

Identified networks performing R&D in the **hydrogen** area were found in the industrial, the mobility and the energy sector. The networks show a large variety, ranging from a consortium with four European profit-entity based members to a PPP with more than 350 members from the academia and corporate sector as well as 27 national associations. The motivation for different actors to become involved in these networks differs. SMEs, for instance, benefit from the access to market and financial support by MNEs. Another important reason was the help of each network-partner to establish and accelerate the new hydrogen market. Academic actors contribute by providing basic research and advantages in the creation of scientific publications.

Similar to the literature-based results, also the expert interviews revealed interceptions between the **battery sector** and mobility and energy. A company from the mobility sector, a vehicle OEM, expects a rising market share for battery electric vehicles that is, from their point of view, expected to be larger than the shares of hydrogen driven vehicles. The largest cross-sectoral technologies concerning batteries were found in the materials and recycling sector and the energy sector. One important network is, for instance, the Global Battery Alliance[31], a formal network with membership and fees. Stakeholders included here are highly diverse and include cell manufacturers, car manufacturers, and materials companies, however some research organisations are included as well. Projects within this Alliance are focussed on finding common innovative solutions in working groups. Funding in this project is provided by company means.

Key enabling technologies and technological maturity

As mentioned above, **hydrogen** itself is an important feedstock that has, as a cross-sectional technology, the potential to decarbonise major high-emission sectors and hence already is a highly prioritised technology itself. To strengthen and secure this position, industries need to focus on deployment of the technology, especially in view of the industries' strengths and capabilities. In order to realise the uptake of hydrogen technology, as outlined in the Hydrogen Roadmap ambitious scenario, technologies that are ready for uptake should be deployed for relevant industries. This would allow for cost reduction due to economies of scale. Yet, there are only few interferences between start-ups operating in the hydrogen sector and start-ups operating in highly policy relevant fields: From 175 hydrogen start-ups recorded in the Crunchbase database, only four are also operating in the KET sector, two in Advanced Materials and two in Biotech, implying few synergy effects.

Similar to hydrogen solutions, **batteries** are also considered to have a clear role in future decarbonisation scenarios at the Global scale and are currently mainly used in the sectors of energy storage and electric mobility. But battery technologies also face diverse challenges on environmental and social integrity as well as its GHG emission footprint. Further barriers are, among others, the viability of battery-enabled applications related to overall profitability, but also recycling challenges (World Economic Forum, 2019).

Analysis of the Crunchbase database resulted in 46 start-ups operating in the batteries sector that are also active in the sector of KET:

[31] https://www.weforum.org/global-battery-alliance/home

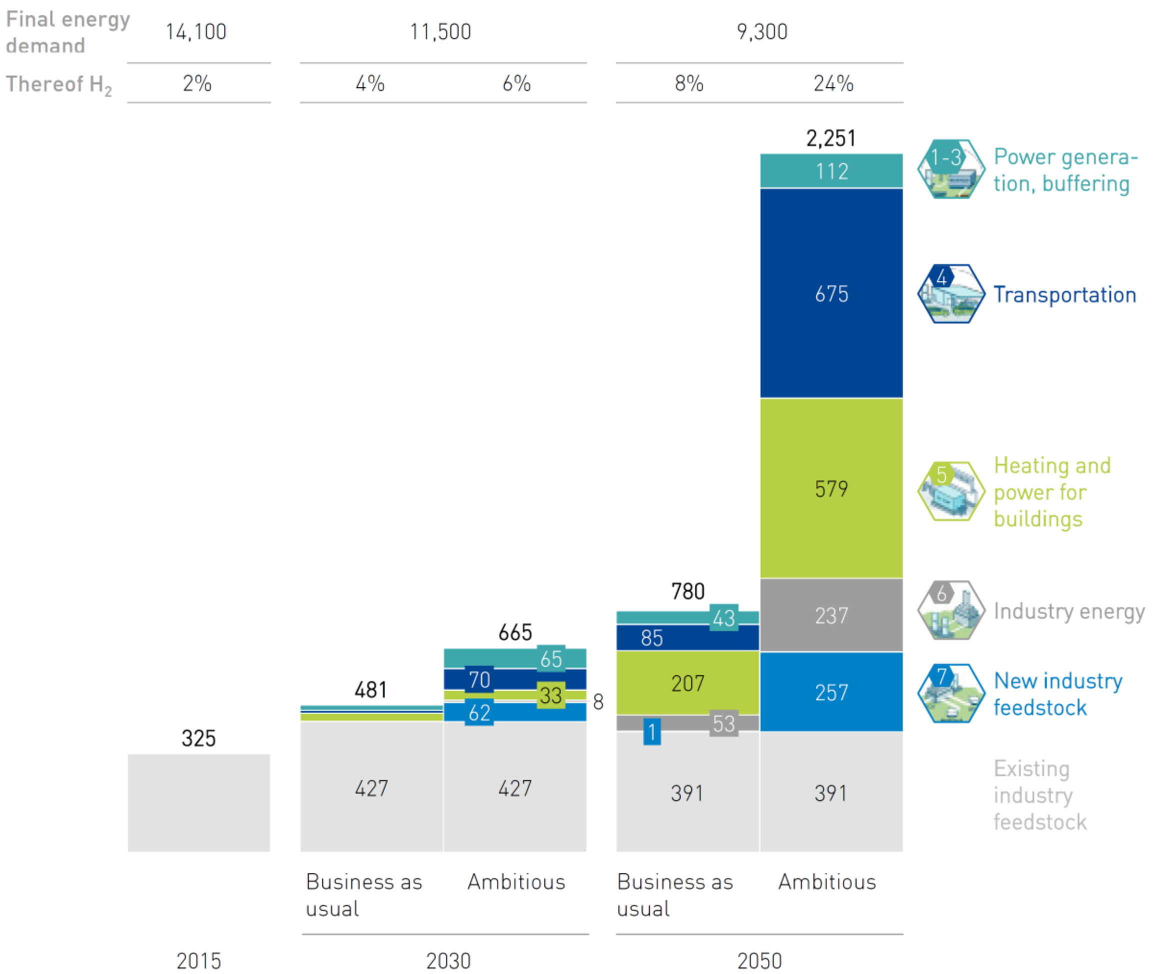
- 25 in KETs (17 in nanotechnology, 8 in advanced materials)
- 18 in Key and emerging software technologies (6 in AI, 11 in IoT, 1 in Quantum computing and one in embedded systems)
- 2 in advanced manufacturing technologies (3D-printing)

These outcomes simply interceptions between the battery sector and key and emerging software technologies and KETs.

Potential for growth

Considering the international competition on the market for **hydrogen** production, Europe is currently considered a technology leader in hydrogen and is aiming to keep this position or even expand their advantage. Figure 37 highlights the ambitious growth scenario for hydrogen deployment in Europe. These plans suggest the hydrogen market in Europe will further grow in the future. Nevertheless, there are still barriers that need to be addressed to ensure the European hydrogen market to grow. The future of the successful uptake of hydrogen technology relies on the role of policies, certification, fostering competitivity and market design, safe and flexible infrastructure, safe and efficient transport, among others (European Chemical Industry Council, 2019).

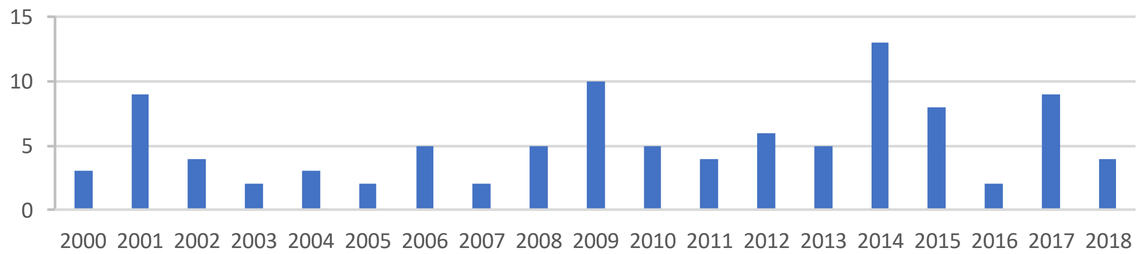
Figure 37: Ambitious scenario for hydrogen deployment in the EU



Source: FCH 2 JU, 2019

Analysis of the current and emerging number of **start-ups** operating in the hydrogen sector gives in total 175 companies, of which the majority (101) has been founded from 2000 onwards, implying a young market that is still gaining more and more emphasis. Yet the number of hydrogen start-ups in the Crunchbase database does not exhibit clear trends from 2000 onwards (Figure 38).[32]

Figure 38: Number of foundations per year, hydrogen sector

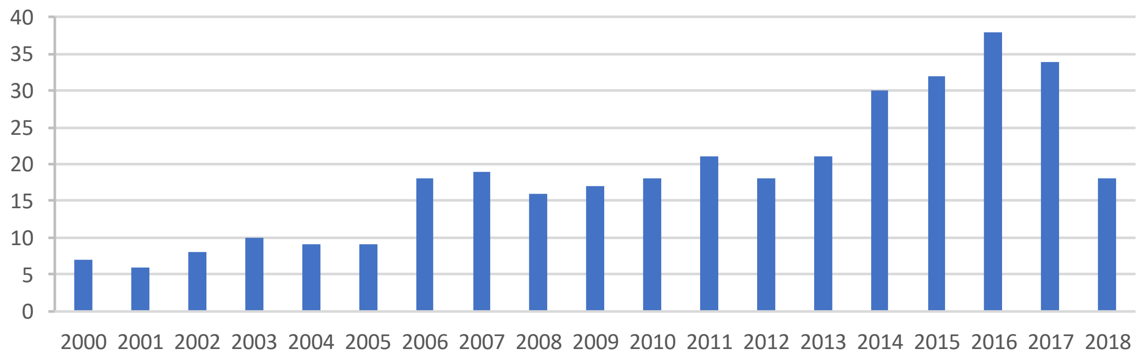


Source: VDI TZ, based on Crunchbase database (2020)

Since **batteries** are classified as important catalysts in transforming emission-intensive industries, this sector is expected to further expand on a global level. Nevertheless, regional growth rates will also differ due to unevenly spread demand for batteries. In line with studies, China is making up the biggest market for batteries (43% in 2030). CAGR will also differ as a function of the different global markets (World Economic Forum, 2019).

Results of the total and emerging number of **start-ups** operating in the battery sector, obtained from the Crunchbase database, confirm the promising growth opportunities from the battery sector. There are 559 start-ups listed in the Crunchbase database, of which about 350 were created from 2000 onwards, implying an almost continuously steep increase, as can be seen in Figure 39. This growing number of companies rises the competition level in a market, leading to decreasing product prices and decreasing company profits, primarily competition is assumed.

Figure 39: Number of foundations per year, battery sector



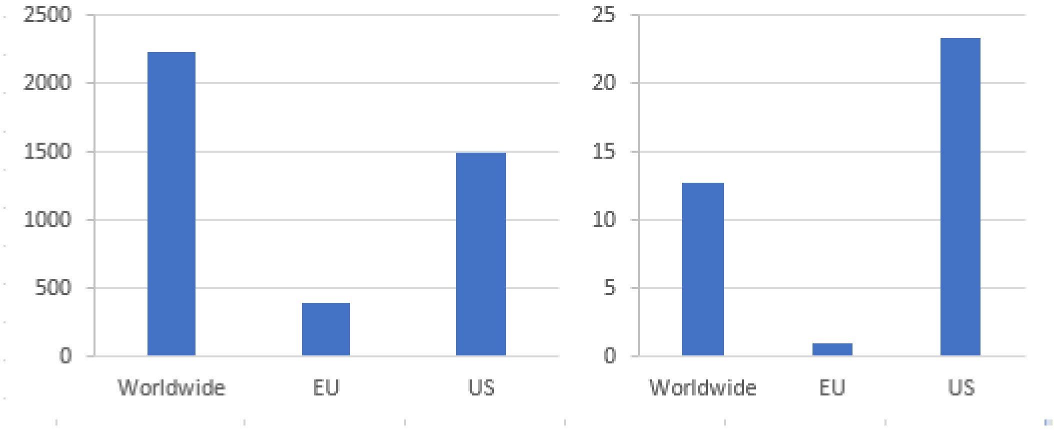
Source: VDI TZ, based on Crunchbase database (2020)

[32] As mentioned earlier, younger years only indicate a trend since it is possible that younger companies are less known and therefore not listed in the Crunchbase database.

This increasing trend indicates a promising sector, in which many actors want to become a part of. Furthermore, an increasing number of companies increases the competition level in a market. This leads to decreasing product prices and decreasing company profits, if it is assumed that companies are primarily competitors.

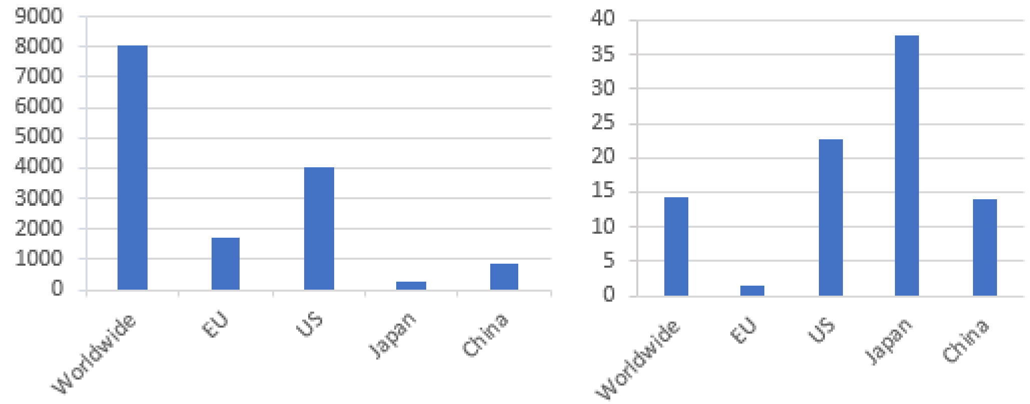
As to **funding** in the **hydrogen** sector, North American countries like the USA and Canada are strong competitors to the EU. Here, start-ups located in the UK, Germany and Sweden are well positioned in terms of both total amount of funding and numbers of companies. Further, the UK leaving the EU will presumably reduce the EU's competitiveness in the hydrogen area, on a regional level. US companies in total receive highest funding in the **battery sector**. On company level, Japanese start-ups receive higher funding (about 37 Mio. USD) in this sector.

Figure 40: Total and average amount of funding (Mio. USD), hydrogen sector



Source: VDI TZ, based on Crunchbase database (2020)

Figure 41: Total and mean amount of funding (Mio. USD), battery sector



Source: VDI TZ, based on Crunchbase database (2020)

Potential related to the Green Deal

The three Green Deal priority areas, industry, energy and mobility, have a high potential to contribute to achieving the goals of the European Green Deal. This is because all three sectors have a long history of being and still are sectors with a large contribution to global GHG emissions. At the same time, these sectors have the potential to decarbonize and turn into sustainable sectors, be it by a **reduction of resource consumption or the increase of recyclability.** It is common sense that the development of sustainable technologies is crucial for decarbonizing the economy (European Investment Bank, 2021).

In the **industrial sector**, we analysed two of the highest emitting areas, steel and chemistry. To reduce the consumption of resources and the emittance of GHG in both areas, certain measures were identified. In the steel sector, **alternative feedstocks** such as hydrogen or CCU technologies as well as the **substitution of conventional** for renewable **energy** play a crucial role. To decarbonize the chemical sector, the use of feedstock based on alternatives for carbon (such as waste and CO_2) and the application of alternative production processes will help here. The Global Innovation Networks (GINs) analysed in the industrial sector[33] highly contribute to these applications by providing research and / or developing (technological) solutions in this field, such as the process of hydrogen production for several sectors. Another GIN is currently developing guidelines for hydrogen charging, which will contribute to supporting and accelerating of a hydrogen economy, whereas the materials technology and recycling company is operating within a GIN, that is, among others, operating in the field of material sciences, recycling and energy efficiency and hereby performing R&D&I also in the area of alternative feedstock for the chemical sector.

The **energy sector** plays a crucial role in contributing to the GHG emissions and is likewise an important actor of the critical infrastructure. A growing share of alternative produced energy is necessary to reduce the energy sector´s emissions. **Reducing the amount of fossil resources** is another relevant factor in contributing to the net zero goal. The energy companies we interviewed are energy producers. Reduction goals such as CO2 emissions, energy consumptions or fossil resource reductions become increasingly essential in their business areas as well. The technologies that the companies focussing on are highly relevant for the European Green Deal and switching to alternative energy consumption is key. Another important factor is the consumption of energy which, if energy reduction is difficult, should be shifted towards renewable energy. Specific objectives in the energy sector lie, for instance, in the production of energy based on wind, or in the use (and correct recycling) of batteries or the use of hydrogen. Within the energy sector, green business sectors and relevant technologies that are addressed within the GINs[34] are for instance geothermal and hydrogen or sustainable energy based on hydrogen and nature-based alternatives. Other technologies the networks are operating in have a focus on biological residues and waste to increase sustainability of products.

New and sustainable technologies have the potential to drive the transition in the **mobility sector**. Some of these technologies are created with the help of different types of actors. As part of this study, we conducted interviews with companies that are part of Global Innovations networks (GINs) and that have direct participation in the development of technologies supporting the decarbonization in the mobility sector.

Relevant technologies in the mobility sector that have been addressed within the interviews, are e. g.

- Renewable fuels, such as the production of e-fuels for the aviation sector, using carbon capture and the production of green hydrogen via electrolysis.
- Sustainable Power, such as the diversification of power trains in e-mobility.

As already mentioned in the background section, many technologies must be combined to reduce emissions, which is the highest goal. Besides synthetic fuels, based on carbon and green hydrogen, biofuels are relevant as well, but the feedstock is limited here. Kerosene produced via the "methanol route" is another way to produce **alternative fuels** for the aviation sector but is regarded more expensive than the use of green hydrogen and CCU. Synthetic fuels' potential to contribute to a circular economy can be seen as very high since CO_2 is extracted from the air and then transformed into e-fuels and related goods. This contributes to the net zero goal.

A growing **electrification of the mobility sector** is another option to contribute to the transformation of the mobility sector. One interviewed company participates in a network that is, among other topics regarding the decarbonization of road transport, currently addressing the issue of diversification strategies for power trains in e-mobility. The network´s objectives are linked with activities to push the development of efficient road transport vehicles and innovative strength and to increase the competitiveness of European firms and the European economy compared to other main world regions.[35] Another network is addressing the dissemination of hydrogen powered trucks throughout Europe. Hydrogen technology and especially its commercial application

[33] Information provided here is based on desk research and interviews conducted with two chemical and a materials technology and recycling company.

[34] The named technologies refer to the activities of the GINs. For information on green innovative technologies the companies themselves are operating in, please consider the case studies.

[35] Based on additional research, mainly conducted via: https://egvi.eu/what-we-do/egvi-cppp-roadmap/.

(e.g. in heavy-duty transportation) constitute a priority area in the European Green Deal.[36] With the help of each project partner, the research consortium aims to establish a market with a favourable framework for efficient hydrogen transport.

Hydrogen and batteries are manifold applicable technologies that have a high potential to support the transformation of many high-emitting sectors. Although the expert interviews were conducted with companies operating in the three Green Deal priority areas identified, both cross-sectional technologies play crucial roles in several R&D&I networks analysed here. Batteries can have a positive value on the decarbonization of the mobility sector, for instance, but the whole value chain must be considered. Efficient battery recycling processes together with producing sustainable high-quality battery chemicals supports the targets of recycling rates and the usage of recycled raw materials presented in the new Batteries Directive proposal of the European Commission. Hydrogen is also used in multiple applications such as feedstock for alternative fuels that addresses reduced resource consumption. According to the interview partners, the use of e-crude based on hydrogen and CO_2 reduces greenhouse gas emissions by 90-95 percent, compared to conventional fuels. Since there is an interplay between these two cross-sectional technologies and the Green Deal priority areas, all technologies in question have positive impacts on more than just one principle.

The companies that were interviewed in the frame of this study exhibit a diverse but, in their fields, specialized skill set and are therefore important actors in contributing to the industry´s shift towards sustainability. According to most of the interview partners, an actor´s skill set is one of the main reasons for other companies to join forces with them. Hence, companies that are mainly operating in sustainable business sectors or shifting their business towards these sectors are likely also organized in GINs focussed on sustainable technology solutions, merging knowledge and skills from different actors. Regardless the specific branch, being organized in a GIN can contribute to reaching the goals of the Green Deal. Consolidation of different professions such as basic research, niche knowledge and innovative ideas, but also financial endowment, business networks and market power help develop new ideas, and support and accelerate the development of new technologies contributing to the Green Deal.

According to the interview partners, sharing risks or the possibility to receive funding can create incentives to perform R&D&I. Further, the inclusion of different groups of actors and from different countries or world regions can also lead to spill-over effects that have a positive impact on the development of sustainable technologies. Being organized in a GIN furthermore increases the outreach to policy makers easing the addressing of general or specific barriers, for instance in the development of a hydrogen economy. This aspect is even stronger if political institutions are directly integrated in these networks, such as in the case of PPPs. Hence, GINs themselves can have a high potential to contribute to reaching the Green Deal´s targets.

[36] https://www.fch.europa.eu/news/european-green-deal-hydrogen-priority-area-clean-and-circular-economy

4 Policy context and policy toolbox

4.1 Framing and main current policy context

Framing

For this study it was necessary to do a framing which is the process of embedding events and topics relevant to our study in interpretive grids. The starting point for this is the European Green Deal. The European Green Deal presented by the European Commission in 2020 is linked with the need for thinking out of the box concerning tailor-made policy instruments and the adequate mixes in a period of numerous transitions and technological breakthroughs. Since we observe already a starting transformation in several industries this is our second point for framing.

Our third point for framing is based on recent research on innovation and industrial policy.[37] This research stresses the need for the so-called intelligent governance of policy instruments and measures. Scholars like Edler and Fagerberg (p.15) (2017) make the case for four governance principles. These are anticipation, participation, deliberation, and transparency. From their point of view, these principles are necessary to ensure that societal preferences and concerns are taken into account in R&D and innovation processes and policies. Recent research also shows that successful innovation and industrial policies combining a whole set of policy instruments have led to radical innovations. It should be underlined that these policies have been more focused on market shaping and creating through direct and pervasive public financing than on market fixing (Mazzucato & Semienuk, 2017; d´Andria & Savon, 2018). This means that instruments are changed and combined with other instruments to address the new (and sometimes 'old') problems and challenges of innovation and industry. The public financing of innovation becomes even stronger as a strategic tool since it can help to shape and create markets. This market shaping approach suggests that the use of policy instruments must be "proactive and bold, creating directions, and transcending the role envisaged by market- or social system fixing approaches" (p. 44) (d´Andria & Savon, 2018).[38]

Main current policy context

In this chapter a description of the main current policy context in place is provided. The focus of this chapter is on existing policy strategies, initiatives and plans, regulatory and financial frameworks, especially regarding the potential effects on the developments in the analysed sectors and technological fields (green energy, green mobility, sustainable industry hydrogen and batteries). The main drivers and barriers for investing in technologies relevant for Europe's Green Deal are also addressed. Most recent developments in the US and China are also important to discuss since they show how the situation in the EU differs from other countries.

The **European Green Deal** (European Commission, 2019a) has the ambitious aim to boost Europe's competitiveness based on cutting-edge innovation in a broad sense. It can be seen as an integral part of the European Commission's strategy to implement the United Nations 2030 Agenda and the **Sustainable Development Goals** (SDGs) (United Nations, 2019). In addition, the European Green Deal can be seen as a paradigm shift in European politics that is designed to lead the change towards making the European economy digitalised and environmentally sustainable. The long-term goal of the new growth strategy is to make Europe the first carbon neutral continent by 2050. The intermediate goal is to decrease greenhouse gas emissions by 55% by 2030. This entails the necessity of efforts in R&D&I that will eventually shape EU policy and have a direct impact on industry and civil society. The growth strategy includes a timeline for guiding documents to be published between 2020 and 2023.

The seven identified policy areas within the scope of the European Green Deal affect all areas of industry, science and civil society, albeit on different scales and at different times. For the analysis in our study the first five items are especially important (European Commission, 2020a):

[37] For a summary of this discussion see for instance Malanowski, N. & Tübke. A. & Dosso, M. & Potters, L. (2021). Deriving new anticipation-based policy instruments for attracting research and development and innovation in global value chains to Europe, Futures, 128 (4), 1-12 and Borras, S. & Edquist, C. (2019). Holistic Innovation Policy. Oxford University Press.

[38] For a more detailed discussion on this Malanowski, N. et al. (2021).

- Clean energy: focussing on alternative, cleaner sources of energy
- Sustainable industry: looking at more sustainable, environmentally respectful production
- Sustainable mobility: promoting sustainable transport
- Eliminating pollution: cutting pollution quickly and efficiently
- Climate action: targeting a climate neutral EU by 2050

In this study we focus on Green Deal priority areas, including clean energy, sustainable industry, sustainable mobility, as well as hydrogen and batteries as two key technologies. The rationale for the selection of these priority areas is three-fold:

1 Contribution to Green Deal objectives: The Green Deal targets, among others, clean energy, sustainable industry and sustainable mobility. Together, the sectors of energy, industry and mobility are responsible for 87% of emissions in the EU-28 (as of 2019). Industrial processes and product use accounts for 8% of total greenhouse gas (GHG) emissions, whereas transport accounts for 25% and fuel combustion (excluding transport) for energy accounts for 54% (Eurostat, 2019). Seeing the overall emissions, these areas also have a great potential, through key innovations, to make positive contributions to emissions reductions.

2 Innovativeness: For the transformation to succeed, all sectors need to respond to the EU's commitment to reduce emissions and tackle climate change. Highly innovative sectors, such as those depicted in the Strategic Value Chains (SVC) of the Important Project of Common European Interest (IPCEI) are linked to key enabling technologies, technological breakthroughs or disruptive innovation. For the Strategic Forum on IPCEI, the aim was to identify strategic value chains for joint or well-coordinated investment and action coupled with a joint vision. The six SVCs including connected, clean and autonomous vehicles, hydrogen technologies and systems, smart health, Industrial Internet of Things, Low-CO2 emission industry, and Cybersecurity. The sectors of energy, mobility and industry have been leading the innovation wave related to low carbon and circular innovation, also within the framework of the SVC, with many examples already present in their works. Not only do these sectors have a proven capacity to innovate, but there is a high willingness amongst major actors to search for and implement new technologies to support further greening (European Commission, 2019b).

3 Competitiveness: The selected areas are positioned within global value chains, where it is particularly interesting to analyse the EU's competitive position as compared to key global players such as China and United States. The IPCEI is a special instrument under state aid rules, which can be used to strengthen the competitiveness of strategic value chains and can also serve as a financing instruments for environment, transport, energy projects of strategic European importance (European Commission, 2019b)

The **European Research Area** (ERA) (European Commission, 2020) is intended continuing to incentivise R&D investment from the private sector. This can be also found in the roadmap (European Commission, n.d.c). that aims to revitalise ERA underlining the importance of a transformative R&I policy that shapes technological and societal change to deliver a sustainable European society. **Horizon Europe** beginning in 2021 is the new programme for research and innovation partly linked with the European Green Deal. It is intended to facilitate collaboration and strengthen the impact of research and innovation in developing, supporting and implementing EU policies while tackling global challenges. It supports creating and better dispersing of excellent knowledge and technologies (European Commission, n.d.a). Horizon Europe is mission oriented. The missions are commitments to solve some of the greatest challenges facing the world like adapting to climate change, protecting our oceans, living in greener cities etc. Each mission shall operate as a portfolio of actions – such as research projects, policy measures or even legislative initiatives - to achieve a measurable goal that could not be achieved through individual actions.

The European Commission emphasises the need for structural transformation of the economy and need for crosscutting policy support towards competitive sustainability where EU companies play a central role in the transition to a more environmentally friendly path while at the same time competing on a global level. There is a **priority on resource and energy intensive industries** in their efforts to adhere to the Green Deal timeline. Focusing on these industries first sets the basis for when member states are expected to update their climate and energy plans in 2023 according to their efforts up to then. In the pursuit of making European industries sustainable, the intention is to stimulate the development of new markets for climate neutral and circular products and make all packaging recyclable or reusable by 2030.

The **European industrial strategy** (European Commission, n.d.b) aims to ensure competitiveness on the global stage via **investments in Strategic Value Chains and Industrial Ecosystems** – e.g. batteries, clean hydrogen and bio-based products – and new forms of collaboration with industry for ensuring Europe's strategic autonomy and technological leadership. This **strategy** launched by the Commission in March 2020 is based on three main focus areas: the green transition, global competitiveness and the digital transition (European Commission, 2020b). Designed to support all minor and major players, the newly presented strategy could be seen as a cornerstone for all European industries as the Commission aims to remove barriers to the single market for European companies while also working toward climate-neutrality. European SME's will be given special attention in the new Industrial Strategy to support them in the green and digital transition by providing them with 'bespoke support' such as sustainability advisors, digital innovation hubs, trainings and a skilled labour force. Some new future actions include:

- Action Plan on Intellectual Property for protecting the competitiveness of European companies and innovators
- Action Plan on Critical Raw Materials and pharmaceuticals for supporting key enabling technologies and introducing a new Pharmaceutical Strategy
- White Paper on distortive effects caused by foreign subsidies in the single market and foreign access to EU public procurement and EU funding
- Alliances on clean hydrogen, low-carbon industries, industrials clouds and platforms and on raw materials (European Commission, 2020c)
- Relating to the **energy sector**, the European Green Deal includes the following **actions** to be undertaken in order to make its ambitions reality:
- Interconnect energy systems and better link / integrate renewable energy sources to the grid
- Promote innovative technologies and modern infrastructure
- Boost energy efficiency and eco-design of products
- Decarbonise the gas sector and promote smart integration across sectors
- Empower consumers and help Member States tackle energy poverty
- Promote EU energy standards and technologies at global level
- Develop the full potential of Europe's offshore wind energy
- End subsidies for fossil fuels

Future **actions in mobility** will only marginally affect manufacturing industries in the short term, but in the medium to long term require manufacturers of transport options to diversify their portfolio and redesign core concepts of production. One example is the push towards shared mobility models in which car-ownership will be discouraged. The Single European Sky Reform entails a 3-fold increase in capacity in air-travel which will require aerospace manufacturers to expand while also investing in the development of biofuels for aviation. At the end of 2020, the European Commission published also the **Strategy for Sustainable and Smart Mobility** (European Commission, 2020j). Following this strategy, the European Commission supports strategic value chains (for instance on batteries, hydrogen and renewable and low-carbon fuels) with regulatory and financial instruments. This is seen as essential to ensuring secure supply of technologies indispensable for sustainable and smart mobility, avoiding Europe's dependence on external suppliers in strategic sectors to achieve greater strategic autonomy. The **Hydrogen Strategy** for a climate-neutral Europe offers a solution to decarbonise industrial processes and economic sectors where reducing carbon emissions is both urgent and hard to achieve. But there are major challenges. Deploying hydrogen in Europe faces important challenges that neither the private sector nor Member States can address alone. The broad application of hydrogen needs critical mass in investment, an enabling regulatory framework, new lead markets, sustained research and innovation into breakthrough technologies and for bringing new solutions to the market, a large-scale infrastructure network. In order to address the issue of **eliminating pollution** the Commission presents several measures including a zero-pollution action plan which will target air, water and soil. Links will be made with other elements of the European Green Deal including **sustainable industry**. Specific measures will address pharmaceuticals, as well as chemicals, with the launch of a new chemical's strategy for sustainability and a toxic-free environment.

The European Climate Law: In March 2020 the European Commission presented its proposal for a European Climate Law (European Commission, 2020d). This piece of legislation goes together with the Commission's European Climate Pact in which citizen consultation will play a larger role than for the Climate Law. This Climate Law proposal represents a "legally binding target of net zero greenhouse gas emissions by 2050" (European Commission, 2020d). The proposal also includes measures for tracking member states' progress as these are expected to update their climate and energy plans in 2023 and every 5 years after according to their efforts up to then and further efforts undertaken by the Commission. Practically, the European Climate Law is designed to:

- interconnect energy systems of the future
- promote innovative technologies and modern infrastructure
- boost energy efficiency of consumer products
- promote EU energy standards and technologies at global level
- develop the full potential of Europe's offshore wind energy

In April 2021 the European Council and the European Parliament agreed on the **European Climate Law** enacting a binding guideline on both the net GHG emissions reduction target and with the goal of achieving an interim target of at least 55 percent minus compared to 2030 (European Council, 2021).

The European Commission **aims to fund the Green Deal by mobilising over EUR 1 trillion** for actions towards climate neutrality through its Sustainable Europe Investment Plan. Half of the resources is planned to come out of the EU budget directly and a quarter from public and private investment. The rest will come from Emission Trading Scheme (ETS) funds, national co-financing, national promotional banks and international financial institutions (IFI). 7.5 billion of this will be new resources generated through corporate and private taxes as well as other funding mechanisms (e.g. carbon mechanism) (European Commission, 2020e). The ETS fund is especially significant to the industry's role in accomplishing the Green Deal's ambitions. It will generate new resources through investments in low-carbon technologies and processes in renewable energy, giving leverage to industry stakeholders with the potential to deliver in these areas.

China just recently introduced its **14th 5 years plan 2021-25**. According to a recent paper by the London School of Economics and Political Science China's new Five-Year Plan "presents a real opportunity for China to link its long-term climate goals with its short- to medium-term social and economic development plans." In addition, "China's recent commitment to achieving carbon neutrality by 2060 has set a clear direction for its economy, but requires ratcheting up ambition on its near-term climate policy" (p. 2) (Hepburn, et al., 2021). Other observers argue that the Chinese renewable energy sector is just one example of the dynamic increase in returns associated with disruptive technological change during the zero-carbon transition (CarbonBrief, 2021). The new plan covers six key areas of energy development, including the construction of eight large-scale clean energy "bases", coastal nuclear power, electricity transmission routes, power system flexibility, oil-and-gas transportation and storage capacity. Besides this, China is seen as one of the world manufacturing leaders of electric cars with enormous investments made (Donato, 2020). President Xi's Made in China 2025 state-led high-tech manufacturing policy strategy has started developing industries including electric cars and rail transport.

After Joe Biden has become president of the **US** in January 2021 a **Green New Deal** has come on the agenda. It seeks to fight the climate crisis and tackle inequality simultaneously and outlines the broad principles of a plan to achieve net-zero greenhouse gas emissions across the US economy by 2030. In addition, it aims to guarantee new high-paying jobs in clean energy industries (Snaith, 2021). According to information on President Biden's own homepage the climate and environmental justice proposal will make a federal investment of $1.7

billion[39] over the next ten years, leveraging additional private sector and state and local investments to total to more than $5 billion (The Biden Plan for a Clean Energy Revolution and Environmental Justice, n.d.). Just recently, President Biden issued a number of executive actions addressing climate change, for instance a rejoining the Paris Agreement and a global pact to reduce emissions and plans to electrify the federal government's fleet of vehicles. According to a recent article by the Council on Foreign Relations "the Green New Deal, (is) a broad and sometimes vague aspiration to rapidly mobilize American government, society, and industry to create a sustainable, low-carbon future. It has become hotly contested among policymakers. For supporters, such an effort represents a last chance to avoid the worst consequences of catastrophic climate change. For detractors, it's a financially profligate proposal concerned more with traditional left-wing economic policies than environmental necessity." (Chatzky & Siripurapu, 2021). Further actions by the newly elected US president reaffirm the US´s return to the sustainability pathway. In April 2021 the US invited 40 leaders of economies that account for a majority of global emissions and GDP as well as "heads of other countries that are demonstrating strong climate leadership, are especially vulnerable to climate impacts, or are charting innovative pathways to a net-zero economy" to the **Leaders Summit on Climate** (The White House, 2021). The Summit aims to bundle efforts in fighting against the climate change (U.S. Department of State, 2021).

4.2 Main drivers and barriers

The main drivers for investing in technologies relevant for Europe's Green Deal are climate change, the need for transformation of industries, new regulation and the expectation of new prosperous business and competition. The need for cross-sectoral and cross-technological innovation, unclear new markets, a new political framework and acceptance in society are the main barriers. The European Green Deal has in general a strong support by industrial companies.[40] But there is still a strong need that some new framework conditions have to be clarified and coordinated as a multi-level governance with the respective Member States' strategies. The application of hydrogen supply in energy intense industries needs policy support short- to medium-term to ensure international competitiveness. Market shaping in democracies for sustainable industries, green energy and green mobility needs highly relevant incentives for major industrial transformations in a highly competitive global environment. Mostly state-run economies in non-democratic countries like in China are certainly in a different position since acceptance in economy and society is not necessarily needed. Since the US is characterized by decentralized organization and a strong concentration of innovations from the private sector like in electrical mobility and batteries it is quite difficult to analyse the influence of the policy context with a just started Green New Deal.

4.3 Policy toolbox for R&D&I policies supporting technologies relevant for Europe's Green Deal

Global Innovation Networks and the European Green Deal

Organisations like European Batteries Alliance or Fuel Cell and Hydrogen 2 Joint Undertaking are Global Innovation Networks of industry actors and other stakeholders such as academia and public institutions that facilitate and/or promote innovation.[41] Their value becomes apparent when they allow an understanding of e.g. firms' relocation decisions or their choice of public-private partnerships. GINs exist within their Global Value Chains (GVCs), where R&D&I processes are becoming more and more widely dispersed, and this dispersion is occurring more and more quickly (Dosso, Potters, & Tübke, 2017). GINs provide a comprehensive understanding of innovation drivers and hampers. GINs allow for a historical as well as projective analysis of companies' locational, operational, and strategical choices and their position in GVCs (Herstad, 2014; Dosso, Potters, & Tübke, 2017). Following this definition, we distinguish between four key building blocks of the GINs related to the European Green Deal:

- Technological maturity

[39] The term billion used as on the European level. A European billion is a trillion in the U.S.
[40] This is one result of the interviews conducted for this study.
[41] For a detailed discussion see Deliverable 2.

- Potential for growth
- High potential related to the European Green Deal (circularity or low carbon)
- Framework conditions (policy, finance, network, geography)

Figure 42: Key building blocks of the Global Innovation Networks (GINs) related to the Green Deal

Source: IDEA Consult

The current policy context and its conditions have enabled the technology development in GINs in areas important for the Green Deal linked with the SDGs through targeted programmes and policy instruments. This also means these GINs are sufficiently connected to incorporate elements of the European Green Deal. In addition, available funding resources from outside of the company are a key to unlocking the technological solution developed. Furthermore, regulation aspects can be discussed already in a quite early stage of development.

The SPIRE Public Private Partnership is one good example of a GIN connecting many companies from the process industries on green technologies. Many companies active here have developed their own sustainability assessment and use it also for evaluation and merger and acquisitions, but further harmonisation of the different sustainability measurement approaches is necessary. Additional good examples are the European Battery Alliance (EBA), European Renewable Energies Federation (EREF), European Clean Hydrogen Alliance or the Fuel Cells and Hydrogen Joint Undertaking (FCH JU).

The rationale behind new policy instruments

In recent years, there has been an enormous increase in the research literature around innovation and industrial policy.[42] There are several prominent arguments concerning the rationale for innovation and industrial policy (the "Why?"). One argument is that innovation policy is necessary because of market failure. This argument continues to be influential among policymakers and justifies funding basic public research (Edler & Fagerberg, 2017). Other authors question the adequacy of this approach for justifying and guiding the design, financing and implementation of innovation and industrial policy (Mazzucato & Semienuk, 2017). Another argument is that innovation needs to be effectively coordinated. According to this line of thinking, strengthening innovation systems ensures positive impacts for business, society and the regions. In addition, there is a prominent argument that path dependencies in innovation prevent change in the long run (Edler & Fagerberg, 2017). These necessary changes can be supported by new forms of innovation and industrial policy, such as open dialogues between established and new innovation actors and sectors in pro-active regions and across sectors (Nepelski & De Prato, 2012).

[42] For a summary Malanowski, N. & Tübke. A. & Dosso, M. & Potters, L. (2021). Deriving new anticipation-based policy instruments for attracting research and development and innovation in global value chains to Europe, Futures, 128 (4), 1-12 and Borras, S. & Edquist, C. (2019). Holistic Innovation Policy. Oxford University Press.

It should be underlined that these policies have been more focused on creating and shaping markets through direct and pervasive public financing than on market fixing (Mazzucato & Semienuk, 2017; d´Andria & Savon, 2018; Mazzucato M. , 2018). This means that instruments are changed and combined with other instruments in order to address the new (and sometimes 'old') problems and challenges of innovation and industry (e.g. linked with the European Green Deal). The ability of public financing of innovation to shape and create markets makes it even stronger as a strategic tool. Mazzucato & Semienuk (2017) stress three features when looking at the public financing of innovation and the way it can shape and create markets:

- investment along the entire innovation chain
- the mission-oriented nature of the agencies involved and
- their leading role in risk-taking, independent of the business cycle.

This market-shaping approach suggests that the use of policy instruments must be "proactive and bold, creating directions and transcending the role envisaged by market or social system-fixing approaches" (p. 44). The properties of innovation in a new era of industry seem to be highly uncertain, cumulative and collective, with very long lead times (Grilli, Mazzucato, Meoli, & Scellato, 2018). Just recently, the Commission of Experts for Research and Innovation (EFI) argued that the agility of policy is another important prerequisite for successfully implementing the transformative change desired by society (Commission of experts for research and Innovation (EFI), 2021).

In recent years, there has also been an increase in the research literature on linking foresight with innovation policy instruments (Malanowski, Tübke, Dosso, & Potters, 2021; Gordon, Ramic, Rohrbeck, & Spaniol, 2020). Saritas (2018) describes foresight in a period of transition. In his view, foresight activities have changed in content, context and process. Concerning the quest for more resilient science, technology and innovation policy, foresight exercises "have become more inclusive with the participation of broader experts and social stakeholders" and indicate a coherent and complementary innovation ecosystem. Saritas observes changes in demand in the use of foresight for science, technology and innovation policy. He suggests "experiential foresight as a novel means of generating knowledge and communicating results" (p. 4), and the use of laboratories for promoting anticipation. Havas et al. (2018) conclude that in a strategic sense, foresight is expected to influence the wider (new) innovation ecosystem in which these specific programmes and initiatives are embedded. This is also the case for using new anticipation-based policy instruments linked with the European Green Deal. Malanowski et al. (2021) discuss new anticipation-based policy instruments to improve the attractiveness of Europe for innovative activities in a world of accelerating innovation. From their point of view the world economy has changed significantly in complexity and in accelerating innovation. Innovation and foresight labs have according to this article a highly experimental but also a game-changing character in highly innovative companies while early signs of developments are addressed. They argue that the same is needed for an ambitious policy to upgrade the EU's R&D&I capabilities by shaping a process for engaging, anticipating, assessing and responding on an ongoing basis.

A review of the recent literature shows that innovation and industrial policy consists of various instruments. Borras & Edquist (2013) suggest three categories of instruments (regulatory instruments, economic and financial instruments, and soft instruments) and point out that the three-fold division is most accepted in the literature on innovation policy instruments. Borras and Edquist observe that most of these instruments influence the development and diffusion of innovations from the supply side rather than from the demand side. From their point of view, instruments focusing more on the demand side might have the advantage of redressing specific types of weaknesses. In particular, a new type of instruments – often called soft instruments – might be able to address different and new aspects of the innovation and industrial system challenged by a number of deep transformations and technology breakthroughs. Borras and Edquist conclude that the design of the mix of instruments must include ultimate objectives which support private organisations and companies in solving problems in the field of innovation that they cannot solve on their own.

Most of the interviewed actors are organized in quite a number of networks. Some of these networks are on a national level, but the majority is operating on an international level. All technologies the actors of the GINs work on are to a certain degree related towards the European Green Deal. The case studies of GINs and interviews with company representatives collected for this deliverable show not just a strong support by industrial companies for the European Green Deal but also a high level of interest in new anticipation-based policy instruments.

Regulations

In general, the existing policy context acts as enabler for the GINs and their related technologies. In some cases, the policy tools seem to have no visible impact on the acceleration of the technologies market entry according to the interviewees. The European Green Deal itself is seen as enabler since it provides important signals especially for the net zero target. Furthermore, regulations are seen on the one hand, as having a negative impact on conventional business sectors, such as the EU ETS which rises the price for CO_2. On the other hand, regulations lead – according to most interviewees - to benefits for sustainable and strongly transformative sectors. Many guidelines and policies are seen as still under development and conditions are seen as subject to further changes. Most regulations and their effects are seen as not fully evaluated, because of the difficulty to evaluate whether regulations act as a market barrier or enable growth for the concerned sector. Generally, regulations for recycling and materials technologies are seen as enabler for growth. It was mentioned that without a push for electric cars, there would be no drive for the need for improved batteries. From the interviewees perspective there are many opportunities for regulation to further improve the framework conditions, e.g. for circular economy business models.

The interviewees provided also a number of specific recommendations for policy. EU regulations like the RED II directive or high-level signals like the net-zero target and the Innovation Fund induce growth within the mobility sector. But there exists also a framework that acts as a market barrier to new companies. As improvements to existing policy instruments to support a development towards a more climate neutral production and R&D&I sector it is suggested that the EU should formulate and communicate clear objectives that have to be reached (e.g. specific share of renewables in specific sectors).

The political instruments regarding sustainable technologies are seen as high and useful on both national and international level. Policy regulations are usually precisely observed and rated as positive framework. The current framework is seen as an enabler for growth and a chance to increase competitiveness. The speed of policies in Europe is seen as too slow to get started necessary actions to initiate concrete activities in a timely manner.

Economic and financial transfers

The interviewees do not report the existence of a funding gap in general. Some interviewees noted the existence of uncertainties in their environment that negatively impact investment activities in sustainable technologies. Further investments in sustainable technologies are seen as positive since the gap between necessary investments to reach climate objectives and actual investments is still increasing. Already existing financial guidelines and funding instruments are seen as beneficial for the transformation towards a sustainable economy, such as CCFD or the EU Innovation fund.[43] The interviewees stressed that public and private funding is an important aspect for the success of an emerging technologies linked with the European Green Deal. Most projects analysed in this study, are partly funded by public authorities.

For an almost carbon neutral industry is the increased availability of renewable energy necessary as well as low emission hydrogen in large amounts and at economically feasible prices. The interviewees stressed that the more affordable renewable energy is available to industry, the more carbon free technologies can be introduced into production processes. Climate ambitions and carbon pricing policies would need to rise globally at a similar level to avoid developing market disruption and difficult export strategies. EU-wide funding structures could help MNEs and SMEs quickly shifting investment priorities to sustainable technologies. According to the interviewees there is currently no effective EU-wide policy framework to allow for the industrial transition. The EU emissions trading system (EU ETS) ensures a reduction of carbon emissions, but risks to drive old technologies out of the market before they can be substituted by new installations. The ETS could be supplemented and reinforced by additional policy tools that increase investment security for MNEs and furthermore encourage the market to spend resources for the development and rollout of carbon-free

[43] A number of interviewees stated that they support the efforts by the European Commission to bring clarity and transparency on environmental sustainability to investors, companies and issuers. From their point of view the development of a common language (EU Taxonomy) could enable knowledgeable decision-making to foster investment in environmentally sustainable activities and technologies like hydrogen.

technologies. It was underlined that carbon border adjustment mechanism can only be an improvement, if competitiveness both on the EU market and for exports can be assured and there is full protection along the whole value chain up to end consumer products.

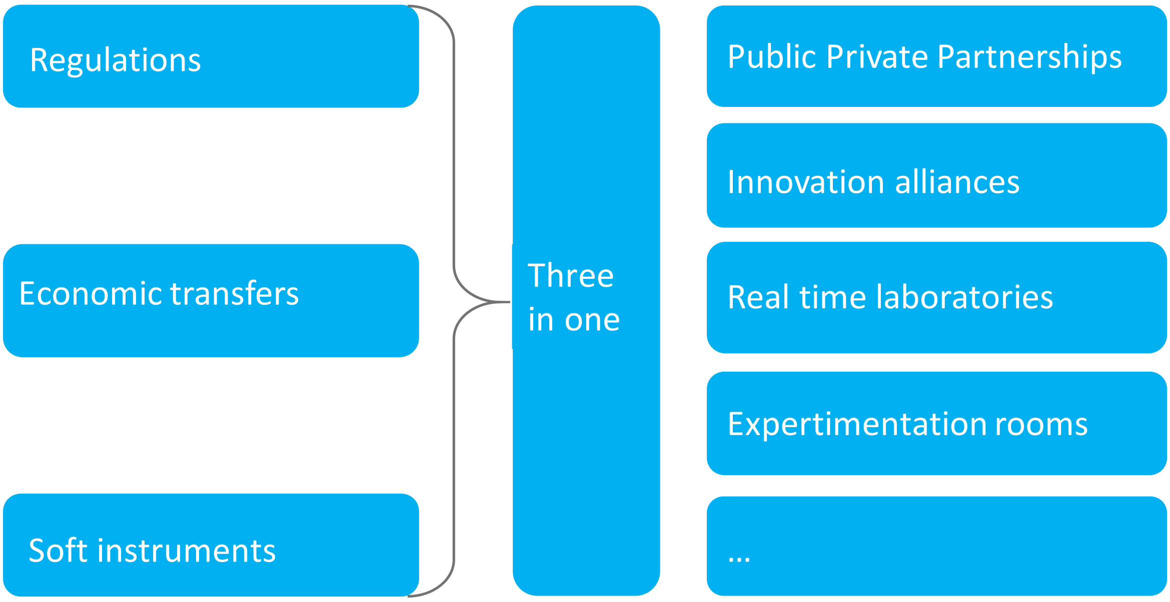
Soft instruments

The interviewees provide some proposals to currently existing political instruments and industrial policy regarding the development towards a climate neutral production and R&D&I sector. Concerning the existing political instruments regarding the development towards a climate neutral production it is suggested improving the dialogue between all necessary stakeholders. To increase the permeability of regulations it is important to involve all relevant actors and to make sure not to alienate them. Besides this, partnerships are seen as needed to jointly being able to address the challenges of the European Green Deal. Furthermore, some interviewees stated that the speed of starting and also stopping R&D&I activities has to increase in a more dynamic, agile and responsive system. It was also stressed that every state and every industry (no matter their size) in Europe should have an active part in the current energy and industrial shift based on the European Green Deal.

4.4 Policy implications

Implementing the European Green Deal and transforming industry in the EU by using anticipation-based policy instruments requires concrete and additional instruments. An outline of options for adjusting and expanding current instruments for EU industrial and R&D&I policies is provided in the form of a concise anticipation-based policy toolbox. It should be kept in mind here that the companies and GINs interviewed (green energy, green mobility, sustainable industry, hydrogen, batteries) and analysed for this study represent a strong trend towards collaborative R&D&I and innovation networks. The anticipation-based policy toolbox below shows instrument categories and combinations of all of them in new or adjusted policy instruments. In addition, this outline based on the case studies and interviews provides options for how public authorities at different levels can address the current opportunities and challenges for innovation and industry related to the European Green Deal and the SDGs. Figure 43 shows three classic categories of policy instruments: regulations, economic, and financial instruments, and soft instruments. The tradition is that they are discussed separately which does not make that much sense when looking on new instruments. These new instruments are quite often 'three in one' which means that they consist of regulations, economic, and financial instruments, and soft instruments. This phenomenon can be found for instance in Public Private Partnerships like SPIRE or Fuel Cells and Hydrogen Joint Undertaking (FCH JU). It can be also found in innovation alliances like European Battery Alliance or European Clean Hydrogen Alliance.

Figure 43: Policy instruments – three in one



Source: VDI TZ

As described by the European Commission (2020b) in the new industrial strategy efforts at the European level need to be matched by national and regional reform efforts. There is a need to join forces behind a holistic and comprehensive strategy for industrial competitiveness linked with the anticipation-based policy toolbox and the options for policy instruments discussed above. In addition, a number of these ‚three in one instruments' are already being used in a systematic way at the national.

Germany, for instance, operates with two, new innovation and industrial policy instruments at the national level. Real-world laboratories and experimental rooms are both "hard" and "economic-promoting" as well as "soft" anticipation-based innovation and industrial policy instruments. They are generally speaking "three in one". Currently, they can be found in Green Deal related fields like hydrogen and batteries. They are aimed at regulating and promoting measures (such as public funding programs) as well as dialogue processes. They differ in a few key points: The real-world laboratory initiatives currently either focus on the energy transition with a targeted focus like hydrogen or they are open to innovation in various industries. In both cases, the focus is on innovative products, processes or services, the development of business models, prospective market penetration and regulatory learning. The thematic focus of experimentation rooms is on work models, internal structures, employee development and employment formats. With a view to employees, works councils and trade unions, they are more participatory and have a stronger dialogue orientation. "Hard" innovation and industrial policy instruments are particularly relevant for legislation and its further development. Both in practical tests and in "laboratory environments" - partly determined ex ante, partly as an (interim) result of the experimental work - regulatory issues are raised and dealt with.

Real-world laboratories or experimental rooms are expressions of the proactive use of new anticipation-based innovation and industrial policy instruments used for instance in German speaking countries. They can also open up new (co-) design perspectives and innovative participation formats for employee actors if there is clarity about the goals, project structures and means as well as the actors involved. The worlds of innovation and work are currently in a profound transformation process linked with the European Green Deal. Job profiles, customer needs and qualification needs, etc. change significantly. Technical innovations offer the potential for more efficient and simplified work processes. Employee skills are to be continuously developed. Companies and their workforces usually need to be able to react quite quickly and flexible to changing requirements resulting from the European Green Deal. New and modified anticipation-based innovation and industrial policy instruments such as real laboratories and experimental rooms offer the opportunity to flexibly test technical and social innovations, business models and new or modified internal processes within an initially limited framework, to evaluate them scientifically and to adapt them as required.

Since the GINs and companies analysed in this study are active in different sectors but also cross-sectoral, it is suggested that the anticipation-based policy instruments and options discussed here will be linked with the future sectoral initiatives organised within the framework of the smart specialisation strategies for sustainable and inclusive growth This gives numerous established and new stakeholders from business, politics, science and society from different Member States and regions, the chance to develop bright ideas for new products, services and processes related to the European Green Deal and to work in a well-structured, open-minded and inter-sectoral environments.

5 Conclusions

This study analysed the EU's R&D&I competitiveness and Global Innovation networks in the framework of the European Green Deal to provide evidence for the potential of European industries to become carbon neutral while simultaneously ensuring job security. Research was focused on three identified Green Deal priority areas, industry, energy and mobility and two cross-sectoral areas, hydrogen and batteries.

The EU has certainly a strong competitive position within the Green Deal priority areas, especially when focusing on R&D expenditures on country level. Yet, on company level US companies on average invest more in the energy sector whereas Japanese companies have higher expenditures on firm level in the industrial sector. Although Chinese firms' expenditures are, compared to other sectors, relatively modest, Chinese firms have displayed a high growth in R&D investments within the past years. If this trend is to continue, Europe might face strong competition from non-EU actors. With respect to funding, on country level US start-ups are best equipped in most sectors, except for the steel sector where EU start-ups receive the highest amount of private equity funding. In terms of patenting activities, Japanese and EU firms are strong key players in all Green Deal Priority Areas.

The EU is well positioned in the mobility sector, where established EU companies are ranked highest in R&D intensity as well as in total R&D investments on both country and firm level. At the same time, private equity funding in innovative mobility technologies is highest for the US and China. Furthermore, Chinese mobility start-ups receive the highest average funding, followed by Japanese start-ups. In the energy and industrial sector, EU companies are highly prevalent among the top R&D investing firms. In both sectors, EU companies also display the highest R&D investments on country level. On firm level, R&D investments in the industrial sector are highest for Japanese companies, whereas US firms on average have leading positions in the energy sector. It can be concluded that EU actors are increasingly focussing on the development of alternative energy solutions, whereas companies in China and 'RoW' are displaying increasing efforts in the development of conventional energy solutions but are also broadly positioned due to recently increasing R&D investments in the renewable energy sector.

Being a member organized in a Global Innovation Network (GIN) is beneficial for companies in each sector since it allows the engagement with different types of stakeholders and provides access to a diverse skill set, reduces investment risks by spreading efforts and promotes synergies between specific areas towards a wider research area. This form of organization has a positive impact on innovation activities. To further promote the development of climate neutral production within GINs, clear policy guidelines that provide higher planning security are necessary.

The EU is already on the path to a successful transformation. Yet some factors that are enabling or hindering R&D&I policies supporting the sustainable transition have been identified. In the current EU policy context, regulations are seen as having negative impact on conventional business, such as the EU ETS which increases the price for CO2 leading to less competitiveness for CO2 intensive business models. At the same time, an appropriate regulatory framework is the cornerstone of the new Industry Strategy for a green and competitive EU industry and can lead to benefits for sustainable and transformative sectors and technologies. To enable sustainable and transformative sectors and technologies, the speed and agility of policies in EU needs to be improved. Economic and financial guidelines are seen as beneficial for the transformation towards a sustainable economy.

A mix of policy instruments that supports companies in their transition is needed. Instead of just focussing on the three classical categories of policy instruments (regulations, economic and financial instruments and soft instruments) separately, it is reasonable to use additionally 'three in one' instruments. This combination of policy instruments to support sustainability efforts in GINs is already used in several European Public Private Partnerships or alliances. The new industrial strategy efforts at the European level need to be matched by national and regional policy efforts. There is also a need to join forces behind a holistic and comprehensive strategy for industrial competitiveness linked with the anticipation-based policy strategy and the options for policy instruments discussed above.

While pushing its Green Deal, Europe's innovation and economic conflicts with both the US and China will become more prominent. At the same time, the US and China are in competition with one another for supremacy in emerging technology and economic fields. For these countries, the protection of (own) new green technologies and markets have the highest priority. Both countries are already quite open about their disputes with one another, but also to a certain extent with the EU – the US for instance by establishing trade barriers to protect their own economy (e.g. steel), China for instance by restricting FDI domestically or by enacting new laws to protect new technologies (e.g. batteries).

It is already clear today that emerging technology fields are increasingly associated with new or modified innovation and industrial policy instruments are being implemented or close to (Bullinger & Malanowski, 2021). This happens in the global competition context for international technology leadership described above. Such instruments usually have a distinctly experimental character. Real-world laboratories and experimentation rooms, in connection with green technologies in sectors like energy, industry and mobility offer the opportunity to test technical and social innovations or changed internal processes specifically within an initially limited framework and to adapt them as required. They can also be used to shape qualification requirements and employment formats in a direct exchange with other innovation and industry players and policymakers in a future-oriented manner.

For employee actors from industry, this can open new design perspectives and innovative participation formats to create robust industries for the next decade. The discussion of critical perspectives brought in by employees must be adequately taken into account when discussing the new deeply transformative developments. In contrast to the US and China, workers' actors in Europe are seen as competent and critical contributors to the transformation of industries (Malanowski N., 2021). This expertise needs to be used in a targeted manner for pushing ambitiously the Green Deal in Europe and its broad acceptance in society and economy. The window of opportunities for doing this is open for the next years but fierce competition with the US and China in this field might reduce the time for proactive innovation and industrial policy on the one hand. On the other hand, climate change might be faster as predicted after the Covid-19 pandemic and climate neutrality is needed earlier. Due to these possible limited opportunities, it could happen that future R&D&I policies supporting technologies relevant for Europe's Green Deal might be reactive instead of pro-active.

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