VDI Technologiezentrum

The potential of Europe's chemical and mobility industry regarding the European Green Deal

Engineering our future

Assessment and implications for policy

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Abstract

The European Green Deal has become a major topic in the general debate on innovation and innovation policy: to reach the goals of the European Green Deal, innovation will prove pivotal. Existing research has shown that Global Innovation Networks play a major role in the innovation ecosystem, but their role for large European companies in achieving green transformation has as yet not been researched. To tackle this task, the paper first assesses the current state and potential of larger European companies regarding the goals of the Green Deal – focusing on chemical and mobility industry, chosen for their importance in terms of jobs and possible contributions to CO_2 reduction. Second, the paper identifies European-centric Global Innovation Networks and analyses their role in implementing the European Green Deal successfully in companies. Third, the paper derives policy implications and proposes anticipation-based policy as a necessary instrument for achieving the goals of the European Green Deal.

Keywords

European Green Deal, Industrial Transformation, Global Innovation Networks, Innovation and Industrial Policy, Foresight

by
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1 Introduction

The European Green Deal represents a paradigm shift in European politics. The longterm goal is to make Europe the first carbon neutral continent by 2050. An important intermediate goal is to decrease greenhouse gas emissions by 55 per cent by 2030 (European Commission, 2021). To attain these ambitious goals, innovation will be crucial.

Existing research has shown that Global Innovation Networks (GINs) play a major role in the innovation ecosystem. GINs are networks of corporate actors and other stakeholders such as academia and public (research) institutions that facilitate and/or promote innovation. According to Dosso, Potters & Tübke (2017), GINs allow for an understanding of companies' relocation decisions and their choice of public-private partnerships. In GINs, Research & Development & Innovation (R&D&I) activities take place in a more dispersed manner. This enables the accumulation of complementary knowledge and thus potentially entail a competitive advantage for companies (OECD, 2017). Agglomeration of knowledge from diverse types of actors within networks or ecosystems contributes to creating new competences, developing new technologies and conquering new markets (Cho et al., 2022). Cantwell (2017) argues that the greater the number of regions and markets involved in the innovation process, the more diverse the gained experiences that can result in innovations of higher quality and hence competitive advantages are. Global Innovation Networks allow for a historical as well as projective analysis of companies' locational, operational and strategical choices, and their position in global value chains (Herstad et al., 2014; Dosso, Potters & Tübke, 2017).

Comprehensive and actionable research on how GINs can contribute towards the goals of the European Green Deal is lacking, and this article therefore aims to tackle this research gap. Our first research question is thereby: **Are GINs in the chemical and the mobility industry structured in a manner that allows them to strategically position themselves to implement the European Green Deal successfully in their companies?**

The second strand of literature our research[1] speaks to is the one on innovation and industrial policy. This research strand 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: anticipation, participation, deliberation and transparency. Recent research shows that successful innovation and industrial policies that combine a whole set of policy instruments are better in enabling radical innovations. It should be underlined that these policies have been more focused on market and formation through direct and pervasive public financing than on market fixing (Boon & Edler & Robinson, 2022; Mazzucato & Semienuk, 2017; d'Andria & Savon, 2018). The newly developed instruments are used to address the challenges (whether 'old' or 'new') of innovation and industry, often in combination with established instruments or subsidies. Public financing of innovation is an important strategic tool that helps 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' (d'Andria & Savon, 2018, p. 44).

Mazzucato & Semienuk (2017) stress three features of how public financing of innovation can shape and create markets, namely

- investments along the entire innovation chain,
- a mission-oriented nature,
- the leading role of public financiers in risk-taking, independent of the business cycle.

[1] The full study "Techno-Economic study on the potential of European Industrial Companies regarding Europe's Green Deal" was carried out on behalf of and with the support of the European Commission, DG Joint Research Centre. The authors of this article would like to express their thanks to the co-authors of the full study. These are Daniela Kretz (IDEA Consult, Brussels) and Simon Beesch (VDI Technologiezentrum, Dusseldorf).

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). Recently, Germany's Commission of Experts for Research and Innovation (EFI) argued that the agility of policy is an important prerequisite for successfully implementing the transformative change desired by society (Commission of Experts for Research and Innovation, 2021).

In recent years, research has increasingly focused on the link between foresight and innovation, as well as the link with industrial policy instruments (Malanowski et al., 2021; Gordon, Ramic, Rohrbeck & Spaniol, 2020). Saritas (2018) argues that foresight activities within a period of transition have changed in content, context and process. Concerning the goal of a more resilient science, technology and innovation policy, foresight activities "have become more inclusive with the participation of broader experts and social stakeholders" (p. 1).

A review of recent literature shows that innovation and industrial policy consists of various instruments. Borras & Edquist (2013, 2019) suggest three categories of policy instruments: regulatory instruments, economic and financial instruments, as well as soft instruments. They observe that regulatory, economic and financial instruments impact innovation from the supply side rather than from the demand side. According to Borras & Edquist, instruments focusing on the demand side, so-called soft instruments, might be more suitable to address different and new aspects of the innovation and industrial system challenged by several deep transformations and technology breakthroughs. At the same time, Borras & Edquist underline the importance of combining different types of policy instruments.

In a publication in 2012, the OECD concludes that the "effectiveness of a policy instrument almost always depends on its interaction with other instruments" (p. 156). In this publication, it is also stressed that beyond 'core innovation policies', such as education or science and technology, other policies and instruments should be taken into account. This includes, for instance, taxation, competition laws and regulations. Furthermore, it is suggested to consider different target groups, desired outcomes and funding mechanisms connected with these instruments (OECD, 2012). In addition, more tailor-made policies at the regional level are suggested (Joint Research Centre, 2019).

Our second research question is focusing on this second strand of literature on policy instruments and is inherently connected to the first research question: **What type of innovation policy instruments are needed to allow for the full potential of GINs?**

This paper is structured as follows. Section 2 details the methodology and data used in the project. Section 3 provides the empirical results: the R&D&I competitiveness of the European chemical and mobility industries regarding the European Green Deal. It also includes a characterisation and assessment of GINs in these two industries (that are European Green Deal priority areas), and the policy instruments suitable for the EU. Section 4 provides the conclusions.

2 Methodology and data

We combine quantitative and qualitative approaches to directly address our research questions. A systematic mixed-methods approach, which leverages the advantages of each method, is used to generate a more holistic view and increase the robustness and explanatory power of the derived conclusions.

2.1 Sector/industry focus

Our analysis focusses on two industries, namely the chemical and the mobility industry. The rationale for the selection of these industries is based on their potential to contribute to the goals of the European Green Deal and on the fact that these industries are considered highly innovative. Furthermore, the analysis includes two cross-sectional technologies strongly inter-linked with the chemical and the mobility industry: hydrogen and batteries. These cross-sectional technologies both have the potential to accelerate the decarbonisation of the European industry (Malanowski et al. 2022). Hydrogen is produced within the energy industry and is used as a source of energy by both the mobility and the chemical industry. Vice versa, the chemical industry is a producer of batteries used for energy storage in the mobility industry.

In the following we refer to chemical and mobility as 'Green Deal priority areas', and to hydrogen and batteries as cross-sectional technologies.

2.2 R&D&I competitiveness

To assess the R&D&I and economic competitiveness of the European chemical and mobility industries, we apply micro and macro data analyses on both innovation input and output level. On the input side, the focus lies on data from R&D investments of large companies based on the EU Industrial R&D Investment Scoreboard (European Commission, Joint Research Centre, 2019), and investment data and funding trends of highly innovative companies based on the Crunchbase database.[2] On the output level, a patent analysis based on the European Patent Office EPO's Worldwide Patent Statistical Database (PATSTAT database[3]) was conducted. These analyses give an overview of the relative innovation position of the world regions.

The purpose of the microdata analysis based on the EU Industrial R&D Investment Scoreboard (European Commission, Joint Research Centre, 2019) is to identify innovative companies in Green Deal priority areas that are highly active in developing new technologies. For answering our research questions, we then try to identify the GINs of selected innovative companies. The analysis assesses Europe's competitiveness compared to other geographic regions (US, China, Japan and other countries) regarding the Green Deal priority areas mobility and industry. The identification and analysis of companies active in industries connected to the Green Deal priority areas is based on the Industry Classification Benchmark (ICB) included in the Scoreboard (see Appendix 1). From the ICB classification, we selected a subset of those classes that mirror the identified Green Deal priority areas (industry and mobility). For each area, relevant numbers such as R&D investment and R&D intensity are assessed.

The EU Industrial R&D Investment Scoreboard includes data on the 2,500 largest R&D investors worldwide, accounting for about 90 percent of global private R&D investments, which is published on an annual basis (European Commission, Joint Research Centre, 2022). Previous research has used the EU Industrial R&D investment Scoreboard to examine Europe's competitiveness in climate change mitigation technologies (Pasimeni et al., 2019; Diaconu, 2019), among others.

We then analyse investments and funding rounds with a focus on start-ups active in relevant areas (Dalle et al., 2017), based on the Crunchbase database. Crunchbase has been used by Cojoianu et al. (2020) to analyse green regional entrepreneurship and by the OECD to identify innovative start-ups (OECD, 2018;

2 www.crunchbase.com
3 https://www.epo.org/searching-for-patents/business/patstat.html

Breschi et al., 2018). Our methodology builds on the OECD approach. The analysis of individual companies is highly relevant as it serves to identify the market power of relevant actors playing a major role in implementing the European Green Deal in Europe's innovation ecosystem and thus to deduce the competitive position of regions. We use industry categories and company descriptions provided by Crunchbase to filter relevant companies (see Appendix 2 for an overview of the applied search queries). The geographical allocation is based on the company headquarters indicated in the database.

Both internal and financial aspects influence the success of a company. Companies that focus on specific applications or specific services might profit from productivity gains or quantity effects in procurement, production or other areas. Companies with a low degree of specialisation who operate in multiple industries, however, can benefit from synergy effects or are less sensitive to economic fluctuations that can be a benefit as well. This effect is even stronger if companies operate in policy relevant fields, like services in megatrends or key enabling technologies.

The patent analysis identifies companies that have registered green patents, indicating R&D&I activities in fields relevant to Europe's Green Deal, thereby focusing on the output level of innovation. We build on a detailed classification of green patent classes provided by the OECD (OECD, 2016; Haščič & Migotto, 2015). In a first step we select all superordinate classes, level 0 in the OECD classification, belonging to one of the Green Deal priority areas (chemical industry and mobility). In a second step we select all patent classes corresponding to at least one of the Green Deal priority areas at a more fine-grained level (level 3 of the OECD green patent classification, see Appendix 3). The patent analysis is based on data from the PATSTAT database. For each of the Green Deal priority areas, we compile a list of all registered patents. We then match the selected patents with the information contained in the JRC-OECD COR&DIP© database,[4] which allows to triangulate the patent data with information related to the company owning the patent, e. g., NACE codes of industries the company is active in, R&D spending and country of headquarters.[5]

2.3 Identification and analysis of Global Innovation Networks and policy instruments

To identify relevant GINs, i.e., companies and other stakeholders active in joint green innovation, we further build on a literature review and results from the preceding analyses. A list of the top-20 European patenting companies, according to number of green patents, was used to identify relevant stakeholders with major activities in green patenting. We also compiled a list of noticeable co-applicants. Patent co-applications can be considered as indicators for potentially existing GINs. This approach allowed us to identify innovative stakeholders that served for in-depth expert interviews offering profound insight into GINs.

The expert interviews with companies and business organisations from mobility and chemical focused on selected GINs and addressed questions related to the policy framework as well as drivers and barriers for investing in R&D&I related to the Green Deal. The interviews aimed to obtain detailed information on the interviewees' potential to become carbon neutral and simultaneously provide job security and growth in the EU, with a special focus on GINs and their role in achieving the goals of the European Green Deal. The results from the preceding analyses are consolidated in case studies on 6 European-centric GINs. Finally, we derive broadly defined as well as specific policy instruments from the case studies and expert interviews.

[4] JRC-OECD, COR&DIP© database v.2., 2019.

[5] PATSTAT assigns patents to the more fine-grained CPC (Cooperative Patent Classification) patent classes, which are also used by the OECD in their green patent classification. As the JRC-OECD COR&DIP© database only contains IPC (International Patent Classification), it was not possible to exclusively rely on the JRC-OECD COR&DIP© database for selecting green patents.

3 Empirical results

The following section assesses the current state and potential of large European companies in relation to the goals of the European Green Deal, as well as the economic and R&D&I competitiveness on both regional and company level. The focus lies on the industrial sector (focusing on the chemical industry where possible), the mobility industry and the cross-sectional technologies batteries and hydrogen. In the following section, we merge this information with insight obtained from expert interviews.

3.1 Chemical industry/industrial sector

The industrial sector takes third place in terms of EU greenhouse gas emissions in 2018, following the energy and transport sector (European Energy Agency, 2019). Decarbonising the industrial sector while simultaneously maintaining job security is thus central for transforming the economy (Capgemini Invent, 2020, p. 58 ff; International Energy Agency, (2021), p. 121 ff). Without further major steps in industrial innovation for low-carbon technologies, the EU will not be able to reach its climate goals (European Commission, Directorate for Research and Innovation, 2022). Within this sector, we focus on the chemical industry, which is an important contributor both to EU GDP and EU CO_2 emissions. Due to data gaps, some of the presented analyses provide results for the whole industrial sector, while other analyses focus on the chemical industry.

3.1.1 Cross-sectional technologies for the chemical industry

Biomass solutions, use of green hydrogen and the industrial transformation from linear towards circular industrial economy play a key role in decarbonising the chemical industry. Carbon Capture and Storage (CCS) is also regarded a promising technology in decarbonising this industry.

According to the Strategic Forum on Important Projects of Common European Interest (2019), for the chemical industry 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, waste and use of electricity,
- production process: use of 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.

Hydrogen is an important feedstock that has, as a cross-sectional technology, the potential to decarbonise major high-emission industries. To strengthen and secure this position, industries need to focus on deployment of the technology, especially in view of the industries' strengths and capabilities. To realise the uptake of hydrogen technology, as outlined in the ambitious Hydrogen Roadmap (Fuel Cells and Hydrogen 2 Joint Undertaking, 2019) scenario, technologies that are ready for uptake should be deployed in relevant industries. This would enable cost savings due to economies of scale.

3.1.2 Potential for growth

To assess the growth potential of the chemical industry, we use innovation indicators at both input level (trends in R&D investments) and output level (the number of patents granted). We also analyse temporal trends in tech start-ups operating in the chemical industry.

Based on the PATSTAT database, we identify the top-100 patenting companies in the chemical industry (Figure 1). Among these, Japanese companies are most frequent, followed by US and EU based companies. Twelve companies have their headquarters in other countries (aggregated as RoW, rest of the world), whereas only three are Chinese companies.

Region	Japan	EU	USA	China	RoW
No. of firms	33	29	23	3	12

Figure 1: Regional distribution of the top-100 patenting companies, chemical industry
Source: Analysis based on PATSTAT database (2020)

The analysis of company R&D investments is based on data from the EU Industrial R&D Investment Scoreboard (European Commission, Joint Research Centre, 2019).[6] Figure 2 shows the regional distribution of total R&D investments for selected world regions. Total R&D investment in the industrial sector has been 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 consistent investment rates on a regional level, whereas Chinese companies invested only a fraction of the spending of other regions back in 2009 yet increased their investment by a factor of 6.7 by 2018, overtaking the US and Japanese R&D investments in 2018.

Considering the industrial sector's R&D expenditure per company,[7] Japan ranks highest, followed by the RoW, US and EU. China again ranked lowest in 2009 but shows an increasing trend and almost reached the EU level in 2018. On average, Japanese top R&D investing industrial companies invested about EUR 124 million in 2009 and EUR 169 million in 2018, whereas in China, this number tripled from EUR 26 million in 2009 to EUR 93 million in 2018.

R&D intensity (Figure 3) is calculated by dividing total R&D investment by net sales per region. Like total and mean R&D investment, R&D intensity of Chinese industrial companies has strongly risen, whereas Japan, RoW and the US show a stable, slightly volatile trend. EU industrial companies demonstrate the highest R&D intensity, followed by Japan, the RoW, US and China.

The development of newly funded start-ups allows to draw conclusions on the relevance of specific industries. It also provides implications on the level of competition and gives indications on market barriers, e. g., due to high fixed costs.

The Crunchbase database lists 431 start-ups operating in the chemical industry. US companies receive the highest amount of funding on both regional and company level, acquiring more than two-thirds of worldwide funding in the chemical industry.

In terms of patenting and total R&D investments on a country level, the EU has a strong competitive position in the chemical industry and the whole industrial sector. The analysis of R&D intensities gives similar results on company level. Japan is 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

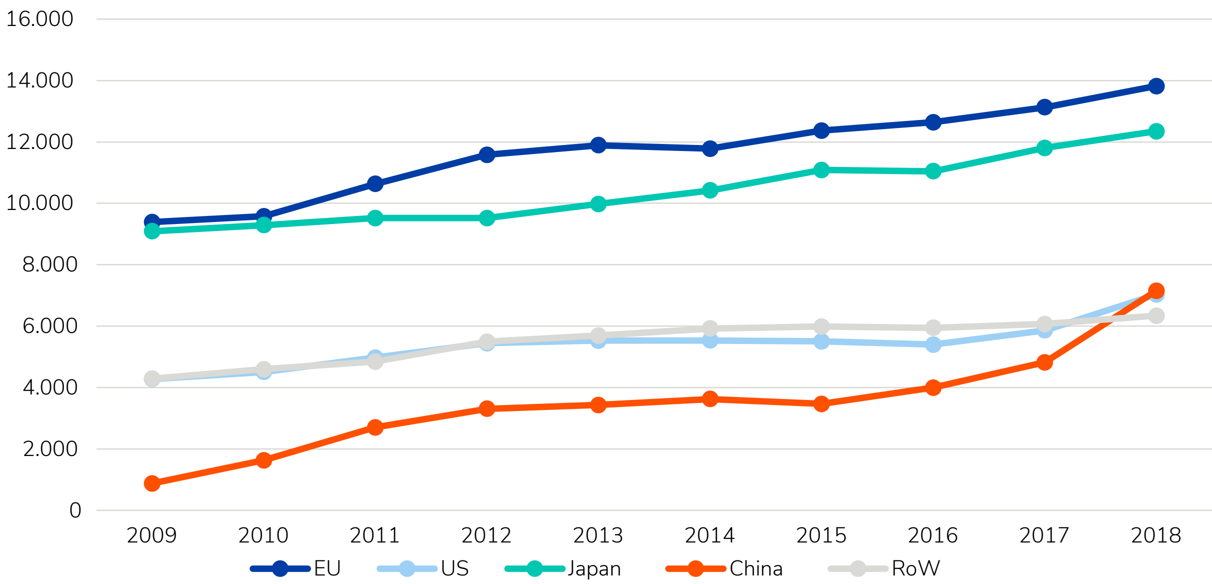

Figure 2: Total R&D investment by region, industry (in millions of euro)
Source: Analysis based on 2019 EU Industrial R&D investment Scoreboard

[6] Due to different reporting standards between regions and companies, there are methodological caveats that must be considered when using the data (European Commission, Joint Research Centre, 2022, p. 140-144).
[7] Amounts are in nominal terms and expressed in Euros with all foreign currencies converted at the exchange rate at the end of each year.

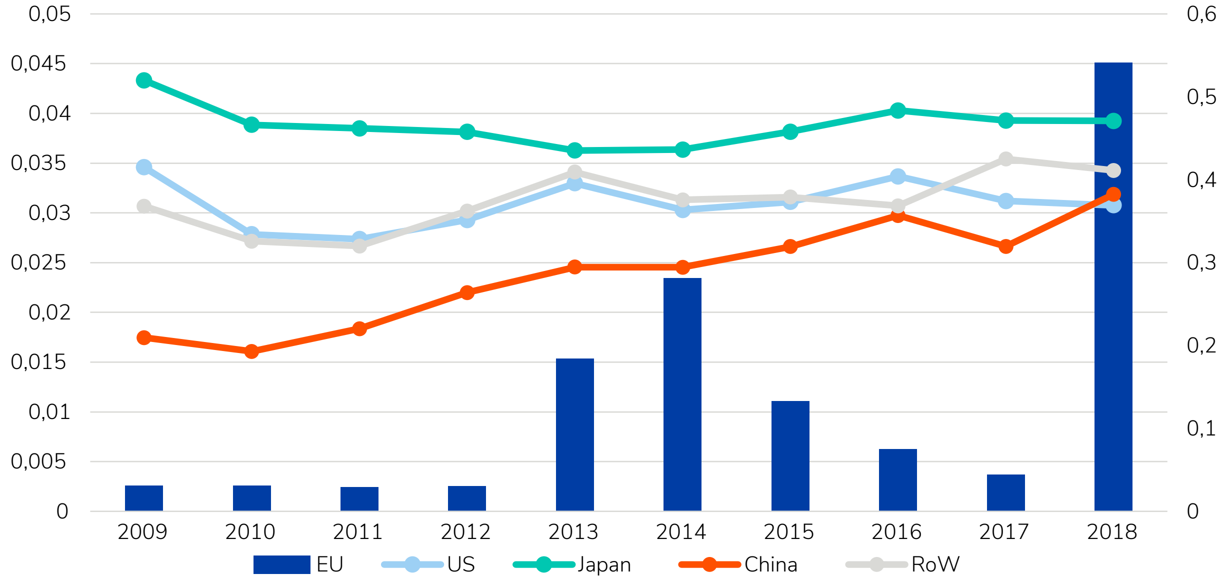

Figure 3: R&D intensity by 5 main regions, industry (shares)
Source : Analysis based on 2019 EU Industrial R&D investment Scoreboard. Lines (here US, Japan, China and RoW values) belong to the left-hand axis, bars (here EU values) to the right-hand axis.

interests in Japan and the RoW respectively. The relatively low number of companies indicates strong market barriers due to high fixed costs (power plants, machinery, etc).

Hydrogen is an important technology when it comes to transforming the chemical industry. Considering the international competition on the market for hydrogen production, Europe is considered a technology leader and is determined to keep this position and even expand this advantage (Kurmayer, 2023). Nevertheless, there are still barriers that need to be addressed to ensure the European hydrogen market can grow. According to the European Chemical Industry Council (2019), the future of the successful uptake of hydrogen technology relies on the role of policies, certification, fostering competitiveness and market design, safe and flexible infrastructure, and safe and efficient transport, among others.

Analysis of the current and emerging number of start-ups operating in the hydrogen area gives in total 175 companies, of which the majority (101) has been founded from 2000 onwards. The number of hydrogen start-ups in the Crunchbase database does not exhibit a clear upwards trend (Figure 4).[8]

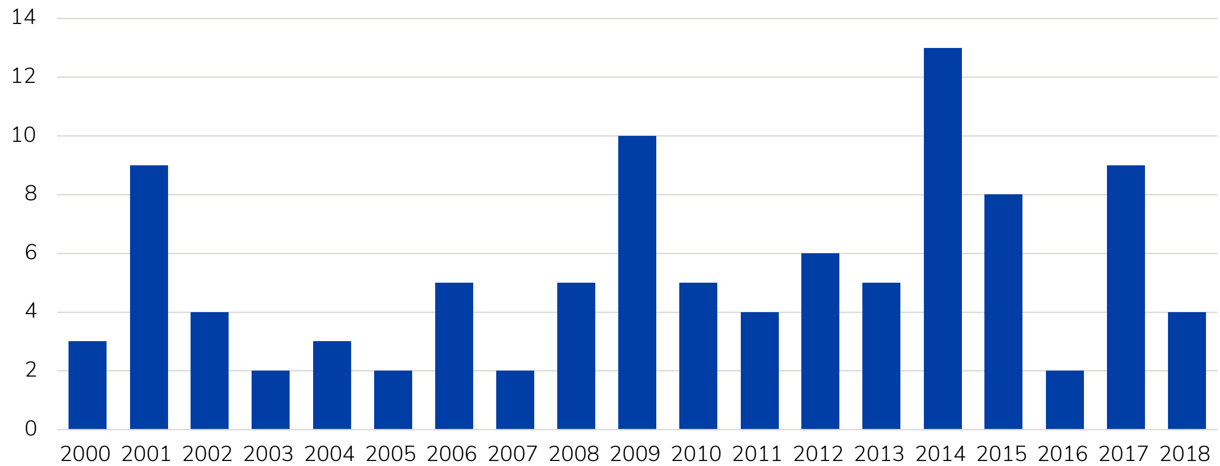

Figure 4: Number of start-ups per year, hydrogen
Source: Analysis based on Crunchbase database (2020)

[8] Numbers for more recent years may be underestimated using the Crunchbase database, as young start-ups may take some time to become known and added to the database.

The US and Canada are strong competitors to the EU in terms of funding in the hydrogen area. In the EU, start-ups located in Germany and Sweden are well positioned in terms of both total amount of funding and numbers of companies. The UK's exit from the EU will probably reduce the EU's competitiveness in the hydrogen area, as some important companies are UK-based.

3.2 Mobility

The mobility industry includes services of transporting goods and people when vehicles and infrastructure are used to enable this movement. Overall, the transport industry has roughly EUR 675 billion Gross Value Added (GVA) and accounts for 5 percent of the GVA in the EU-28 in 2017 (European Court of Auditors, 2018). In the EU, transport accounts for 25 percent of the greenhouse gas emissions in the EU-28. Transformations in this industry are key to unlock the potential of the European Green Deal (Eurostat, 2019).

To support and accelerate the decarbonisation within the mobility industry, 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 to ensure sustainable mobility for the European Green Deal include zero- and low-emission vehicles in connection with the manufacturing industry and sustainable alternative fuels such as advanced biofuels. Hydrogen serves as a cross-sectional technology and has the potential to support and accelerate the decarbonisation and transformation of industries with high emissions. In industries where full electrification is not possible, such as the mobility and transport industry, the use of hydrogen represents an important alternative. Batteries can also act as catalyst for the transformation of the mobility industry and enable transformations in industrial processes to lower CO_2 emissions and at the same time support the energy system.

3.2.1 Cross-sectional technologies for the mobility industry

The transformation processes in the transport industry will be accompanied by technological change going beyond decarbonisation. 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 have the potential to reshape the mobility industry (Arthur D. Little, 2018). Relevant technologies prioritised in the EU's Strategic Transport Research and Innovation Agenda's Roadmaps (European Commission, n.d.) 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, 2017). Other key solutions listed by the International Renewable Energy Agency (IRENA) that support the decarbonisation of key emitters in the transport industry include electrification, hydrogen, biofuels and synfuels (IRENA, 2020).

Batteries are considered to have a clear role in future decarbonisation scenarios at the global scale and are currently mainly used in energy storage and electric mobility. Battery technologies also face diverse challenges on environmental and social integrity as well as its greenhouse gas 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).

3.2.2 Potential for growth

To assess the growth potential of the mobility industry, we use innovation indicators at both input level, (trends in) R&D investments, and output level – such as the number of patents granted. We also analyse temporal trends in tech start-ups operating in the mobility industry.

Region	Japan	EU	USA	China	RoW
No. of firms	44	25	15	2	14

Figure 5: Regional distribution of the top-100 patenting companies, mobility industry
Source: Analysis based on PATSTAT database (2020)

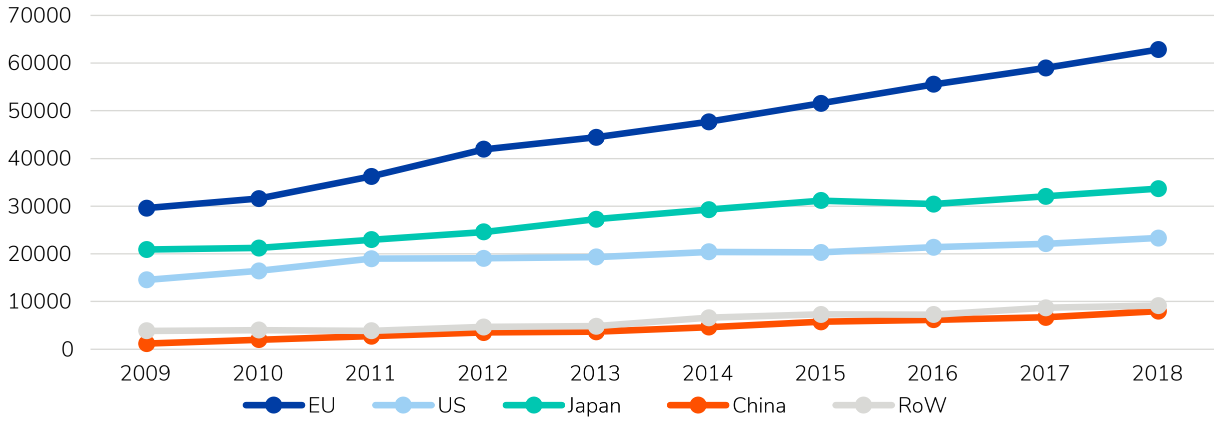

Figure 6: Total R&D investment by region, mobility industry (in millions of euro)
Source : Analysis based on 2019 EU Industrial R&D investment Scoreboard

Analyses of the PATSTAT database identified almost 20,000 green patents within the mobility industry. The distribution of the top-100 patenting companies is concentrated in a few world regions. Most companies (Figure 5) are headquartered in Japan, followed by 25 companies from the EU. Both the US and RoW rank similarly regarding their patenting activities. Only two Chinese companies are listed among the top-100 mobility patenting companies.

The analysis of total R&D investments per region (Figure 6), based on the 2019 EU Industrial R&D Investment Scoreboard, shows that total R&D investment 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.

Similar to total R&D investment, EU Scoreboard companies have the highest amount of R&D expenditures (total R&D expenditures in shares of the number of companies), followed by Japan and the US. The EU demonstrates the highest R&D intensities, calculated as total R&D investments per net sales (Figure 7), reaching a share of almost 0.3 per cent 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 intensity (0.46%), followed by China (0.37%), Japan (0.35%) and RoW (0.34%). In total, China and RoW show a significant increase in R&D intensity 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 intensity.

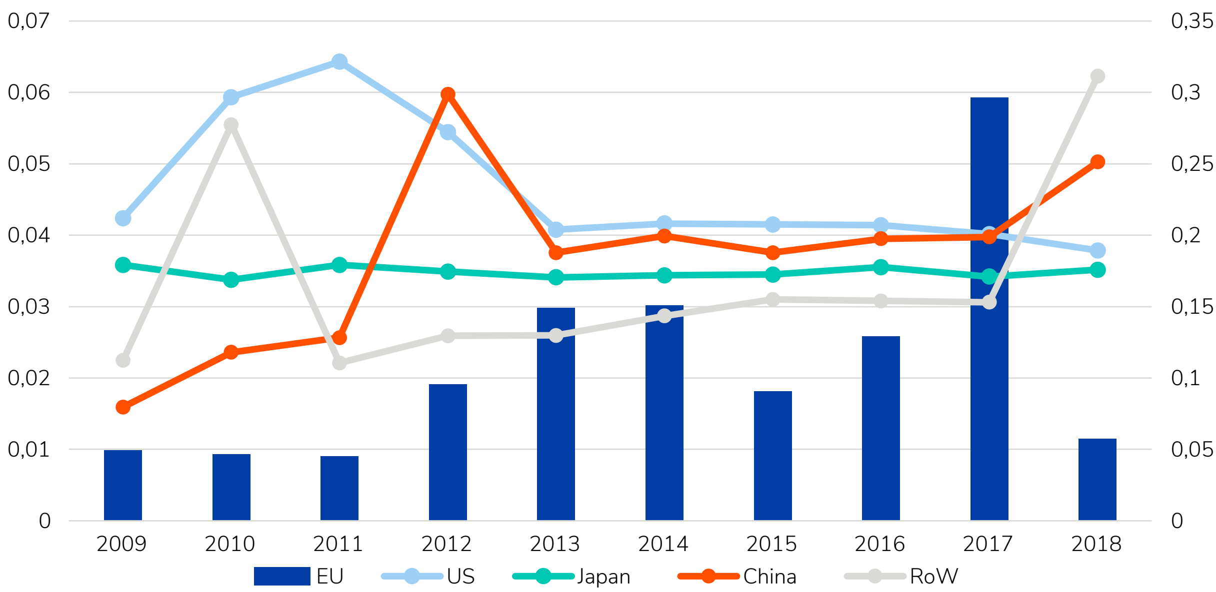

Figure 7: R&D intensity by 5 main regions, mobility industry (shares)
Source : Analysis based on 2019 EU Industrial R&D investment Scoreboard. Lines (here US, Japan, China and RoW values) belong to the left-hand axis, bars (here EU values) to the right-hand axis.

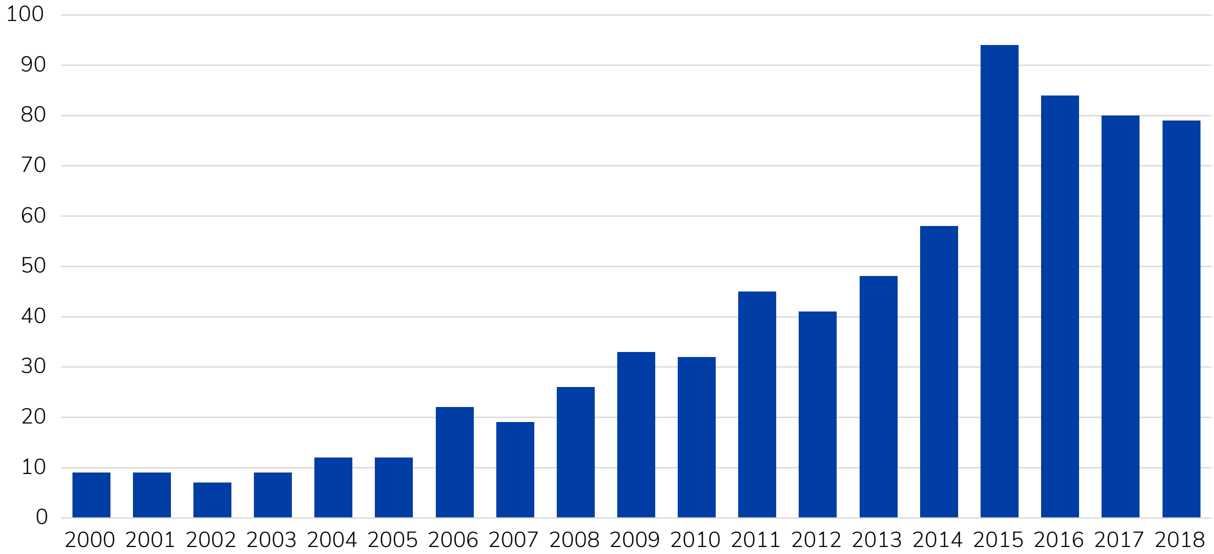

Figure 8: Number of start-ups per year, mobility industry
Source: Analysis based on Crunchbase database (2020)

Figure 8 shows the development of start-ups in the mobility industry. Between 2000 and 2018, 719 start-ups were founded in mobility. Furthermore, there is a clear trend in the number and development of start-up activities in this industry. Beginning with 9 start-ups in 2000, the number of start-ups was then tenfold by 2015 with a slight decrease in the subsequent years. This indicates that the mobility industry represents a very promising market with a potential to realise high profits.

Since batteries are considered important catalysts in transforming emission-intensive industries, such as the transformation from conventional to e-mobility, this technology is expected to further expand on a global level. Nevertheless, demand for batteries will vary regionally. China will become the largest market for batteries (43% in 2030) and the compound annual growth rate will also differ within the function of the various global markets (World Economic Forum, 2019).

Results of the total and emerging number of start-ups operating in the battery industry confirm the promising growth opportunities. 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 (see Figure 9). This growing number of companies increases the competition level

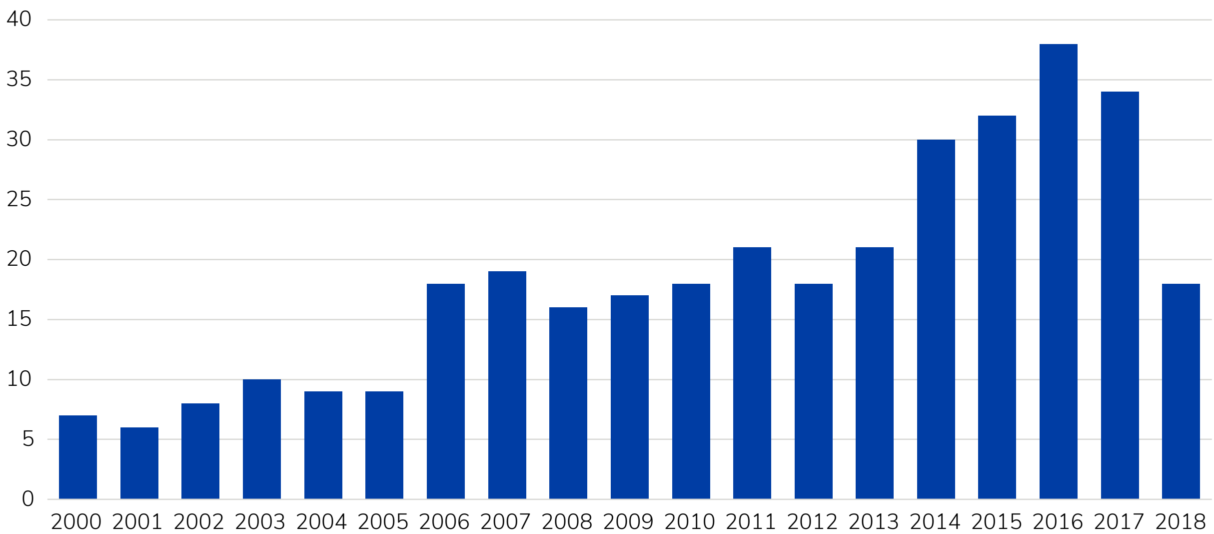

Figure 9: Number of start-ups per year, batteries
Source: Analysis based on Crunchbase database (2020)

in the market, leading to decreasing product prices and decreasing company profits due to competition.

3.3 The role of GINs in the dissemination of green technologies

To complement the theoretical implications of the role of GINs in the innovation and dissemination process, especially of companies active in sustainable technologies, we performed six case studies related to specific companies that are active in GINs. The choice of companies is based on the results from the patent analysis (see Figure 10) and complementary desk research. The selected companies are of particular interest in view of their role as R&D investor. They invest in start-ups, help smaller companies 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 analysis also includes a few mid-sized companies. In-depth information on the involvement of large R&D investors, as well as mid-sized companies in Global Innovation Networks, is primarily obtained from 12 in-depth expert interviews, but is triangulated against other results at each step of the study to generate a comprehensive picture and to increase validity. Based on these analyses, we identified and contacted relevant actors within each of the Green Deal priority areas under consideration and conducted structured surveys to establish comparability between the case studies.

The case studies provide general information on a given GIN and its members, the technological context of the technology in question, its growth potential and potential contribution to achieving the targets of the European Green Deal. Furthermore, the case studies analyse actually and potentially constraining and enabling policy conditions that are further discussed in Section 3.4.

Three case studies focus on the mobility industry. The first case study concerns a smaller GIN centred in North-Western Europe consisting of one SME, two MNEs and one investment company. The second GIN has almost 90 members based in 19 different countries including 17 European countries, the US and Japan. 50 per cent of its members are industrial partners, more than a third are research institutions, and the remaining members are associate partners. The third GIN represents a research consortium with members headquartered in Germany, the Netherlands, Italy and Austria, while the centre of the research consortium is located in Sweden. According to the taxonomy of Barnard and Chaminade (2011), only the second GIN is a global one and the others are more comparable to an internalised network.

Three other case studies focus on the chemical industry. The first case study is based on a GIN that comprises eight industrial companies headquartered in North-Western Europe. It can be viewed again as an internalised network. The second GIN represents a group of eight industrial and financial companies, and two research organisations. Participants are headquartered in Europe, Japan and the US. Therefore, according to Barnard and Chaminade (2011) it is a global network, as is the third case, which focusses

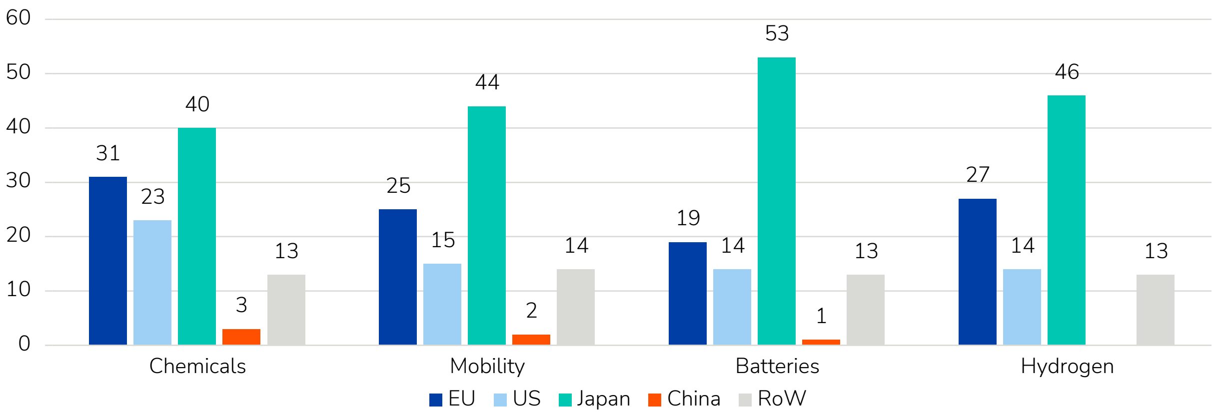

Figure 10: Number of companies among top-100 patenting companies by industry and world region
Source: Analysis based on Crunchbase database (2020)

on a GIN consisting of six regionally organised, Europe-based innovation hubs. Overall, 317 actors from 33 countries (of these 28 are EU countries) are involved. Key actors involved in this network include European universities, research and technology organisations (RTOs) as well as large companies, MNEs and start-ups.

A meta-analysis of these six case studies provides branch specific and subordinate insights. It reveals a positive correlation between a network's geographical scope and its size compared to the number and diversity of the members involved. Most GINs consist of both economic actors and academia. The interviewees agreed that the choice of members and the types of members included is crucial as each stakeholder has a specific role in the network. Project-based networks typically consist of a limited number of actors compared to public private partnerships (PPP). Being EU-based is often seen as an enabler to become carbon-neutral and as stimulating the demand for 'green' technologies.

In general, there are several reasons for stakeholders to be organised in a Global Innovation Network, including access to knowledge and a diverse skill set, as this increases exchange and synergy effects between different research and technological areas leading to new ideas, the reduction of risks by spreading (financial) efforts, the possibility to engage with stakeholders and to form new partnerships, the scaling up of technologies and the possibility to access new markets. Larger GINs especially act as a solid basis for providing input into policy making.

Another key reason for actors to engage in GINs is the access to different stakeholders enabling contributions. Focusing on economic actors, MNEs contribute with resources, broad knowledge of, and access to markets, technologies on a high TRL and the ability to increase visibility. SMEs contribute with niche knowledge of specific markets or technologies, they provide ideas and a specified skill set, and accelerate the transfer from research to commercialisation. Academic actors such as universities or RTOs provide fundamental research on different focal points like specific materials or processes, or social research on the possible effects of a new technology on society. They often further act as accelerators of project creation.

The interplay of a diverse set of actors in a GIN enables the mapping of all stages of the R&D&I chain. At the same time, the case studies reveal that R&D&I is often performed by all partners at different stages of the innovation process. For confidentiality reasons, a detailed description of the technologies developed within the examined GINs is not possible, but all addressed technologies contribute towards a green or sustainable transformation. Relevant technologies in the mobility industry in which the GINs are active are, for instance, renewable fuels, such as the production of e-fuels for the aviation industry and alternative powertrains in e-mobility. In the chemical industry, the addressed GINs are performing R&D&I in the areas of technical gases with a focus on hydrogen for the transportation industry, methane pyrolysis to dissociate hydrogen and carbon or recycling technologies, e. g., for batteries.

The development of sustainable technologies is crucial for decarbonising our economy (European Investment Bank, 2021). Technologies can often affect more than one principle of the European Green Deal, but significant potential to all targets of the European Green Deal can be expected from the various technologies addressed. The interviewees underline a significant growth potential in the markets related to their technologies. This growth potential is linked with expectations on policy conditions pushing the demand for 'green solutions'. Since most technologies addressed are related to the companies' key business areas, market growth can enable turnover and profit increases for the companies at large.

There are still some aspects that inhibit the growth expectations of GINs. R&D&I projects are often accompanied by high risk, although being organised in a GIN allows to spread and reduce risks. Our case studies reveal that policy regulations are seen as a chance to further accelerate an environment that leads to growth. As most of the policy conditions related to the Green Deal are rather new, their growth effects are seen as insecure. According to the interviewees, existing policy conditions act as enabler for the GINs and their related technologies. The EU Green Deal itself is particularly seen as enabler as it provides an important signal which holds for the net-zero target. Environmental regulations, such as the EU ETS, are seen as a negative impact on conventional technologies and businesses and, therefore, benefit actors that are active in sustainable branches. Certain financial guidelines and funding instruments are seen as beneficial for the transformation towards a sustainable economy, such as Carbon Contracts for Difference (CCfD) or the EU Innovation Fund. The interviewees stress that public and private funding is an important aspect for the success of an emerging technology. Most of the projects considered are partly funded by public authorities. Some actors noted the existence of uncertainties in their environment negatively impacting investment activities in sustainable technologies. From this, a need for improving the dialogue between stakeholders can be derived. Involving all relevant actors can increase the permeability of regulations.

The main drivers for investing in technologies relevant for Europe's Green Deal are climate change, the need for the transformation of industries, new regulations, the expectation of competition and new business opportunities. 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 is, according to the interviewees, in general strongly supported by industrial companies. There is a need to further clarify and coordinate particular framework conditions related to multi-level governance with the respective member state strategies. The application of hydrogen supply in energy intense industries for instance needs policy support in the short- to medium-term to ensure international competitiveness. Market shaping in democracies for sustainable industries 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 China are certainly in a different position since acceptance in economy and society is not necessarily needed.

3.4 Policy implications for the EU

3.4.1 Policy context and framework conditions

The technologies the GINs tend to focus on within the case studies are to a certain degree related with the European Green Deal. The case studies and interviews with company representatives not only show strong support from industrial companies for the European Green Deal, but also a demand for new types of policy instruments. As we outline in more detail in Section 3.4.2, this can be subsumed on a conceptional level as an increasing demand for anticipation-based policy.

Regulations

The existing policy context acts as enabler for GINs and their related technologies. According to the interviewees, policy tools sometimes have no visible impact on the acceleration of the technologies' market entry. The European Green Deal itself is seen as enabler since it provides important signals, especially for the net-zero target. Furthermore, regulations are seen as having a negative impact on conventional industries such as the EU ETS, which raises the price for CO_2. According to most interviewees regulations additionally lead to benefits for sustainable and transformative industries. Most 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, and it is often not clear whether regulations act as a market barrier or enable growth for the concerned industry. Generally, regulations for recycling and materials technologies are seen as enablers for growth. It was mentioned that without a push for electric vehicles 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 also provide 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 industry. As improvements to existing policy instruments to support a development towards more climate neutral production and R&D&I, it is suggested that the EU should formulate and communicate clear objectives that must be reached (e. g. specific share of renewables in specific industries).

The policy instruments regarding sustainable technologies are considered useful on both a national and international level. 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 start the 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.[9] The interviewees stress that public and private funding is an important aspect for the success of emerging technologies linked with the European Green Deal. Most projects analysed in this study are partly funded by public authorities.

To achieve a carbon neutral industry, an increased availability of renewable energy is needed, including low emission hydrogen in large amounts and at economically feasible prices. The interviewees stressed that the more affordable renewable energy becomes available to industry, the more carbon-free technologies can be introduced into production processes. Climate ambitions and carbon pricing policies would as such need to rise globally at a similar level to avoid developing market disruption and complicated export strategies. EU-wide funding structures could help MNEs and SMEs shift investment priorities to sustainable technologies. According to the interviewees, there is currently no effective EU-wide policy framework connected to economic and financial transfers that allow for the industrial transition. The EU emissions trading system (EU ETS) ensures a reduction of carbon emissions but risks driving 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 technologies. It was underlined that a carbon border adjustment mechanism can only be an improvement if competitiveness both on the EU market and for exports can be assured, and if there is full protection along the whole value chain up to end consumer products.

Soft instruments
Concerning the existing policy instruments regarding the development towards a climate neutral production, it is suggested to improve the dialogue between all necessary stakeholders as one soft instrument. Besides this, partnerships are seen as a second soft instrument needed to be able to jointly address the challenges of the European Green Deal. Furthermore, some interviewees stated that the speed of starting and stopping R&D&I activities has to increase in a more dynamic, agile and responsive system. It is also stressed that every state and 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.

3.4.2 Policy instruments for supporting technologies relevant for Europe's Green Deal

Following the discussion on the necessity of identifying why and how the current European policy toolbox can be strengthened, this section provides an outline of options for adjusting and expanding current instruments for EU industrial and innovation policies. The interviewees de-

[9] 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 lan-guage (EU Taxonomy) could enable knowledgeable decision-making to foster investment in environmentally sustainable activi-ties and technologies like hydrogen.

scribe the need for stronger anticipation-based policy. In the following, we therefore suggest an anticipation-based policy toolbox. The toolbox proposes instrument categories and their combinations in new or adjusted policy instruments. In addition, it 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.

As described by the European Commission (2020) in its new Industrial Strategy, efforts at the European level need to be matched by national and regional reforms. There is a need to join forces behind a holistic and comprehensive strategy for industrial competitiveness linked with anticipation-based policy and the options for policy instruments discussed above. The three classic categories of policy instruments – regulations, economic and financial instruments, and soft instruments – are usually discussed separately from each other. In the future there is a need to combine them in a so-called 'three-in-one instrument' (Figure 11). Such 'three-in-one instruments' are already being used in an experimental way at the national level. This phenomenon can also be found to a certain extent in Public Private Partnerships and innovation alliances on the European level.

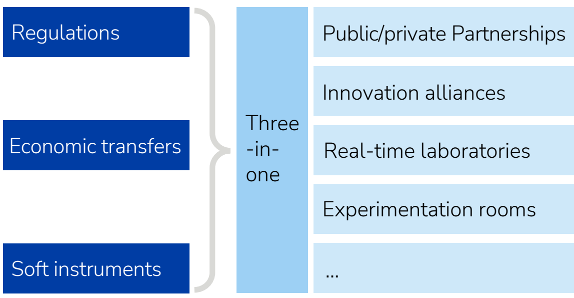

Figure 11: Innovation and industrial policy instruments – three-in-one

Germany, for instance, is experimenting with two new innovation and industrial policy instruments at the national level (Bullinger & Malanowski, 2021). These real-world laboratories and experimentation 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 as trials in Green Deal related fields like hydrogen and batteries. They aim at regulating and promoting measures (such as public funding programmes) as well as dialogue processes. Real-world laboratories and experimentation rooms differ in a few key points: the former currently either focus on energy transition with a targeted focus like hydrogen or 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, on the other hand, 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. Both in practical tests and in 'laboratory environments', partly determined ex ante and partly as an (interim) result of the experimental work, regulatory issues are raised and dealt with.

Side note

Real-world laboratories or experimentation rooms are expressions of the proactive use of new anticipation-based innovation and industrial policy. Real laboratories and experimentation 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. 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 flexibly to changing requirements resulting from the European Green Deal.

4 Conclusions

While pushing its Green Deal, Europe's innovation and economic conflicts with the US, China and Russia will become more prominent. The US and China are in competition with one another for supremacy in emerging technology and economic fields. The protection of new green technologies and markets have the highest priority. Both countries are already quite open about their disputes with one another, but also with the EU – the US, e. g., by establishing trade barriers to protect their own economy, China, e. g., by restricting FDI domestically or by enacting new laws to protect new technologies. For the EU, this implies that emerging green technology fields, their development and their market implementation have to be increasingly associated with new or modified innovation and industrial policy instruments.

This paper examined the EU's R&D&I competitiveness and European centric Global Innovation Networks in the framework of the European Green Deal. Research was focused on two identified Green Deal priority areas, the mobility and the chemical industry, and two cross-sectoral areas, hydrogen and batteries. Furthermore, it was discussed why and what kind of policy instruments are needed in the market-shaping and mission orientation policy approach followed by the EU for strengthening the chemical and the mobility industry.

The EU certainly has a strong competitive position within the two analysed Green Deal priority areas, especially when focusing on R&D expenditures on country level. Yet, on company level, Japanese companies have higher R&D expenditures in the industrial sector. Although Chinese company expenditures are, compared to other industries, relatively modest, Chinese companies have displayed a high growth in R&D investments over the past years. If this trend continues, Europe might face strong competition from non-EU actors. With respect to funding, US-based start-ups are best equipped in most industries. In terms of patenting activities, Japanese and EU companies are strong key players in the two selected Green Deal priority areas.

The EU is well positioned in mobility, where established EU companies are ranked highest in terms of R&D intensity as well as in total R&D investments on both country and company 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 amount of average funding, followed by Japanese start-ups. In the chemical industry, EU companies are highly prevalent among the top R&D investors. EU companies also display the highest R&D investments on country level. On company level, R&D investments in the industrial sector are highest for Japanese companies.

Forming part of a Global Innovation Network (GIN) is beneficial for companies since it enables engagement with different stakeholder types and provides access to a diverse skill set, reduces investment risks by spreading efforts and promotes synergies between specific areas towards a wider research and innovation area. This form of organisation has a positive impact on innovation activities. To further promote the development of climate neutral production within GINs, clear and coherent policy instruments that provide higher planning security are needed.

Several factors that are enabling or hindering innovation policy supporting the sustainable transition have been identified. In the current EU policy context, regulations are seen by a few business actors as having negative impact on conventional business, such as the EU ETS, which increases the price for CO_2 leading to less competitiveness for CO_2 intensive business models. At the same time, an appropriate regulatory framework is seen by several business actors as the cornerstone of the new industrial 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 the EU needs to be improved. Economic and financial guidelines are beneficial for the transformation towards a sustainable economy.

A systematic mix of policy instruments that supports companies in their transition is required. Instead of just focusing on the three classical categories of innovation and industrial policy instruments (regulations, economic and financial instruments, and soft instruments), it is suggested to include '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. New industrial strategy efforts at the European level should be aligned 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 an anticipation-based policy strategy and the options for policy instruments discussed in this article. For further research, this implies that the demand-side of future markets in transformative innovation and industrial policy has to be addressed in more detail. This also counts for the level of innovation and industrial policy in the current transformative process. "It cannot be a completely top-down … but it will not organically grow bottom-up either" (Boon & Edler, 2018, p. 11). Further research might focus on analysing where the appropriate spaces in-between top-down and bottom-up activities are. Participatory foresight exercises as part of innovation and industrial policy instruments might offer opportunities to enhance reflexivity and competitiveness as well as employment in transforming industries.

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5 Appendix

ICB code	ICB label	Green Deal relevant industry
1350	Chemicals	Industry
1357	Specialty Chemicals	
1353	Commodity Chemicals	
1750	Industrial Metals & Mining	
2757	Industrial Machinery	
1757	Iron & Steel	
1755	Non-ferrous Metals	
3353	Automobiles	Mobility
3350	Automobiles & Parts	

Appendix 1: Industry Classification Benchmark (ICB) – classes and their relation to Green Deal priority areas
Source: VDI Technologiezentrum / IDEA Consult based on FTSE Russell (2019) and EU Industrial R&D Investment Scoreboard

Green Deal priority area	Crunchbase search strategy		
	Crunchbase company classification ('Industry')		Crunchbase search strategy
Industry (chemicals)	'Chemical' or 'Chemical engineering'	And	'sustainable' or 'sustainability' or 'environmentally friendly' or 'green' or 'green-house gas reduction' or 'carbon reduction'
Mobility	'Electric vehicle'		
	'Automotive' and 'Fuel cell'		
	'Aviation' and 'Battery'		
	'Aviation'	And	'hydrogen'
	'Aviation' and 'Fuel cell'		
Batteries	'Battery'		
Hydrogen	'Chemical' or 'Energy'	And	'hydrogen'
	'Fuel cell'		

Appendix 2: Search strategy for the identification of relevant companies inside the Crunchbase database
Source: VDI Technologiezentrum

Level 0 class	Level 1 class	Level 2 class	Level 3 class	IPC patent class(es)	Industry
ENVIRON-MENTAL MANAGE-MENT	WASTE MANAGE-MENT	Material recovery, recycling and re-use	-/-	H01M 6/52	Batteries
CLIMATE CHANGE MITIGATION technologies related to ENERGY generation, transmission or distribution	ENABLING TECH-NOLOGIES IN ENERGY SECTOR	Energy storage	Batteries	Y02E60/12	Batteries
		Hydrogen technology	-/-	Y02E60/30-368	Hydrogen
		Fuel cells	-/-	Y02E60/50-566	Hydrogen
CLIMATE CHANGE MITIGATION technologies related to TRANS-PORTATION	ROAD TRANSPORT	Electric vehicles	Electric machine technologies for appli-cations in electromobility	Y02T10/64-649	Mobility
			Energy storage for electro-mobility	Y02T10/70-7094	Mobility
			Electric energy management in electro-mobility	Y02T10/72-7291	Mobility
	AIR TRANS-PORT	-/-	-/-	Y02T50	Mobility
	ENABLING TECH-NOLOGIES IN TRANSPORT	Electric vehicle charging	-/-	Y02T 90/10-169	Mobility
		Application of fuel cell and hydrogen technology to transportation	-/-	Y02T 90/30-38	Mobility/ hydrogen
				Y02T 90/40-46	Mobility/ hydrogen

Level 0 class	Level 1 class	Level 2 class	Level 3 class	IPC patent class(es)	Industry
CLIMATE CHANGE MITIGATION Technologies related to WASTEWA-TER TREAT-MENT OR WASTE MA-NAGEMENT	SOLID WASTE MANAGE-MENT	Reuse, recycling or recovery technologies	Recycling of batteries	Y02W 30/84	Batteries
			Recycling of fuel cells	Y02W 30/86	Hydrogen
CLIMATE CHANGE MITIGATION technologies in the PRO-DUCTION OR PROCESSING OF GOODS	TECH-NOLOGIES RELATING TO CHEMICAL INDUSTRY	-/-	-/-	Y02P 20	Industry (chemical)
		Reduction of greenhouse gas [GHG] emissions during produc-tion processes	-/-	Y02P 30/10	Industry (chemical)
	TECH-NOLOGIES RELATING TO OIL REFINING AND PETRO-CHEMICAL INDUSTRY	Carbon capture or storage [CCS] specific to hydrogen production	-/-	Y02P 30/30	Industry (chemical/ steel)
	TECH-NOLOGIES IN THE PRO-DUCTION PROCESS FOR FINAL INDUSTRIAL OR CON-SUMER PRODUCTS	Manufacturing of batteries and fuel cells	-/-	Y02P 70/54-56	Batteries/ hydrogen
CLIMATE CHANGE MITIGATION technologies related to BUILDINGS	ENABLING TECH-NOLOGIES IN BUILDINGS	Application of fuel cells in buildings	-/-	Y02B90/10-16	Hydrogen

Appendix 3: Patent classes from OECD patent classification with relevance for Green Deal priority areas
Source: OECD (2016) and own selection based on Green Deal priority areas identified

Recommended citation
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