EUROPEAN
COMMISSION

Brussels, 23.3.2023
SWD(2023) 68 final

COMMISSION STAFF WORKING DOCUMENT

Investment needs assessment and funding availabilities to strengthen EU's Net-Zero technology manufacturing capacity

EN EN

EXECUTIVE SUMMARY

Fostering a competitive and resilient European net-zero industry can play a significant role in reducing high import dependence for key net-zero technologies, while guaranteeing affordable, reliable, and sustainable clean energy. In the Commission Communication on a Green Deal Industrial Plan for the Net-zero Age of 1st February 2023, the Commission referred to a needs assessment with a view to mobilising and rechannelling more investments for the manufacturing of net zero technologies at EU level.

This Staff Working Document has been finalised in light of the Net-Zero Industry Act (NZIA) legislative proposal and, as such, it focuses on the manufacturing capacity of EU producers of net-zero technologies. This Staff Working Document is divided into two parts.

Part I estimates investment needs associated with boosting EU manufacturing capacity for a part of strategic net-zero technologies, focusing on wind, solar PV, heat pumps, batteries, and electrolysers. The assessment is based on the European demand created by the ambitions of the Fit for 55 Package and REPowerEU. It considers 3 scenarios:

1) A Status quo scenario: The current market shares of EU manufacturing of these NZ technologies remain the same up to 2030. Maintaining the current market shares in the current global competition context will already require substantial efforts given the high growth in deployment demand, and the pressure on the EU trade balance in areas like wind technologies and heat pumps, i.e. such a status quo scenario of growth in line with the market cannot be taken for granted as the likely trajectory in an unchanged policy environment..
2) NZIA policy scenario: The EU manufacturing market shares of these technologies are boosted to reach the indicative technology-specific objectives outlined in the recitals to the Net-Zero Industry Act Proposal.
3) NZIA+ scenario: EU manufacturing capacity meets all EU demand for these technologies, which could translate into the EU gaining a higher global market share.

For each scenario, the assessment estimates the cumulated investment needs over the period 2023-2030 to obtain the corresponding additional manufacturing capacity. The assessment also considers the possible range of public support that would be necessary to generate the projected total investments. Finally, the section addresses investment needs related to skills.

The analysis indicates that in the NZIA policy scenario, the accumulated investment needs amount to around EUR 92 billion over the period 2023-2030, with a range between about EUR 52 billion in the status quo scenario to around EUR 119 billion[1] in the scenario with no dependence on imports. The following caveats need to be applied to these figures:

- They represent investment needs only for a part of the net-zero technologies listed in the annex of the Net-Zero Industry Act, excluding solar thermal, tidal and wave

[1] The estimate of EUR 119bn for the EU compares with the USD 149bn for Europe (which includes UK, NO, CH and western Balkans) to meet the clean energy demand in 2030. (BloombergNEF, Europe's New Clean Industrial Strategy Falls Flat, February 10, 2023).

technologies, storage other than batteries, geothermal, fuel cells, biogas and biomethane technologies, grid technologies.

- They are subject to a number of uncertainties, in particular related to the deployment figures applicable to those 5 technologies. This notably relates to the projected deployment of batteries, where the industry projects much higher figures than the models and literature on which this assessment is based.
- Up- and downstream supply chains (e.g. raw and processed inputs) are beyond the scope of NZIA[2] and are not covered in the investment needs in manufacturing capacity.

Taking the above into account, the core estimate of **EUR 92 billion investment needs until 2030 is therefore likely to be at the lower end of the range.**

To be noted, for transparency's sake, that, if one were to use the industry projections for battery deployment as high as 1000 Gwh, this would increase the overall 2030 manufacturing investment needs assessed for batteries in the NZIA policy scenario by around 60%. These numbers are included simply to illustrate the industry claims; while they exceed the amounts supported by the Commission services' analysis, they tend to confirm the prudent character of the latter.

To determine the respective share between the **public and private sector investments**, this Staff Working Document reviews the different programmes, approaches, and multipliers of past programmes.

As a proxy based on estimates that cover a much broader range of interventions linked to energy and climate, one could apply a ratio of 17-20% of required public investment. If this ratio is applied to the NZIA policy scenario, which identifies EUR 92 billion in investment needs, it would result in **public funding requirements of EUR 16 – 18 billion**. A higher level of support may be warranted given the need to ensure the competitiveness of EU net-zero industry and a fast roll-out of net-zero technology manufacturing capacity for the support of the EU climate goals. Additionally, third countries are rolling out support schemes that aim at anchoring and attracting clean tech industry (cfr. Annex 4) which presents a competitive challenge for the EU to maintain and develop its own industry.

Such a proportion of 17-20% of public investment may be regarded as a prudent basis for calculation in the EU context, against the background of the support levels in other jurisdictions[3].

[2] NZIA applies to final products, specific components and specific machinery primarily used for the production of those products. It may be noted, on the other hand, that the Temporary Crisis and Transition Framework for State Aid also applies, as regards a subset of technologies within the scope of NZIA, to the related critical raw materials.

[3] Based on Commission internal calculations, the average aid intensity for manufacturing capacity related to green hydrogen, batteries, solar PV, and wind turbines under the US IRA, for example amounts to 40%. That figure is based on the provisions related to OPEX support under the Advanced Manufacturing Tax Credit and a comparison of current production cost for the respective technologies, which is subject to a number of uncertainties. The two market contexts are not fully comparable, as the demand pull for deployment of such technologies is likely weaker in a market where fossil energy prices are structurally lower, carbon emissions are not priced as under the EU's ETS system and a policy framework such as that of Fit for 55 and REPowerEU did not previously exist. To be noted that in the EU Temporary Crisis and Transition Framework of March 2023 (C(2023) 1711 final) provides, under specific conditions, the possibility of aid for the production of a number of net-zero technologies with 15% to 60% intensity, depending on the area where the project is located, including 5% bonus if it is a tax credit or loan and 20% top-up for SMEs.

Part II addresses the available EU funding for the net-zero transition covering innovation, manufacturing, and deployment, as well as the availability of individual EU programmes and programmes implemented by EU Member States. It finds that currently, most EU funding is geared to innovation and deployment. More specifically the following amounts could be identified within the relevant EU financing programmes over the period of the current Multiannual financial Framework (2021-2027):

- Up to EUR 36 billion for the upstream R&D development of net zero technologies;
- Up to EUR 124 billion for the downstream deployment of the net zero technologies;
- **Up to EUR 8 billion could be available for supporting first-of-a-kind installations and net-zero technology production plants.**

The latter is however a theoretical maximum, that does not fully account for the fact that the programmes in question are demand-driven and/or target a wide range of policy objectives. Accordingly, for several programmes, assumptions had to be made regarding the amount that might be allocated to the net zero technologies targeted by this document, as the actual amount will depend on the choices by the Member States' authorities managing the funds concerned or the demand coming from applicants.

This breakdown reflects the design of the EU funds, which focus predominantly on the early stages of technological development and on the uptake stage of these technologies by downstream users. Among the EU funds, only a few can currently cater for support to strengthen manufacturing capacities (such as the Innovation Fund – mostly for first-of-a-kind installations, REPowerEU package under RRF or financial products established under the InvestEU Programme, and the Modernisation Fund). Most of the identified possible support to manufacturing capacity tends to be limited to small companies, e.g. EIC Accelerator, Structural funds, and others.

Moreover, it should be recalled that the investment needs necessary to boost the EU manufacturing capacity of five key net-zero technologies are only part of the overall investment needs to deliver on the Green Deal and REPowerEU objectives. The additional private and public investment needs in relation to the green transition are estimated at EUR 477 billion per year between 2021 and 2030[4], whereas delivering the REPowerEU objectives requires an estimated additional investment of up to EUR 35 billion per annum between 2022 and 2027.[5] In view of these extremely challenging overall investment needs, the scope for reallocating to net-zero manufacturing support part of the available EU financial support currently foreseen for upstream development or deployment is probably limited.

In light of the above it becomes apparent that, while funding possibilities have recently increased, the current EU budget has insufficient possibilities for supporting the objectives of the Net-Zero Industry Act and for ensuring a level-playing field between Member States, relative to the identified public investment needs.

[4] From those additional investments, EUR 272 billion per year correspond to the decarbonisation of the energy sector, including energy-related investments in the buildings and transport sectors, such as investments in the power grid, power plants, industrial boilers and new fuels production and distribution, investments in building insulation, and energy renovation. Additional transport-related investment is estimated to be about EUR 205 billion per year. See Table 9 in Annex 2.

[5] Communication from the Commission to the European Parliament, the European Council, the European Economic and Social Committee and the Committee of the Regions, REPowerEU Plan, COM(2022) 230 final, p. 12.

Last but not least, **Annex 4 includes an analysis of the state of play in markets and technology for several key EU net-zero technology manufacturing industries**. It finds that the competitiveness of the EU net-zero industry varies across key net-zero technologies and their supply chains. For **several steps in the supply chain there are significant security of supply vulnerabilities and risks.**

For wind, European wind manufacturing currently accounts for 85% of domestic wind farm production, but higher deployment rates until 2030 require further expansion of manufacturing capacity, taking into account the need for rare earths and potential supply chain bottlenecks. Regarding solar, while the EU has several world-leading R&D clusters in solar PV production, the high dependence on imports from China in ingots & wafers, cells, and modules manufacturing poses a risk for EU's security of supply and the economic viability of its solar industry, with potential adverse repercussions on its energy system resilience and decarbonisaton objectives. For batteries, in the EU, a high demand for stationary and EV batteries is projected in the coming decades but battery manufacturing depends on third countries for sourcing raw materials and lithium refining. EU heat pump manufacturing covers around 73% of today's EU heat pump needs but current shortages of labour and an increasing share of extra-EU imports pose a potential risk for the resilience of the sector. Finally, regarding electrolysers, Europe is technologically advanced with a good presence in, e.g., Polymer Electrolyte Membrane (PEM) electrolysers, but higher cost of production in comparison to third countries and dependence on concentrated supplies of critical raw materials pose a risk for the resilience of the supply chain related to electrolyser production.

For CO_2 capture Europe holds a leading position in terms of CO_2 capture technologies and usage in industry, but the unavailability of operating storage sites is a bottleneck to set up such decarbonisation value chains, which would allow industries with hard-to-abate emissions to decarbonise. The EU would need at least 50 Million Tonnes per year of CO_2 storage capacity available by 2030 to meet demand associated with carbon capture projects under development

Concerning grids, besides the network expansion and upgrade needs required for the decarbonisation of the power system and which entail significant amounts of mostly imported materials, such as copper and aluminium, a major risk related to missing grid capacity is the creation of congestions in the grid, often resolved via expensive and CO_2-emission intensive re-dispatch measures, which could undermine the achievement of EU climate targets. However the smart electricity grid technologies enable a better management of electricity transmission and distribution networks, including congestion management, especially as the electrification of various sectors will progress. In this respect, the market for smart metering solutions in Europe is highly competitive. Furthermore, an increasing trend for industrial installations is the autonomous production of part of the energy they need for their operations using net-zero technologies, for which their integration in the energy grid as producers is important. As for biomethane, the EU has a strong position in the global biogas and biomethane market, with several biogas upgrading technologies to biomethane available developed by EU companies. Nonetheless these technologies display high investment costs related mostly to the manufacturing of the biogas production plant and upgrading section. There is limited availability of waste feedstock partly due to competition with alternative uses of feedstock. Moreover, there are additional capital expenditures for grid injection, with many facilities being small scale and presenting complex logistics.

How do the manufacturing investments compare to the other types of investments?

The investment needs assessments exclusively refer to investments in capital expenditures (Capex) to expand existing manufacturing capacity or build new facilities for the respective five net-zero technologies. They include investments into the manufacturing stages of main components and technological assemblies (e.g. ingots/wafers, solar cells, and modules to produce solar PV panels).

In the development, production, and deployment cycle, various types of other costs and investment needs can be distinguished that are dealt with in various other EU policies and funds, The manufacturing investment needs, therefore, represent only a part of the necessary investment. Other types of investment and costs that do not fall within the scope of the three scenarios (Section 3) include:

- Deployment investments to install the necessary technologies for the ambitions of the Green Deal transition (for an overview see Table 10 and Table 11);
- The investment needs of other manufacturers further upstream in the supply chain beyond the scope of NZIA[2] (e.g. covering raw and processed materials), as well as infrastructure investments;
- Investment needs for technologies that fall beyond the scope of the analysis (PV solar, wind, heat pumps, batteries and electrolyzers);
- R&I investments that are injected in the various technology development stages in order to reach a sufficiently high Technology Readiness Level for commercialisation;
- Investment needs related to attracting, reskilling, upskilling, and maintaining the workforce are assessed separately in Section 4;

The production costs of manufacturing (‘OPEX’), such as input costs (e.g. processed materials), are also outside the scope of this assessment. Annex 4 gives an overview on how other major economies support net-zero technologies (incl. OPEX).

PART I: NEEDS ASSESSMENT

1. Context and objectives

In its conclusions of 15 December 2022, the European Council underlined the "*importance in the current global context of an ambitious European industrial policy to make Europe's economy fit for the green and digital transitions and reduce strategic dependencies, particularly in the most sensitive areas, while ensuring a level playing field*" and invited the Commission to conduct an analysis and make proposals.

This SWD provides an analysis of the status quo of EU's net-zero industry and its contribution to clean energy deployment needs and greenhouse gas emission reductions; its strengths, weaknesses, opportunities, and threats, when placed within a global supply chain perspective, as well as the investment needs that would be required to strengthen the European manufacturing capacity of net-zero technologies and help deliver on the Fit for 55 and REPowerEU objectives. Both security of supply and price competitiveness aspects are covered. It has been finalised in light of the Net-Zero Industry Act (NZIA) legislative proposal and, as such, it focuses on the manufacturing capacity of EU producers of net-zero technologies.

Across the supply chain of net-zero industries, the EU's significant dependency on imports of critical raw materials and components necessary for the low-carbon transition, coupled with potential global supply disruptions, political instability, concentrated sources of supply, international price volatility, and long lead times may result in shortages of clean energy technologies, which could pose a considerable risk for the Union's energy security and its decarbonisation ambitions. As such, this document looks at how the EU can increase its manufacturing capacity and, as part of a broader diversification strategy, create conducive conditions for its industries producing more of the materials, machinery, and components that make net-zero technologies operational.[6]

This SWD has been finalised to accompany the Net-Zero Industry Act, and it is complementary to other relevant Commission legislative initiatives, such as the Chips Act Regulation proposal[7] and the Critical Raw Materials Act Regulation proposal.[8] Furthermore, this SWD explores the investments needed to strengthen and boost the EU's manufacturing capacity of strategic net-zero technologies in order to meet EU's climate and energy targets, reduce vulnerabilities in the supply chain and improve security of supply perspectives, and enhance energy system resilience, as also promoted under the various EU industrial alliances.[9] The annexes of this SWD provide the underlying methodologies.

---

[6] Strengthening EU's manufacturing capacity of net-zero technologies does not preclude seeking win-win partnerships (e.g. within the framework of the Global Gateway strategy which could further contribute to the diversification of supply chain.

[7] Proposal for a Regulation of the European Parliament and of the Council establishing a framework of measures for strengthening Europe's semiconductor ecosystem (Chips Act), COM/2022/46 final

[8] Proposal for a Regulation of the European Parliament and of the Council establishing a framework for ensuring a secure and sustainable supply of critical raw materials, COM/2023/XX final

[9] Such as the European Solar Photovoltaic Industry Alliance, the European Battery Alliance, and the European Clean Hydrogen Alliance, amongst others.

2. Market for net-zero technologies

2.1 The global market for manufacturing net-zero technologies

Globally, investments in the energy transition reached a milestone in 2022, as it was the first year when they surpassed the USD 1 trillion threshold, with renewable energy and electrified transport accounting for the lion's share.[10] Investment in the manufacturing of net-zero technologies and their supply chains (solar, wind, batteries, electrolysers) in 2022 grew to almost USD 80 billion, with investments in producing batteries and related components representing the largest share (USD 45.4 billion), followed by solar factories (USD 23.9 billion) (Figure 1).[11]

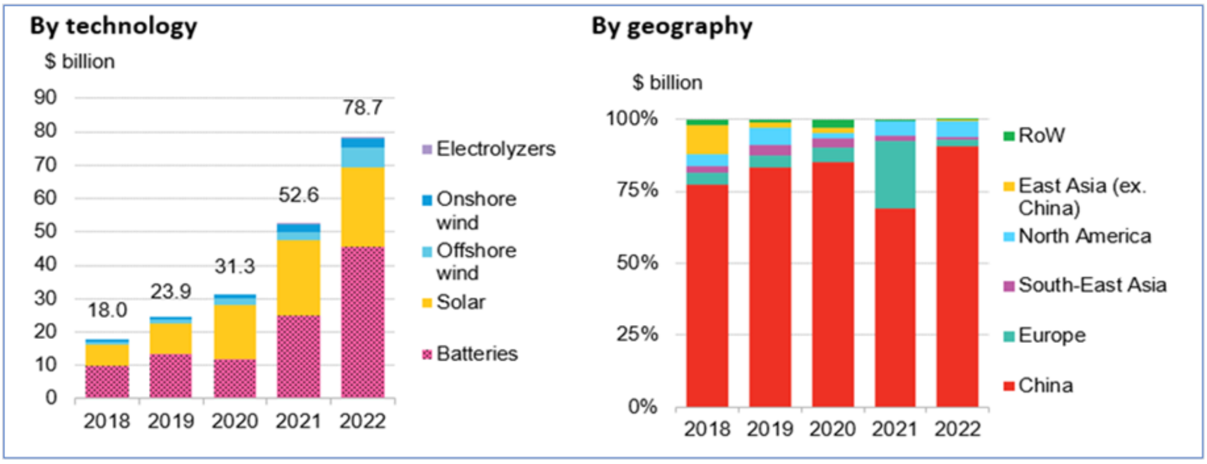


Figure 1: Investments in manufacturing of clean energy technologies. Source: Bloomberg NEF.

Notes: Sectors include upstream inputs and components, such as polysilicon for PV and anodes for batteries, although there were no electrolyser investments recorded before 2022. The right-hand chart does not include wind.

There are significant gains for economic growth and employment to be made from mass-manufacturing net-zero technologies for decarbonising the world economy. For instance, if countries worldwide fully implement their announced energy and climate pledges, related clean energy manufacturing jobs could more than double from 6 million today to nearly 14 million by 2030, with over half of these jobs attributed to the expansion of the electric vehicles, solar PV, wind, and heat pump industries.[12] According to the International Energy Agency,[13] to decarbonise the world economy, total investment in clean energy technologies and infrastructure must reach over USD 4.5 trillion in 2030. Global production of electric vehicles increases 15-fold to 2050, while the deployment of renewables nearly quadruples. Deployment of heat pumps increases more than six times in 2050 compared to today, and production of hydrogen from electrolysis or natural gas-based hydrogen with carbon capture and storage reaches 450 Mt in 2050. This translates into global cumulative manufacturing

[10] According to BloombergNEF (2023) "Tracking energy transition investment trends 2023", global investments in renewable energy, electrified transport and heat, energy storage, and other technologies reached USD 1.1 trillion by end of 2022, equalising global investments in fossil fuels and USD 1.38 if investments in the power grid are included).

[11] Based on BloombergNEF (2023) "Tracking energy transition investment trends 2023"

[12] IEA (2023) "Energy Technology Perspectives 2023", International Energy Agency

[13] IEA, Energy Technology Perspectives 2023.

investments of USD 1.2 trillion required to bring enough capacity online for the clean energy technology supply chains to be on track with the global 2030 targets, out of which USD 640 billion for six clean energy technologies (wind, solar PV, EV batteries, electrolysers, heat pumps, and fuel cell trucks).[14] Most investments in clean energy supply chains need to happen in the coming two years (because of project lead times), at an average of USD 270 billion per year, which is nearly seven times the average rate of investment over 2016-2021.[15] Manufacturing capacity at the global level is found not to be a major bottleneck in the short-term as existing manufacturing capacities are sufficient to meet the bulk of demand (especially for solar PV and electrolysers).[16] However, there are major geographical distribution constraints in terms of very limited supply chain diversification, as China accounts for 90% of investments in manufacturing facilities (up from an average of around 80% over 2018-2021).[17]

China is currently the leading global supplier of clean energy technologies today and a net exporter for many of them, holding at least 60% of the world's manufacturing capacity for most mass-manufactured technologies (e.g. solar PV, wind systems and batteries), and 40% of electrolyser manufacturing (Figure 2).[18] Europe, on the other hand, is typically a net importer of clean energy tech, with about one-quarter of electric cars and batteries, and nearly all solar PV modules and fuel cells are imported, with an exception being wind turbine components for which European manufacturers have a stronger international business, installing around 65% of their output in other regions, where they have built local manufacturing facilities.[19] Concerning battery production, through the European Battery Alliance, the EU is also increasingly developing its supply chain although more needs to be done as regards the dependencies on raw materials. Regarding heat pumps, global manufacturing capacity (excluding air conditioners), according to the IEA, amounted to around 120 GWh at the end of 2021, being dominated by China (almost 40% of total capacity), North America (30%), Europe (15%), and other Asia Pacific (over 10%).[20]

[14] IEA (2023) "Energy Technology Perspectives 2023", International Energy Agency. The rest of investments covering around 45% of the total refer to other technologies that are key to decarbonisation such as energy efficiency technologies, grid technologies, biomass/ biogas technologies or hydropower technologies,

[15] IEA (2023) "Energy Technology Perspectives 2023". Announced investments cover around 60% of this estimated total of USD 1.2 trillion cumulated investments 2023-2030.

[16] BloombergNEF (2023) "Tracking energy transition investment trends 2023"

[17] BloombergNEF (2023) "Tracking energy transition investment trends 2023"

[18] IEA (2023) "Energy Technology Perspectives 2023"

[19] IEA (2023) "Energy Technology Perspectives 2023"

[20] IEA (2023) "Energy Technology Perspectives 2023"

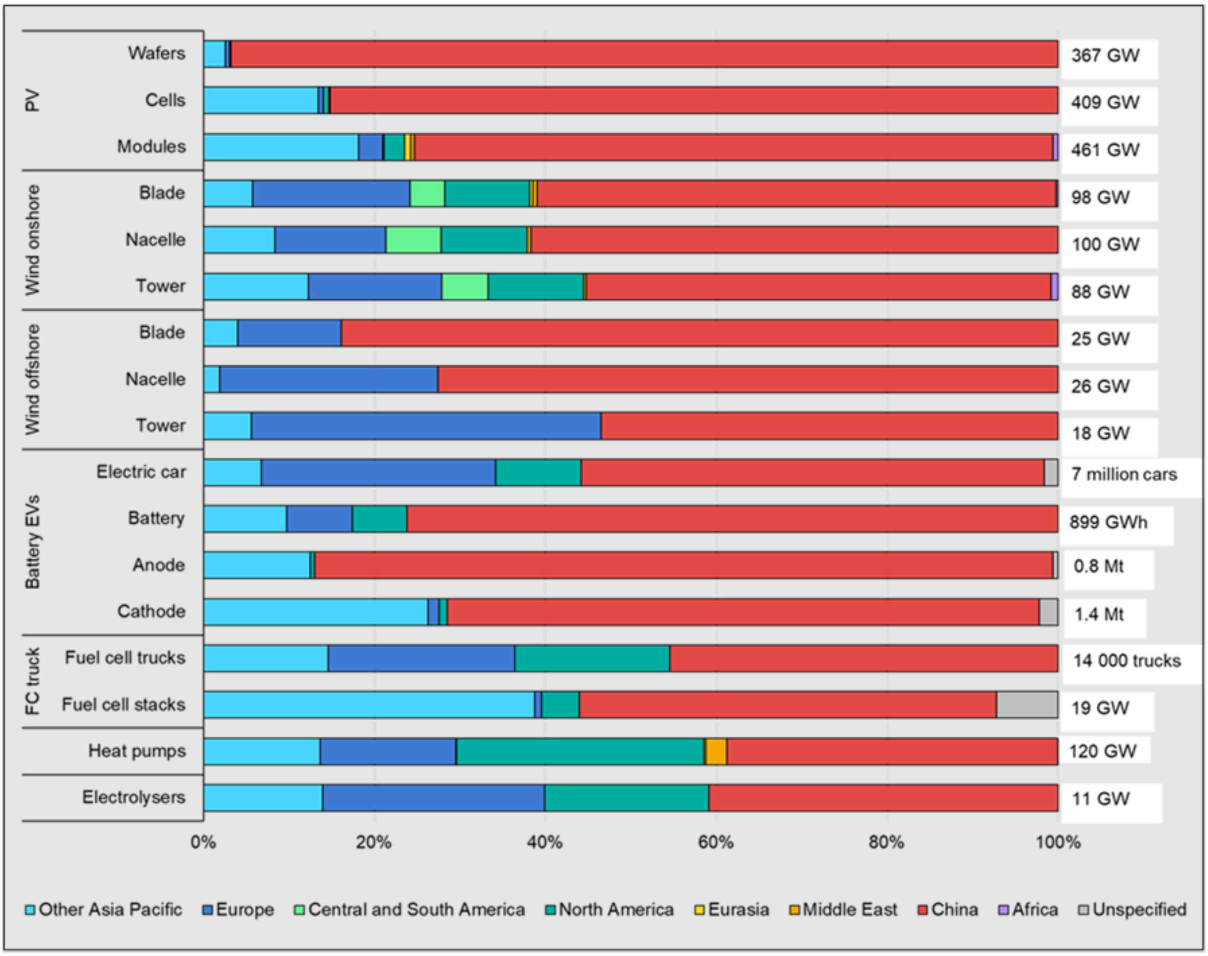


Figure 2: Regional shares of manufacturing capacity for selected mass-manufactured clean energy technologies and components. Source: Energy Technology Perspectives 2023, International Energy Agency

2.2 The EU market for manufacturing net-zero technologies created by the Fit-for-55 package and REPowerEU climate and energy policy objectives

Achieving the climate, pollution-prevention and energy policy objectives of the Fit for 55 package requires significant investments in the energy system and transport sector (in this case, vehicles and charging/refuelling infrastructure) in the period 2021-2030[21]

The Commission estimated that meeting the objectives of the Fit for 55 package would require annual investments of about EUR 487 billion in the energy system and EUR 754 billion for transport[22] in the 2021-2030 period[23]. In particular, annual investments in the energy system are estimated to be EUR 272 billion higher, or 127% higher, in 2021-2030 compared to the 2011-2020 period. Similarly, the transport sector will need to invest EUR 205 billion per year more than in the previous decade, and the industry has to almost triple

[21]The targets set are reproduced in Table 10in Annex.

[22] Transport investments include the full cost of the new vehicles and the charging infrastructure.

[23] SWD(2021) 621 final

their investments to reach the estimated EUR 34 billion per year to achieve the Fit-for-55 targets (see Table 9 and Table 10 in Annex 1).

On the energy supply side, these investments include the electricity transmission and distribution network, power plants and the production of hydrogen and renewable and synthetic fuels. On the energy demand side, this includes energy efficiency and renewable energy investments in the tertiary and industrial sectors[24], investments in energy renovations and heating systems of buildings, district heating and cooling systems, as well as in energy efficient household appliances to deliver Zero Emission Buildings. For transport they cover investments into new vehicles and recharging and refuelling equipment[25].

These investments on the supply and demand sides cover all cost items required for the manufacturing and installation of relevant equipment, including energy, labour, commodities, intermediary input, and the capital expenditures (CAPEX), but do not differentiate whether these supply chains originate from inside or outside the EU. Investment trends are expected to continue in the long term in order to reach the even more ambitious target of climate neutrality by 2050. The investment expenditures of Fit for 55 and RePowerEU remunerate the investments of the manufacturers abroad for the imported goods, and the investments of the manufacturers of EU produced goods. Scaling up EU industrial manufacturing, instead of imports, may lead to additional short-term costs to the extent that EU manufacturing is currently more expensive than certain imported goods (in simple price terms, before accounting for quality, sustainability, and resilience factors).

In Europe, a market for CO2 storage services is gradually developing, starting from less than 2 million tonnes of CO2 being stored geologically per year today in the EEA. Due to the Emission Trading System (EU ETS) and a legal framework for the environmentally safe geological storage of CO2, a number of energy-intensive 'hard-to-abate' sectors (e.g. cement industry) are increasingly developing investment plans in CO2 capture, which are expected to reach a positive economic return before 2030 based on projected carbon prices. The annual demand for storage is expected to surpass 50 million tonnes of CO2 by 2030[26].

2.3 Competitiveness perspectives and security of supply concerns

The available literature, and insights from discussions with stakeholders provide a relatively varied picture of the EU manufacturing of net-zero technologies and their international competitiveness stance. However, for many key net-zero technologies produced in the EU, there are significant existing vulnerabilities or potential risks, for which warning signals have been triggered. Competitiveness and security of supply for net-zero technologies are interlinked in complex ways. While short-term cost-minimisation efforts may lead to temporary gains in competitiveness, a more diversified and risk-aware configuration of supply chains can ensure competitiveness in a more sustainable way. In addition,

[24] The required investment to decarbonise the core industrial production processes in the EU amounts to approximately EUR 5.1 billion per year. Source: European Commission, Directorate-General for Research and Innovation, ERA industrial technology roadmap for low-carbon technologies in energy-intensive industries, Publications Office of the European Union, 2022, p.53.

[25] Of the EUR 754 billion annual investments needs for transport over the 2021 to 2030 period, around EUR 46 billion would be needed for rail rolling stock and EUR 4.1 billion for public and private recharging and refuelling (for hydrogen) infrastructure.

[26] The preliminary findings of ongoing JRC study.

competitiveness needs to be seen from a more holistic perspective, as covering both the cost/price aspects and the quality/non-price dimension (e.g. sustainable, durable, high-performance, and reliable technologies, for which the EU has developed a solid track record). At the same time, as illustrated by PV production which is today more expensive in the EU than in other trading partners, building up manufacturing capacity in the EU to serve a greater part of deployment needs may lead to an increase of the cost of the energy and climate transition overall.

Solar cells and modules are an example of a "common dependency", where the EU and other global actors strongly depend on China's manufacturing capacities (exceeding 90% in certain upstream segments of the value chain, such as ingots and wafers). In 2021, global energy and raw material prices as well as increased transport and logistical costs, coupled with country-specific events have had a serious impact on the EU's import and deployment of solar PV panels, with stakeholders reporting that 20-25 % of planned EU solar projects were either postponed or cancelled entirely for these reasons.[27] There is a significant shortfall in EU manufacturing capacity in relation to solar PV deployment needs as envisaged in REPowerEU and the EU's Solar Energy Strategy, particularly for the ingot, wafer, cell, and module segments of the supply chain. The cost gap between China and the EU in relation to producing solar modules is currently estimated to be between 25 to 30 percent more expensive in Europe.[28] However, with increasing scale, capital and operational excellence, logistics savings, and technological advantage, amongst other factors, there are important strides to be made in improving the competitiveness of EU's solar industry. For instance, some analyses show that around half of the initial cost gaps to Chinese companies could be cut by reaching the critical mass of several GW for each solar PV component at plant level.[29]

The EU heat pump and wind markets, although led by EU manufacturers, are increasingly being challenged by Asian competitors. Nonetheless, there are several factors that have been signalled by the EU heat pump industry that may pose a supply risk, undermining the feasibility of sustaining the current EU heat pump deployment rate. These include increased import dependencies for some components (e.g. HFC refrigerants), the chip shortage, and limited financial capacity to invest fast in new production lines, among others. Volatile international prices for metals (copper, steel, aluminium, silver) are also a concern affecting competitiveness and security of supply. Air-to-air heat pumps for residential applications contain around 15-20 kg of copper, predominantly in their pipes and valves, making up roughly 10% of the overall cost of the device, whereas residential hydronic heat pumps typically contain more than twice as much aluminium and 15 times more copper and brass than their condensing gas boiler equivalents.[30] For components, the industry estimates that some companies entering the heat pump market experience delivery times exceeding 50 weeks, semiconductors (used in electronic controls and other parts) are already a bottleneck, and permanent magnets are a supply risk (as for other technologies), although EU legislative proposals already aim to address some of these (e.g. the EU Chips Act).

[27] EU strategic dependencies and capacities: second stage of in-depth reviews, SWD(2022) 41 final

[28] Based on McKinsey & Co. (2022) "The energy transition: A region-by-region agenda for near-term action".

[29] McKinsey & Co (2022) "Building a competitive solar-PV supply chain in Europe",

[30] IEA (2022) "The future of heat pumps", World Energy Outlook special report based on International Copper Alliance

The EU wind sector is one of the strongest players on world markets and the EU market is still led by domestic companies. However, Chinese manufacturers/providers/developers have recently been making in-roads and started to win auctions in Europe, and the EU wind industry is finding itself in an increasingly difficult financial position. Rare earth permanent magnets are critical to delivering high efficiency and performance levels of (especially offshore) wind turbines' electric generators. To meet REPowerEU and climate neutrality targets, the demand for permanent magnets and rare earth elements will see a five-fold increase by 2030 relative to current levels[31], which may act as a serious constraint for the European wind industry. The manufacturing of wind blades is also at risk, as EU industry estimates that its industrial capacity to supply the necessary glass and carbon fibre corresponds to an estimated 65% of the current EU wind energy market. The industry also warns of an expected under-capacity from the manufacturers of the offshore wind turbines' foundations. Foundations are largely composed of steel. Largely, for offshore wind, turbines, offshore cables, foundations, vessels and port upgrades, and the tidal and wave devices for ocean renewables, are the key areas where supply chain capabilities need to develop in order to meet the offshore renewable political ambitions of the EU.

Although the EU has a growing battery ecosystem, it does not have the technological production capacity required to meet the rapidly growing demand for production at giga factory level. The European Battery Alliance has identified a significant mismatch between capacity available upstream and downstream, with the main capacity gaps being for raw material refining, cathode production, and anode production. Part of the announced investments in battery cell manufacturing in Europe may also be at risk of not materialsing, as some companies may choose to re-evaluate their expansion strategies considering the international context and incentives provided elsewhere.[32] Furthermore, the battery recycling market in Europe is less mature than that of Asia, although both established and new players are seeing the potential in this emerging industry.[33]. In addition, investments are needed in production of manufacturing equipment, as Europe is today almost entirely dependent on the import of manufacturing equipment used in the battery industry, which generates additional trade dependencies and bottlenecks to the upscaling of giga factory production in the EU.[34] Nonetheless, the European Battery Alliance launched in 2017 has worked towards addressing some of these challenges. From a cost-competitiveness perspective, China's average costs for building new battery gigafactories (CAPEX investment costs) is around EUR 68 million for a GWh of new battery production capacity, whereas North American gigafactories are, on average, around 40% more expensive to build (e.g. due to higher inflation and interest rates), at an average cost of over EUR 94 million / GWh (although the cost of expanding existing

[31] Carrara, S., Bobba, S., Blagoeva, D., Alves Dias, P., Cavalli, A., Georgitzikis, K., Grohol, M., Itul, A., Kuzov, T., Latunussa, C., Lyons, L., Malano, G., Maury, T., Prior Arce, Á., Somers, J., Telsnig, T., Veeh, C., Wittmer, D., Baldassarre, B., Buesa, A., Black, C., Pennington, D., Christou, M., *Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study*, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/386650, JRC132889.

[32] For example, an analysis finds that around 16% of the total announced capacities for 2030 are at high risk of not coming online, whereas around 52% are at medium risk (Transport & Environment "How not to lose it all: Two thirds of Europe's battery gigafactories at risk without further action", T&E report, March 2023)

[33] European Battery Alliance "The sustainable future of batteries in Europe rests on a developed recycling industry", December 2022

[34] "European Battery Alliance (2023). *Fostering the global leadership of the European battery industry in the face of the Inflation Reduction Act and other recent challenges.* EBA Discussion Paper for the 7th High-Level Meeting of the European Battery Alliance. Published 1 March 2023. Available at: EBA_DiscussionPaper_Battery-Ministerial_01_03_2023.pdf (eba250.com)"

capacity is significantly cheaper, particularly on existing automotive production sites.[35] On the other hand, EU's costs for building new battery gigafactories average around EUR 100 million / GWh (investment costs for the cell producer largely including buildings and machinery to produce cells), which can increase to EUR 150 million for a GWh when investments in cathodes and anodes production are added.[36]

Regarding electrolyser production, the global technological lead of European companies in the manufacturing of electrolysers is slowly eroding as Asian and American competitors are catching up. Although the EU is currently a technological leader in the design of electrolysers, this technological leadership is challenged by China, which has the biggest share of planned electrolyser manufacturing capacity globally. In addition, the Inflation Reduction Act in the US is drawing further investment in the upscaling of manufacturing capacities . There is a real risk that a key technology in the EU's decarbonisation targets for energy-intensive industry is undermined by more favourable investment climates elsewhere that might lead EU manufacturers to focus their energies on upscaling their manufacturing capacities in China or the US to capture the growing renewable hydrogen markets there.

For developing sufficient CO2 storage capacity, the EU faces a market failure common in other emerging markets with limited demand and supply and heavy infrastructure capital investments. Despite the growing incentives from the EU ETS, the industries investing in CO2 capture face a significant risk of not being able to access a storage site, while CO2 storage operators face upfront costs to identify, develop and appraise storage sites even before they can apply for a regulatory permit that is necessary to operate. These costs are only justifiable if long-term storage customers can be secured early on. Both sides, suppliers and customers, therefore, depend on each other to kick-start a nascent CO_2 service market facing significant regulatory uncertainty. To establish carbon capture and storage as climate solution for hard-to-abate industries, CO2 storage sites need to be available ahead of market demand. Assets, skills and know-how of the European oil and gas industry could be redeployed in an CO2 storage service market with likely much lower profit margins but higher security of income over longer time-periods.

Many major world regions are investing heavily and rolling out support measures to innovate and strengthen their production capabilities, such as China, the United States, Japan, and India. For example, the United States' Inflation Reduction Act (IRA) provides a more favourable regulatory framework and incentive and is estimated to mobilise over USD 360 billion by 2032, including direct payments per tonne of CO_2 captured and stored. As a result, some European companies are considering investing in the US.

Furthermore, the competitiveness situation of EU manufacturers is in turn reflected in the extent to which industries are confident in the current investment environment, as well as future prospects. Based on regular business surveys carried out by the Commission, it was

[35] Benchmark Mineral Intelligence "Investment in battery gigafactories near USD 300 billion since 2019 as China extends battery dominance", 4th of January 2023. An end-of-year exchange rate for 2022 of around 0.94 EUR / USD was applied. Costs refer here to typically battery cell producers for expanding their capacity.

[36] BNEF (2022) "Localizing Clean Energy Supply Chains Comes at a Cost". In addition, the industry estimates that when the entire value chain is considered (e.g upstream mining production, raw materials processing, recycling), these costs could increase further by around 50%-75%.

found that EU net-zero industries and their supply chains have been exposed considerably to global developments due to their high level of integration and dependence on inputs from other world regions, leading to volatility in their confidence levels (Annex 2).

2.4 Summary of bottlenecks or inhibiting factors limiting the scale up of manufacturing capacity

Overall, several significant barriers and bottlenecks would have to be removed to help materialize industrial opportunities for EU manufacturers of net-zero technologies across their supply chain, especially given that current production/supply is already affected by shortages. Such limiting factors relate to:

Global supply chain and price constraints

As with many other global players, the European net-zero industry's appetite for investment is being undermined by volatility in international material prices, more expensive transportation and financing, and continued supply chain bottlenecks. For instance, stakeholders have reported that 20-25 % of planned EU solar projects were either postponed or cancelled entirely in 2021 due partly to global energy and raw material price hikes, and other global economic developments [37]. EU heat pump industry players argue that given the relatively small size of their industries compared e.g. to the car industry, their sectors are typically at the end of the queue for accessing chips. Electrolysers require critical raw materials, such as platinum group metals and rare earth elements. Though research has allowed their required volumes to be reduced, the upscaling of electrolyser manufacturing may further increase their scarcity and price.

Lead times necessary to start a new production line or significantly increase an existing one

Lead times to open new manufacturing facilities vary across net-zero industries. At the global level, the IEA estimates the range to be greater for the production of EV batteries, with up to 5 years for opening new facilities to manufacture anodes and cathodes, whereas lower lead times are reported for solar PV with respect to facilities producing polysilicon, ingots/wafers, cells, and modules or for wind of up to 2 years; and for mobile fuel cells or heat pumps of up to around 3 years (*Figure* 3).[28] Regarding electrolysers, the same IEA report suggests that commissioning gigafactories would take two to three years. European established operators have confirmed this and indicated that it would take two years from final investment decision to the beginning of commercial operations. On top of the permitting procedures and construction work, additional time is needed to launch the manufacturing process, which can take up to a year depending on the complexity of the process and the company's experience. Shortening the time for building production capacity in the EU would be an advantage for the EU industry over its main partners.

If manufacturing capacity is increased by expanding production at existing sites rather than building new facilities, this would translate into lower lead times. For example, the IEA indicates that building new production lines for solar PV wafers, cells and modules at

[37] EU strategic dependencies and capacities: second stage of in-depth reviews, SWD(2022) 41 final

existing factories can take as little as 4 months, once the go-ahead has been given. Factories to assemble final clean energy technologies can also be built relatively quickly, where the assembly technology is mature and standard machinery is being used. However, various constraining factors limiting the expansion of net-zero manufacturing (e.g. shortage of skills or specialist machinery used as a factor of production) could work to further increase these lead times across the board.

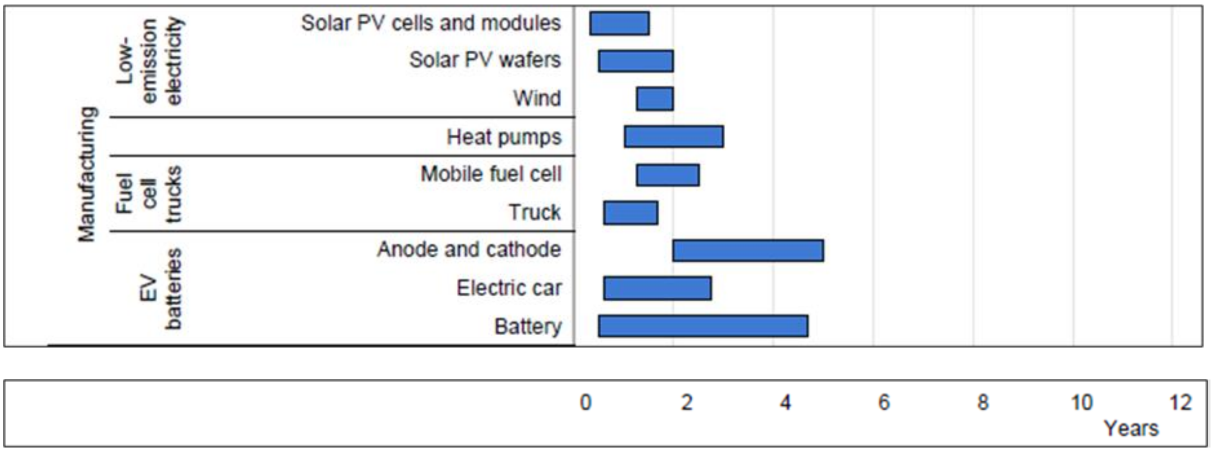


Figure 3: Range of global average lead times for selected net-zero technologies. Source: Energy Technology Perspectives 2023, International Energy Agency. Notes: Lead times include a time component on feasibility, engineering, and permitting, and a time component on construction.

Furthermore, even with infrastructure (buildings and other elements of industrial parks) fully ready, some EU manufacturers are reporting significant delays until they become operational. For example, EU producers of heat pumps indicate that starting production on factory sites ready to produce requires at least one year (notably to install and certify production machinery), while developing an industrial park from scratch takes at least 2.5 years, notably due to lengthy permitting procedures,[38] although the expansion of production can also occur via increased utilisation of spare capacity and repurposing of existing machinery. There are also significant barriers to entry for new players in some net-zero industries. For example, in the case of heat pumps, the industry highlighted a year ago that newcomers who wanted to enter the market had to expect delivery times exceeding 50 weeks, with delays of more than 120 weeks for some components.[39]

<u>Quickly ramping up production also requires significant labour and skills</u>

Both skill and labour needs can act as a bottleneck, particularly in sectors characterised by high specialisation. For instance, in the heat pump industry, it is estimated that the sector employs approximately 90,000 employees, out of which 37% are employed in heat pump manufacturing, 29.5% in installation work, 18.5% in component manufacturing and 15% in maintenance services.[40] For the hydrogen sector, the shortage of required technical skills and

---

[38] Based on EHPA estimates

[39] Based on EHPA estimates

[40] EurObserver "Heat pumps barometer 2021"

technical workforce is also expected to be an important issue for the manufacturing, installation, and operation of electrolysers. The skills dimension is discussed in more detail in section 4 and Annex 5.

3. Investment needs

This section estimates the investment needed to build EU-based manufacturing capacity for five key net-zero technologies: wind, solar, batteries, heat pumps, and electrolysers. It does not cover all the technologies discussed in Annex 4, due to some technologies not being produced in dedicated factories (e.g. CCS, grids) and data limitations. Investment needs related to attracting, reskilling, upskilling, and maintaining the workforce are assessed separately in section 4 and Annex 5. The data is based on the literature in Annex 8 (e.g. CAPEX) and the Fit-for-55 and REPowerEU scenarios for net zero demand.

3.1 Scenarios

Three policy scenarios were developed to analyse the investment needs for cleantech manufacturing capacity: a status quo scenario, an NZIA policy scenario, and an NZIA+ scenario, whereby full deployment demand is met by EU manufacturing and the EU captures a larger share of the global markets. The three scenarios use identical assumptions and differ only in the share of EU deployment that is covered by EU manufacturing in 2030. Tables 1, 2, and 3 list the manufacturing investment needs for all five technologies and three scenarios.

Investment Needs for manufacturing: Methodology

Tables 1, 2 and 3 show in the first column the physical deployment needs in 2030 for the respective five technologies (as determined in the Fit-for-55 and REPowerEU energy modelling scenarios). The analysis is based on the REPowerEU scenario with the renewable energy share reaching 45% in 2030, and 10 million tonnes of hydrogen produced in the EU by 2030[41]. Installed capacity reaches 510 GW for wind and 592 GW for solar PV in 2030. The annual deployment until 2030 defines the need for manufacturing capacity and these physical deployment needs are translated into annual additional deployment investment between 2023 and 2030 ('Annual technology deployment between 2023 and 2030').

The second column of the tables represent the current installed manufacturing capacity in the EU. The third column shows the market share of EU production or manufacturing of the respective technology that meets the level of the demand required to fulfil the decarbonisation deployment needs that we aim at in the EU. The fourth column ('New manufacturing capacity needed') is calculated by {[Market share of EU production][Annual technology deployment in 2030]}-[Current installed EU manufacturing capacity].*

*The fifth column is the investment needed in manufacturing (measured in Factory CAPEX – operational costs are not relevant for determining manufacturing investments needs) to increase the manufacturing capacity by one GW(h) per year. The last column ('Manufacturing capacity investment needs') is the results of [New manufacturing capacity needed] * [Factory CAPEX].*

41 Communication on the REPowerEU Plan (COM/2022/230 final) and Staff Working Document "Implementing the REPOwer EU Plan: investment needs, hydrogen accelerator and achieving the biomethane targets" (COM(2022) 230 final).

The Electrolyser Joint Declaration of 5 May 2022 also endorse the objective of producing 10 Mt of hydrogen in the EU, which would require an installed electrolyser capacity of 90-100 GW hydrogen output capacity, equivalent to up to 140 GW electricity input.

The investment needs refer exclusively to investments in capital expenditures to expand existing manufacturing capacity or build new facilities (Factory CAPEX) for the respective five net-zero technologies. They include investments into the manufacturing stages of main components and technological assemblies (e.g. solar cells, ingots, and wafers to produce solar panels), although they do not cover all production costs, such as operating costs, nor the deployment investment costs to reach the ambitions of the Green Deal transition. Neither do they include input costs (e.g. processed materials) or the investments needs of other manufacturers in the part of the supply chain further upstream.

Factory CAPEX and the corresponding manufacturing capacity investment needs cover only the investment needs for building factories, and include final products, specific components and specific machinery. They do not cover the difference in production costs of the different technologies once the factory is built. There is limited available information on the competitiveness of EU manufacturing vis-à-vis its trading partners, and the evolution of this competitiveness in the future will depend on many factors.

3.1.1 Status Quo

All five technologies, EU manufacturing in 2030 maintain the same shares in deployment needs as in 2022. To keep these current market shares constant, new investments will be needed due to a growing market and an increase of the deployment of these technologies. This scenario assumes an adapted policy environment which would allow and facilitate those new investments, as under current conditions companies face difficulties to scaling up, in light of the increasingly competitive and subsidised global competitors[42].

Technology	Annual technology deployment in 2030	Current installed EU manufacturing capacity*	Share of EU production in EU demand	EU manufacturing capacity in 2030	New manufacturing capacity needed	Factory CAPEX (M€/unit/year)	Manufacturing capacity investment needs (Bn EUR)
Wind	42	13	85%	36	23	260	6.073
Solar PV	53	1	3%	2	0,4	340	0.129
Heat Pump	51	14	60%	31	17	333	5.624
Battery cell	610	75	54%	327	252	144	36.249
Electrolysers	25	2,3	10%	2.5	0	60	0.007
Total							**48.082**

Table 1: Manufacturing capacity needed and investment needs per technology in a status quo scenario. Capacity is expressed in GWh/year for batteries and GW/y for the other technologies (GW of electricity for electrolysers, GWAC for solar PV).

In this scenario, investment needs are limited in manufacturing of solar PV, simply because EU market share is only 3% today, and deployment needs in 2030 are only slightly higher than the capacity deployed in 2022 (46 GW vs 41 GW). As illustrated by Table 1, investment needs are higher for wind and heat pumps, representing respectively EUR 6.1 billion and EUR 5.6 billion. The bulk of investment needs (75% of total investment needs) are for batteries manufacturing. The EU will need to invest EUR 36.2 billion in this sector if it wants

[42] As detailed in Annex 3.

to keep its current market share in 2030. Overall, investment needs for five technologies (without CCS) in this scenario are EUR 48 billion[43].

3.1.2 NZIA policy scenario

In this scenario, for all five technologies, the EU manufacturing increases its market shares in the period 2023-2030 to the **benchmarks , as stipulated in the recitals of the Net-Zero Industry Act proposal**, as follows:

- For solar EU aims to increase the competitive edge of its solar PV industry and improve its security of supply perspectives by aiming to reach at least 30 GW of operational solar PV manufacturing capacity by 2030 across the full PV value chain (equivalent to a share of manufacturing in deployment needs of around 45%).[44]
- EU manufacturers of wind and heat pump technologies are projected to consolidate their competitive edge and maintain or expand their current market shares throughout this decade (translating into a projected share of manufacturing in deployment needs in 2030 of 85% and 60% for wind and, respectively, heat pumps).
- With respect to the manufacturing of battery technologies, the NZIA policy benchmark draws on the objective of the European Battery Alliance, which aims at almost 90% of the EU's battery annual demand to be met by the EU's battery manufacturers.
- Finally, for EU electrolyser manufacturers, the REPowerEU plan[45] projects 10 million tonnes of domestic renewable hydrogen production, translating to a 100% policy share of manufacturing in EU electrolyser deployment needs[46].

The above objectives would be achieved through the implementation of the Net-Zero Industry Act and an active support as part of other relevant policy measures, including industrial alliances and financing.

Technology	Annual technology deployment in 2030	Current installed EU manufacturing capacity*	Share of EU production in EU demand	EU manufacturing capacity in 2030	New manufacturing capacity needed	Factory CAPEX (M€/unit/year)	Manufacturing capacity investment needs (Bn EUR)
Wind	42	13	85%	36	23	260	6.073
Solar PV	53	1	45%	24	22	340	7.579
Heat Pump	51	14	60%	31	17	333	5.624
Battery cell	610	75	90%	549	474	144	68.244
Electrolysers	25	2.3	100%	25	22	60	1.332
Total							**88.852**

Table 2: Manufacturing capacity needed and investment needs per technology in a NZIA policy scenario. Capacity is expressed in GWh/year for batteries and GW/y for the other technologies (GW of electricity for electrolysers, GWAC for solar PV).

[43] Including CCS, the investment needs of the status quo scenario amounts to EUR 52 billion.

[44] As set out in the European Solar PV Industry Alliance and supported under the EU Solar Energy Strategy SWD(2022) 148 final. This is expressed in DC Wp which is equivalent to around 24 GW in AC terms (for deployment purposes). Although, the European Solar PV Industry Alliance refers to the 30 GW within the 2025 timeframe, it relates to when financial decisions have been allocated with a view to the respective manufacturing capacity to become operational by 2030.

[45] COM(2022) 230 final

[46] A further up to 10 million tonnes of renewable hydrogen may be imported by 2030 but this is assumed to be achieved via electrolysers manufactured and deployed abroad

In this NZIA policy scenario, total investment needs are 84% higher than in the status quo scenario and reach EUR 89 billion, without CCS (Table 2). More than three quarters of total investments are for battery manufacturing, while wind, solar and heat pumps represent each 7 to 8% of investment needs. With a comparatively limited deployment in 2030 compared to other mass technologies even in the optimistic scenario of 10 million tonnes of hydrogen produced in the EU, electrolysers represent an investment need of EUR 1.3 billion.

Adding the 50Mt capacity of CCS as in the regulation, is estimated to have about 3.5bn investment needs (ranging from 2.6bn to 4.5bn) with a mix of onshore and offshore projects. This brings the **total manufacturing investment needs for the 6 selected technologies to about EUR 92 billion.**

How do the technology specific indicative objectives outlined in the proposal for a Net-Zero Industry Act relate to the 40% headline objective laid out in Article 1 of the Act?

Article 1 of NZIA provides that "by 2030, the net-zero technologies manufacturing capacity in the Union approaches or reaches a benchmark of at least 40% of the Union's annual deployment needs for the corresponding technologies necessary to achieve the Union's 2030 climate and energy target".

The manufacturing investment needs in the NZIA policy scenario is about 89bn (excl. CCS). Each of the manufacturing shares for the five technologies in the NZIA policy scenario are significantly higher than the 40% headline objective. The aggregate 40% EU benchmark thus accounts for a larger diversity in technologies and their entire supply chains. As an aggregate, it naturally refers to a lower level of ambition than benchmarks for key manufacturing capacity for specific individual net zero technologies. In particular:

- *The aggregate 40% EU benchmark is a minimum ambition.*
- *NZIA has a wider scope of technologies than those analysed in this section. The NZIA Annex also includes solar thermal, geothermal energy, biogas or biomethane, other storage technologies, CCS and grid technologies, and the definition of net zero technologies as a whole is even broader.*
- *For various technologies, certain steps in the upstream supply chain (such as raw materials) have a considerably lower EU manufacturing share than the final technology.*
- *Post-2030 the market for net-zero technologies will continue to grow, and manufacturing investment needs will need to anticipate this future demand and growth.*

While the benchmark can be considered more or less ambitious for the various concrete net-zero technologies, it represents an overall political ambition of achieving high resilience across net-zero technologies built on EU capacity and diversified supply chains.

3.1.3 NZIA+ scenario

In this scenario, for all five technologies, the EU manufacturing covers 100% of the EU deployment needs in the period 2023-2030, translating into the EU gaining a higher market share of global markets for the respective technologies and their supply chains. For electrolysers for instance, this means that the necessary electrolyser capacity to domestically produce 10 Mt of hydrogen (REPowerEU) is entirely produced in the EU.

As illustrated by , this scenario implies the highest investment needs, at EUR 116 billion (CCS not included). Adding the investment needs of CCS, the NZIA+ scenario amounts to EUR 119 billion. Batteries still represent the largest share of investment needs with EUR 77 billion. This is followed by solar (EUR 17.4 billion), heat pumps (EUR 12.4 billion), wind (EUR 7.7 billion) and electrolysers (EUR 1.3 billion). **The total investment needs do compare well with the USD 149 billion (EUR 140 billion) for Europe (incl. e.g. UK, NO, CH, and western Balkan) estimated by Bloomberg New Frontiers[47] to meet the European clean-energy demand in 2030**.

Technology	Annual technology deployment in 2030	Current installed EU manufacturing capacity*	Share of EU production in EU demand	EU manufacturing capacity in 2030	New manufacturing capacity needed	Factory CAPEX (M€/unit/year)	Manufacturing capacity investment needs (Bn EUR)
Wind	42	13	100%	42	30	260	7.720
Solar PV	53	1	100%	46	51	340	17.425
Heat Pump	51	14	100%	51	37	333	12.416
Battery cell	610	75	100%	610	535	144	77.027
Electrolysers	25	2	100%	25	22	60	1.332
Total							**115.919**

Table 3: Manufacturing capacity needed and investment needs per technology in a NZIA+ scenario. Capacity is expressed in GWh/year for batteries and GW/y for the other technologies (GW of electricity for electrolysers, GWAC for solar PV).

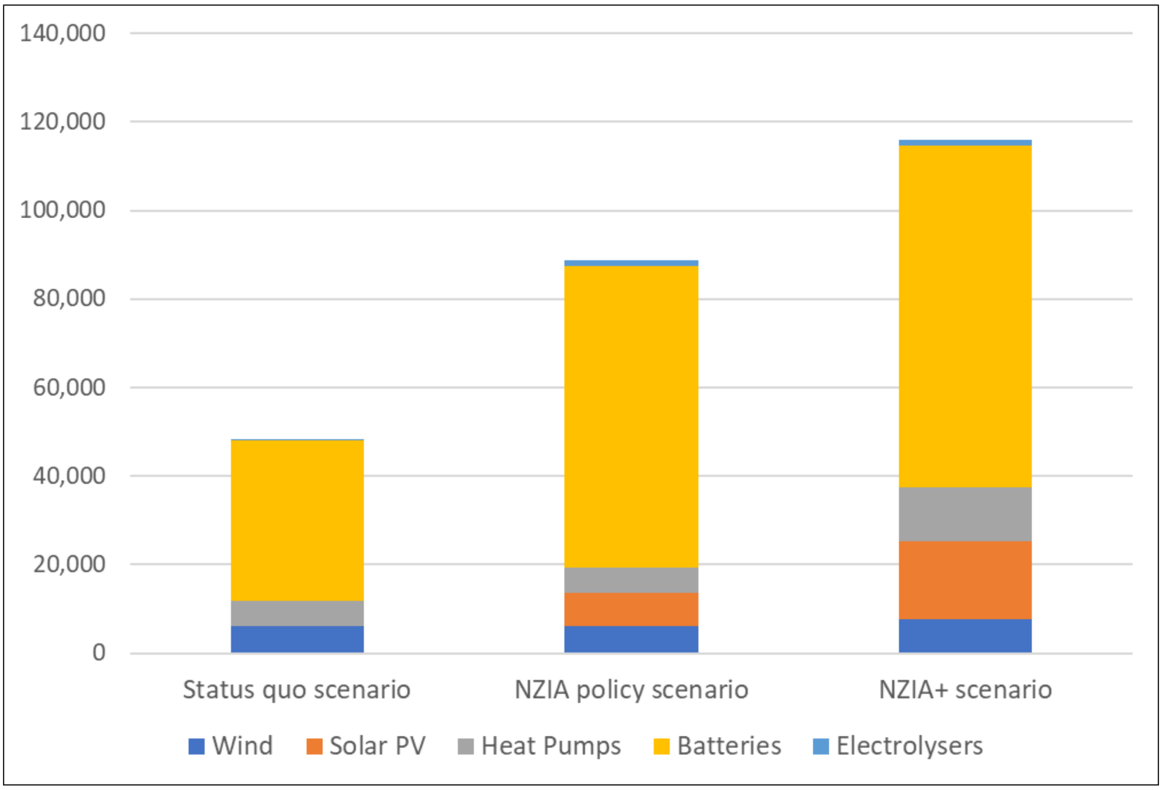


Figure 4: Investment needs to expand EU net-zero technology manufacturing capacity according to different scenarios (EUR million, cumulative 2023-2030)

The overall estimated investment needs assessed across the three policy scenarios and across the five key technologies are illustrated in Figure 4.

[47] BloombergNEF, Europe's New Clean Industrial Strategy Falls Flat, February 10, 2023.

3.1.4 Uncertainties in estimating investment needs

The manufacturing investment needs for the key Net Zero technologies are subject to a number of caveats:

- Assumptions: The CAPEX numbers are based on literature review (e.g. BNEF or other). The deployment numbers are derived from the Fit for 55 and REPowerEU scenarios.
- Scope: The calculated investment needs only focuses on five key mass-produced Net Zero technologies. While these five key mass produced NZ technologies represent the bulk of the investment needs, the NZIA proposal also includes a number of technologies, which have not been quantified. When the scope of focus changes, the investment needs also change accordingly.
- Up- and downstream supply chains (e.g. raw and processed inputs) are beyond the scope of NZIA and are not covered in the investment needs in manufacturing capacity. At the global level, clean technology manufacturing would represent approximately 50% of global investment in the clean energy supply chains if investments in mining and critical material production are taken into account[48].
- The calculations include the investment needs for additional manufacturing capacity. They should not be confused with the deployment costs and investment of the Green Deal transitions (Table 9)

As such, considering the above, the projected investment needs for boosting EU's manufacturing capacity of net-zero technologies that have been estimated for each scenario may vary depending on several parameters. An illustrative example is that of batteries, for which the projected 2030 EU demand varies considerably, according to the literature and the estimates provided by various stakeholders. For instance, the European Battery Alliance estimates the demand to be much higher than what the literature typically finds (and which was included in our scenario tables above), i.e. about 1000 GWh per year in 2030.[49] Since, battery manufacturing investments represent the lion's share in the overall investments estimated for the five technologies (around 80%), using this higher battery demand would result in an increase in the overall 2030 manufacturing investment needs by around 60% (e.g. from EUR 92 billion to EUR 145 billion in the NZIA policy scenario).

For transparency and illustrative reasons, *Table* 4 lists the industry estimates of the investment needs for the respective 5 technologies. These industry estimates tend to be sector-focused, and not to be based on integrated and consistent scenarios such as the Fit-for-55 and REPowerEU scenarios. These numbers are only included to illustrate the industry estimates but are not supported by the Commission analysis.

[48] The IEA estimates in the Energy Technology Perspectives 2023 that the total cumulative investment in mining, critical material production and manufacturing of the clean energy technologies (wind, solar PV, EV batteries, heat pumps, fuel cells and fuel cell trucks, electrolysers) to bring the necessary capacity online by 2030 amounts to approximately USD 1.2 trillion. Out of this, manufacturing represents USD 640 billion, or 53% of USD 1.2 trillion.

[49] European Battery Alliance Discussion Paper for the 7th High-Level Meeting of the European Battery Alliance. Published 1 March 2023.

	Manufacturing
	Investment needs (cumulative € bn) to reach the NZIA+ scenario technology-specific manufacturing benchmarks
Solar PV (annual, GW)	18
Wind (annual GW)	60
Heat pumps (mln units)	5
Batteries (GWh)	76
Electrolysers (annual, GW hydrogen)	10
Total	169

Table 4: Industry estimates of manufacturing investment needs

However, Table 4 should be read with appropriate caveats, notably:

- For solar PV, the EUR 18 billion represents the lower-end of the range for manufacturing investment needs as estimated by SolarPower Europe and EIT InnoEnergy.
- For wind, 2030 investment needs for manufacturing are based on industry estimates[50]: around EUR 50 billion for offshore wind and around EUR 10-20 billion for onshore. These figures however include a part of the installation and deployment, and not only manufacturing cost.
- For heat pumps, the investment needs for manufacturing refer here only to the announced investments made by industry (European Heat Pump Association).
- For batteries, 2030 deployment refers to estimated demand for lithium-ion batteries in GWh, based on industry estimates.
- Electrolyser manufacturing is estimated to require cumulative investment needs up to EUR 10 billion by 2030. These figures include also a part of the installation and deployment and not only manufacturing cost.

3.2 Investment Needs post-2030

According to our recent analysis, demand for key energy transition technologies will remain high in the long term, driven by the climate neutrality target in 2050. According to our projections in the framework of REPowerEU, installed capacity for wind, solar and batteries will more than double in 2050 compared to 2030. The pace of annual deployment will stabilize at high levels after 2030. This trend is due to increased electricity consumption, fuelled in part by demand for hydrogen.

Demand for electrolysers follows a similar path but delayed in time as most of the deployment occurs after 2030. For heat pumps, on the other hand, deployment seems to reach a plateau after 2030. This could be due to market saturation or simply to the lack of dedicated policies after 2030. However, these trends are subject to significant uncertainties. The

[50] Wind Europe "Ensuring the supply chain can deliver an expansion of offshore wind in Europe", Recommendations to NSEC Governments, October 2022

emergence of new technologies (e.g., new heat pumps suitable for novel applications in industrial processes) may disrupt the trend presented.

3.3 Increase in deployment costs

The investment expenditures of the Fit for 55 and RePowerEU (Table 9 in Annex 1) remunerate the investments of the manufacturers abroad for the imported goods, and the investments of the manufacturers of EU-produced goods. Scaling up EU industrial manufacturing, instead of imports, may lead to additional costs to the extent that EU manufacturing is more expensive than imported goods. A particular point of attention is to what extent a build-up of manufacturing capacity in the EU may increase the cost of the green transition.

There are currently no vertically integrated PV manufacturers in Europe or the US. The CAPEX in the EU and USA is estimated to be three times higher than in China due to higher equipment and construction costs. Diversifying global PV supply chains may come at a cost, though not an unaffordable one in terms of capex. Most of the cost of making solar panels is the operating expenditure for the factories. Producing PV in the EU is currently about 25%-35% more expensive than in China and about 15% more expensive than in the US. Electrolysers from China are sold at about 25% of the price of those produced in the EU and US. These current cost differences do not need to stay like that. Innovation breakthroughs, economies of scale or integration, and competitiveness improvements (e.g. cost, productivity, or fiscal) may be able to close the gap. E.g. markets experts assess that by 2035 the EU and US electrolysers will have closed the gap with China.

3.4 Public versus Private Investment

The focus of this part of the analysis is on two aspects of the relationship between public and private financing. While the first part of the information gathered below concerns the amounts/shares of public/private financing in relation to the investment needs, the other part is focused specifically on observed or expected multipliers for certain financial instruments supported by the EU and national budgets (including financial instruments from the cohesion policy funds as well as InvestEU), i.e. financing mobilised by a particular instrument. The elements below could be used to give an indication of the ratios between the public and private support and identified multipliers.

Ratio of public-private investments in energy and climate related investments[51]

In the period 2011-2020, the share of public investments in total investments was about 15%, with a high degree of heterogeneity across countries. Bruegel estimates[52] the range between 1:4 to 1:5 for the energy and climate dimension. This estimate is based on a variety of factors and data sources from different points in time, therefore it represents a very crude estimate. Furthermore, it does not cover net-zero manufacturing per se, but a broad range of interventions related to the energy and climate dimension.

[51] Please note that it is not a multiplier indicating mobilised private resources.

[52] Zarvas, Z. and G. Wolff (2021) 'A green fiscal pact: climate investment in times of budget consolidation', Policy Contribution 18/2021, Bruegel

The ratio differs depending on technologies, markets, and the timeline of investments. For example, in the EPBD Impact Assessment[53] investment needs for building renovation will be covered only partially by public sources (EU budget, ETS, EIB, national programmes) at the level of EUR 33 billion per year on average until 2030. It means that estimated annual investment needs ranging from EUR 125 billion (2023) to EUR 275 billion (2030) will be covered from public sources at the level of 26% to 12% respectively. According to global assessments, the corporate sector invests on average at least three times as much in clean energy R&I as the government sector[54]. Investment by the EU's business sector accounts for 80% of the R&I spending in the Energy Union R&I priorities[55] .

The public/private ratio is not only dynamic in time and sector, but also depends on correlation between availability of finance on the market versus planned investments in particular technology and energy costs. For some Member States like ES, LV and EL availability of finance is perceived as a major obstacle for investments. In ES, PL, CY, LV, PT and EL it may be correlated with high energy costs,[56] which may be important while assessing investment needs. Intensity and form of public intervention is supposed to address these obstacles accordingly.

Multipliers of financial instruments

Type of financial instrument	Average target multiplier from a mapping of national and EU-level financial support schemes[57]	Median achieved leverage as at 31 Dec 2020 – financial instruments under ERDF/CF[58]
Loans	1.57x (based on 29 instruments with available target multiplier)	1.3x (based on 451 instruments)
Equity	1.25x (based on 2 instruments with available target multiplier)	1.8x (based on 211 instruments)
Guarantees	1.57x (based on 10 instruments with available target multiplier)	4.8x (based on 87 instruments)

Table 5: Overview of selected multipliers, preliminary draft study on current energy sector investment instruments and schemes in energy generation in EU-27[59]

Multipliers[60] alter significantly between the different types of financial instruments, the different market segments, supported technologies and their maturity as well as considering access to capital. The information gathered in this section refers mostly to the deployment of

[53] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12910-Energy-efficiency-Revision-of-the-Energy-Performance-of-Buildings-Directive_en

[54] IEA, Tracking clean energy innovation - A framework for using indicators to inform policy, 2020.

[55] COM(2022) 643 final - Report from the Commission to the European Parliament and the Council – Progress on competitiveness of clean energy technologies

[56] European Investment Bank Investment Survey 2021.

[57] These multipliers were identified during the analyses in the preparation of a *Study on current energy sector investment instruments and schemes* in energy production, which is prepared under the Investors Dialogue on Energy. The Study is still to be finalized, so results provided by the contractor are preliminary.

[58] These figures are based on financial instruments (using loan, equity or guarantee products) adopted under the ERDF and CF programming period 2014-2020 until 31st December 2020. Source: European Commission's annual report summarising the progress made in financing and implementing financial instruments (FIs) supported by European Structural and Investment Funds (ESIF) for the period until end December 2020

[59] The study is procured under the Investors Dialogue on Energy initiative and will be ready in Q1/Q2 2023.

[60] Here understood as the instrument's capacity to attract additional private financing compared to the instrument's initial public budget.

clean technologies to give examples of the expected impact of public funding in catalysing private investments. Grant instruments only cover a share of the investment project costs and are complemented by other (private) funding sources. However, their main goal is usually not to trigger simultaneous private co-investments. As a consequence, it is more difficult to estimate multipliers/ratios for grants. Hence Table 5 focuses on financial instruments. While the first column depicts the average multipliers for national and EU-level financial support schemes supporting energy generation investments the second column includes information on estimations for the financial instruments implemented under the cohesion policy funds.

European Regional Development Fund and Cohesion Fund Financial Instruments (2014-2020) – by the end of 2020, EUR 10.0 billion of ERDF and CF funding paid to final recipients mobilised EUR 37.4 billion of financing (in the form of loans, loans backed by guarantees supported from programme resources, and equity support or similar), and achieved an average multiplier between 1.3x and 4.8x, depending on the type of instrument (Table 5). However, these multipliers are not directly relevant in the context of assessing availability of funding for large scale manufacturing capacity investments since financial instruments under ERDF and Cohesion Fund focus almost exclusively on SMEs.

The InvestEU overall expected multiplier is 11.4.[61] This is a guarantee facility de-risking investments. Such multiplier is achieved because of the overall risk diversification based on a highly granular portfolio. The financing of manufacturing projects would not lead to such a high multiplier.

Conclusions

The above shows that ratios between public and private funds as well as multipliers of financial support schemes vary substantially with respect to type of financial instrument, the industry, technology, and geographic location, amongst other factors.

There are significant limitations in availability of data to estimate the share between public and private funding as no observable ratios for clean tech manufacturing exist. As a very crude proxy and based on estimates that cover a much broader range of interventions linked to energy and climate, one could apply a ratio of 17-20% of required public investment. If this ratio is applied to the NZIA policy scenario, which identifies EUR 92 billion in investment needs, it would result in public funding requirements of EUR 16 – 18 billion.

A higher level of support may be warranted given the need to ensure the competitiveness of EU net-zero industry and a fast roll-out of net-zero technology manufacturing capacity for the support of the EU climate goals, and the fact that the used ratios are crude and not manufacturing-specific. Additionally, third countries are rolling out support schemes that aim at anchoring and attracting clean tech industry (cfr. Annex 3) which presents a competitive challenge for the EU to maintain and develop its own industry.

[61] Frequently asked questions about the InvestEU Fund

4. Skills and related investment needs

The scaling-up of manufacturing capacities not only needs investment into physical infrastructure, but also requires additional skilled workers, which implies significant investment in re-skilling and upskilling the workforce. Their number depends on various factors such as the specific technologies used, the pace of adoption and innovation, the scale of investments and policy frameworks. Workforce requirements for the energy transition in Europe can vary depending on different scenarios and the level of ambition of the transition. While different assumptions can lead to different estimates, it is clear that the energy transition will require a significant increase in the number of skilled workers in a range of sectors, including renewable energy, energy efficiency, and energy storage.

According to the report published by European Labour Authority,[62] there are ongoing labour shortages in the EU both at professional and technician levels. Multiple Member States report relative severe shortages in professions that essentially constitute the skills-base upon which net-zero industries depend on for large part of their value chain, or the skills-pool of candidates that would need extra sectoral specialisation and training to fulfil roles on new green technologies. These professions include: plumbers, pipe fitters, welders and flame cutters software developers, application programmers, carpenters and joiners, civil engineers, steel and metal workers, heavy truck drivers, electricians and electric engineers etc.

A significant investment in education and training will be needed to ensure that the workforce is equipped with the skills and knowledge necessary to meet the challenges of the transition to a low-carbon economy. Based on the manufacturing capacities above (Section 3), the additional manufacturing jobs created in the industries and the corresponding investment needs for retraining/reskilling/upskilling up to 2030 would amount to about 1.7 billion Euro under the status quo scenario, EUR 3.1 billion under the NZIA Policy proposal, and EUR 4.1 billion under the NZIA+ scenario with 100% of demand satisfied by EU manufacturing (Table 6).[63] Despite a lower labour-to-capital ratio compared to other technologies, the majority of jobs will be created in battery cell production as this is the technology with the largest capacity increase under all scenarios. Overall, in case of lack of adequate support to education and training, the required increases in human capital across sectors may exacerbate existing shortages.

In addition to these specific investments in human capital in particular manufacturing sectors, additional workforce will be needed for the installation of these technologies. More generally, the energy transition will require that the EU and its Member States invest in education and training programmes that provide workers with the necessary skills and knowledge.[64] This could include programmes that focus on Science, Technology, Engineering, and Mathematics (STEM) education, as well as vocational training programmes that provide practical, hands-

[62] Report on Labour Shortages and Surpluses, November 2021.

[63] The values have been calculated by taking the capital investment needs from section 3 as a starting point. Employment needs were obtained by converting capital investments into annual capital rental payments and using labour/capital cost ratios of the corresponding sectors. Investment needs in skills multiplies additional employment with training cost from the 2020 Employments and Social Developments in Europe (ESDE) report, without differentiating social investment costs by skills/education level, sector or Member State.

[64] Czako, V., Skills for the clean energy transition, European Commission, Petten, 2022, JRC129676

on experience. Women are strongly underrepresented in the renewables sector (32%) and even less in the STEM professions. Skilling investment should be tailored to increase participation of women in the new jobs that will arise.

Table 6: Additional jobs in manufacturing and investment needs for retraining/reskilling/upskilling until 2030.

Scenario	Status quo		NZIA Policy Proposal		NZIA+ Scenario	
Technology	Additional Jobs (in thousands)	Investments in Skills (mio EUR)	Additional Jobs (in thousands)	Investments in Skills (mio EUR)	Additional Jobs (in thousands)	Investments in Skills (mio EUR)
Wind	31	270	31	270	40	353
Solar PV	<1	3	25	223	66	578
Heat Pump	28	243	28	243	60	529
Battery cell	139	1214	261	2284	294	2578
Electrolysers	0	0	5	41	7	59
Total	198	1730	350	3062	468	4097

Source: JRC estimate based on manufacturing capacity expansion derived in section 5, GECO 2021 macroeconomic baseline, and training expenses from ESDE 2020 report.

PART II: AVAILABLE FUNDING FOR THE NET ZERO TRANSITION

5. EU funding at the different stages of development of technology projects

This section provides an overview of the potential available funding to support a Green Deal Industrial Plan for the Net-Zero Age for strengthening the European value chain and manufacturing capacity of net-zero technologies that are key to meet the climate neutrality goals, such as batteries, windmills, heat pumps, solar, electrolysers, carbon capture and storage technologies.

EU funding provides support to net-zero technologies at different stages of development. These stages depend on how close to the market stage the technology is, from technologies that are at development, demonstration, or prototype stage today, to technologies that are commercially available and for which markets already exist. In addition, EU support is available for the deployment and use of these technologies, for example when private individuals purchase heat pumps to upgrade existing buildings, when they purchase electric vehicles to decarbonise their transport or when energy companies invest to install wind turbines or new photovoltaic installations to expand renewable energy generation.

The analysis provides an indicative split of the available instruments in the current programming period 2021-2027 (while the investment needs analysis in section 3 covers the 2023-2030 period) in three categories:

1. Support to the **upstream development of net-zero technologies**: this includes research and innovation, up to the prototype demonstration in an operational environment (Technology Readiness Level 1-7);
2. Support to **net-zero manufacturing capacities for large scale production**: this covers measures supporting the establishment of manufacturing capacities at industrial scale (including first-of-a-kind ones) for net-zero products and relevant components and sub-components, including the machinery specifically used to produce these (Technology Readiness Level 8-9);
3. Support to the **users of net-zero products for accelerating their uptake**: this includes support to delivery and uptake of net-zero products from manufacturers (e.g. support to households for the installation of heat pumps, support to electrification of industrial processes and use of green hydrogen).

The Table 7 also distinguishes programmes implemented by the Commission and programmes implemented by the Member States.

Programmes referenced below have amounts earmarked for or minimum targets/thresholds dedicated to climate objectives. Part of these amounts could be activated for the net-zero technologies, as in most cases, the five technologies fall under the targeted areas of those programmes. However, the full amount under these programmes cannot be exclusively earmarked for the net-zero technologies and will compete with other sectors for grants or loans backed by the EU budget. Available amounts are therefore presented as “up to” amounts. To the extent possible, the overview of funding takes into account the supply chain perspective, namely main components and assembly, which are included in the investment needs analysis.

Furthermore, and not included in the analysis, are the proceeds from the sale of ETS allowances under the ETS Directive over which Member States have full control in terms of spending, provided that it complies with the ETS Directive and the applicable State Aid rules. These revenues were around EUR 25 billion in 2021 and around EUR 30 billion in 2022 (i.e. excluding Innovation and Modernisation Fund).

Table 7: EU Programmes

EU programmes able to finance net-zero technology ***(for the period 2021-2027; EUR million)***	**Contextual information: Overall budget available to support the EU energy transition**	***Of which:*** **Support to the upstream development of net-zero technologies**	***Of which:*** **Support to net-zero manufacturing capacities for large scale production**	***Of which:*** **Support to the users of net-zero products for accelerating the uptake**	**Details/Implementation**
Programmes centrally implemented by the Commission					
Innovation Fund (ETS proceeds based)	28 000[65]	2 800[66]	up to 4 000[67]	up to 12 000[68]	Grants awarded following calls for proposals
Horizon Europe	up to 11 240[69]	10 560[70]			Grants awarded following calls for proposals
	10 100[71]	up to 990[72]	0[73]		EIC open calls for innovative deeptech companies in all sectors and calls focused on predefined challenges
LIFE Clean Energy Transition	1 000			up to 350	Grants awarded following calls for proposals
InvestEU	7 900[74]	600	600[75]	1 800	Loans and equity through EIB, EIF and other Implementing partners
EU Programmes implemented by the Member States					

[65] Approximated amount for the period 2021-2027 based on a pro rata split; total amount for the 2021-2030 period of EUR 40 billion from ETS revenues (this is an estimate based on an average carbon price of EUR 75 EUR per tonne CO2).

[66] Estimate based on the third large scale call under the Innovation Fund, which has a budget of 10% for the pilot topic focussed on highly innovative, disruptive or breakthrough technologies in deep decarbonisation.

[67] Estimate for the net-zero technologies of the third call for clean tech manufacturing and the assumption that a similar budget will be mobilised in the coming years.

[68] Extrapolated estimate based on projects funded so far under existing calls.

[69] Overall budget estimate for the period 2021-2027 to support the energy transition, including the planned resources for the hydrogen valleys.

[70] This includes the support provided for measures under Cluster 4. Digital, Industry and Space and 5. Climate, Energy and Mobility, as well the estimated support provided by the European Institute of Innovation and Technology through EIT InnoEnergy (for the period 2021-2024).

[71] This is the total budget of the European Innovation Council (EIC) for the period 2021-2027.

[72] Based on an estimate that maximum 15% of the EIC grant budget (excluding the EIC Accelerator grants and equity) will be used to support the development and testing of net-zero technologies.

[73] EUR 525 million could be available for net-zero manufacturing, ased on an estimate that maximum 15% of the EIC Accelerator (which provides grants and equity finance) is used, however this would support only SMEs and small midcaps.

[74] This amount reflects the 30% climate target for the total budgetary guarantee of EUR 26.2 billion. Please note that the indicated amount is a budgetary guarantee which is provisioned at 40%.

[75] It is expected that around EUR 3 billion of EU Guarantee could be dedicated to the three categories of this table. The split between the categories is estimated ex-ante based on the existing financial products and expected uptake by market. It is estimated that 20% of EUR 3 billion (i.e. EUR 600 million) would be dedicated to large scale net-zero manufacturing projects.

Recovery and Resilience Facility (RRF)	251 000[76]	13 000[77]	2 300[78]	37 000[79]	Measures contributing to the green transition in the 27 adopted national Recovery and Resilience Plans
REPowerEU package and RRF remaining loans	22 000[80]		up to 1 000[81]	up to 21 000	Grant part: Member States will decide on the allocation through the RePowerEU Chapter in the national RRP.
	225 000[82]		To be determined by MS	To be determined by MS	Loan part - MS will decide on use and allocation
ERDF/Cohesion Fund/Just Transition Fund	85 000[83]	7 800	0[84]	10 100[85]	Projects that will be selected by MS
Modernisation Fund (ETS proceeds based)	39.000[86]			27 300[87]	Implemented by MS
Social Climate Fund (ETS proceeds based)	14 900[88]			up to 14 900	Implemented by MS
Total	695 140	**up to 35 750** (plus potential addition of RRF remaining loans)	**up to 7 900** (plus potential addition of RRF remaining loans)	**up to 124 450** (plus potential addition of RRF remaining loans)	

[76] This amount equals the measures (investment and reforms) supporting the green transition in the currently adopted national Recovery and Resilience Plans.

[77] This reflects the estimated RRF support of measures under *intervention field 022 - Research and innovation processes, technology transfer and cooperation between enterprises focusing on the low carbon economy, resilience and adaptation to climate change*, which includes – but is not limited to research and innovation processes on green energy, including hydrogen.

[78] This includes an estimate of the RRF support to manufacturing capacities in clean-tech.

[79] This is the budget under the policy area "Renewable Energy and Networks" , and under "energy efficiency": the former includes hydrogen and storage; the latter includes measures supporting the transition from fossil-fuel based heating systems to decarbonized systems such as, but not exclusively, heat pumps..

[80] This concerns the additional RepowerEU grants (EUR 20 billion) and includes the Brexit Adjustment Reserve (BAR). . Member Statesinformed the Commission of their intention to transfer EUR 2 billion to the REPowerEU package budget.

[81] Based on an assumption that Member States will allocate a share (i.e. 4,4%) of the budget to support Net-zero manufacturing capacities equivalent to what has been observed under the currently adopted national Recovery and Resilience Plans..

[82] This concerns the remaining RRF loans (EUR 225 billion) that are available for Member States (and not yet committed). Member States are requested to inform the Commission within 30 days after the entry into force of the RePowerEU Regulation if they have an interest in requesting RRF loans. The legal deadline for commitment is August 2023.

[83] This includes the planned support to renewable energy and clean technologies and intervention fields that indirectly support renewables and clean-tech. EUR 60.5 billion is available for indirect support to renewables and clean-tech.

[84] Estimate based on data extrapolated from the Smart Specialisation Strategies. EUR 6 600 million may be available for clean tech manufacturing based on data extrapolated from the Smart Specialisation Strategies. However, such amount would only be available to SMEs.

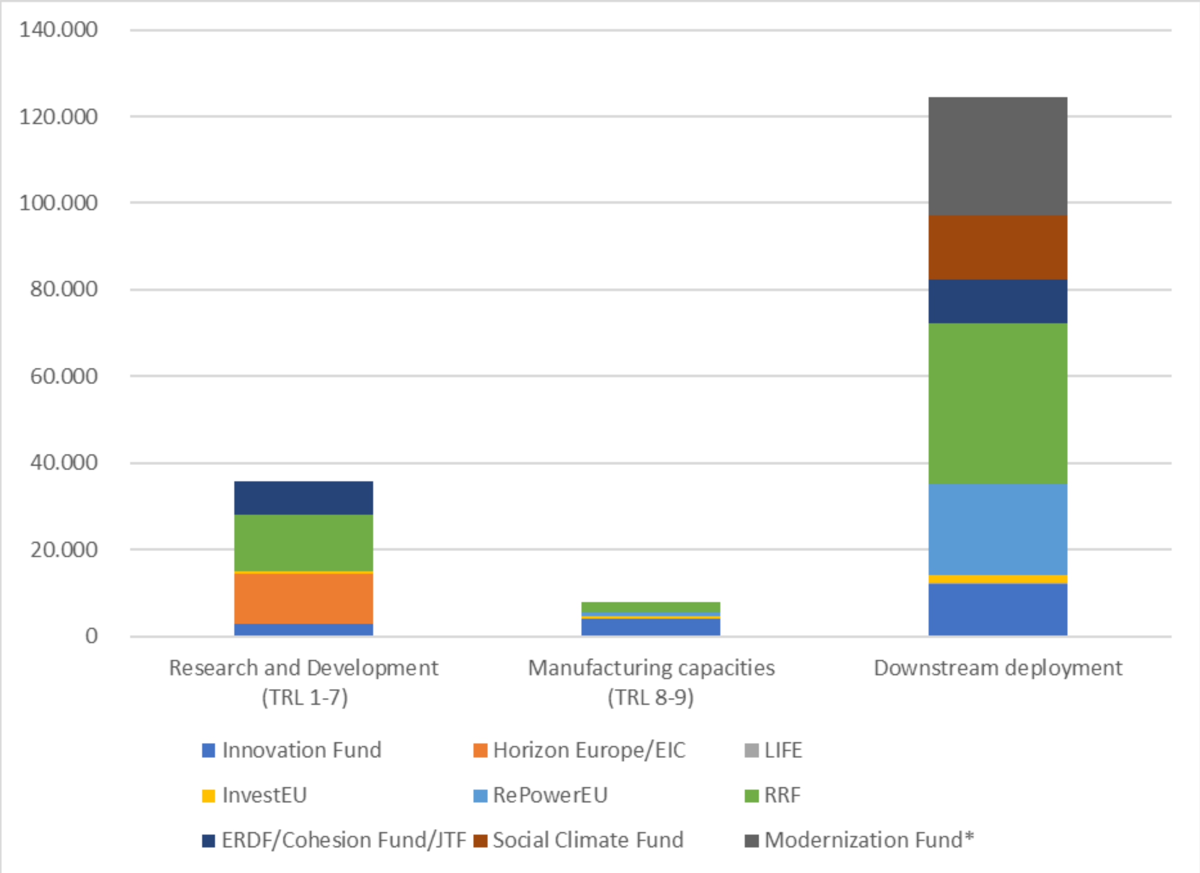
[85] Estimate based on the data extracted from the cohesion policy programmes.

[86] Approximated amount for the period 2021-2027 based on a pro rata split; total amount for the 2021-2030 period of EUR 56 billion from ETS revenues (this is an estimate based on an average carbon price of EUR 75 EUR per tonne CO2, and includes the transfer of Member States into the Modernisation Fund as communicated up to date).

[87] This accounts only for projects in the priority areas where so far only deployment projects were supported as the beneficiary Member States have not submitted project for net-zero manufacturing so far.

[88] In current prices, the SCF will be exceptionally and temporarily financed by external assigned revenues generated from the auctioning of allowances from ETS. This is the maximum amount for the years 2026-2027 considering the start of auctioning of the ETS II in the year 2027.

Figure 5: Estimated potential maximum support to different stages of net zero technologies in the EU between 2021 to 2027 (EUR million)



As shown by the above graph, the support from EU funds is concentrated on the development-phase, such as research and innovation, and to a larger extent on the use of net-zero technologies (the deployment-phase), categories 1 and 3 above. A comparatively low amount of direct support is provided to manufacturing capacity. The main programmes are the following:

- Horizon Europe mostly provides support to technologies at their early stages, through research and innovation grants or through the European Innovation Council (EIC) in the form of grants and equity support when companies (SMEs and small mid-caps with up to 499 employees) require scale-up support and aim to reach industrial scale.
- The Innovation Fund, financed from the auctioning of EU Emissions Trading System allowances, is well placed to address the higher TRL phases for the demonstration at commercial scale of innovative low-carbon technologies, independently of the size of the company putting it forward for funding. Under the Innovation Fund, competitive calls are organised regularly both for small- and large-scale projects.
- InvestEU can also support the financing of the net-zero technologies through facilitating access to finance for debt or equity for research and innovation activities and the rolling out of technologies to the market, for the scaling up of innovative companies, as well as

for investments in and deployment of renewable energy and energy efficiency infrastructures and products.

- ERDF/Cohesion Fund can mobilise investments in support of the net-zero technologies under the cohesion policy objective for a greener, low-carbon transition towards a net-zero carbon economy. The ERDF supports the development of SMEs by enhancing their sustainable growth, competitiveness, and job creation in SMEs, including productive investments[89]. The Just Transition Fund (JTF) complements the cohesion policy efforts by providing targeted support to territories facing serious socio-economic challenges in moving towards a green economy, which can include productive investments in other enterprises than SMEs under specific requirements, for instance to achieve deep greenhouse gas emission reductions from activities under the EU Emission Trading System.
- The Recovery and Resilience Facility (RRF) and REPowerEU cover a large spectrum of the development stages and can virtually address any net-zero technologies' needs insofar as they are included in the Member States national Recovery and Resilience Plans (RRPs).
- The Modernisation Fund is a programme that currently supports 10 Member States (to be increased to 13 in 2024) to meet 2030 energy targets by helping to modernise energy systems and improve energy efficiency. The majority of the resources of the Modernisation Fund (at least 70%, and further increasing following the EU ETS Directive revision) must be invested in priority areas specified in Article 10d(2) of the ETS Directive (i.e. generation and use of electricity from renewable sources, improvement of energy efficiency, energy storage, modernisation of energy networks, support to a just transition in carbon-dependent regions). Under the revised EU ETS Directive, the list of priority investments will also include renewable heating and support for low-income households to address energy poverty.

Overall, it is estimated that **a total of up to EUR 8 billion could be activated from the programmes** mentioned above to support net zero manufacturing capacities. In addition, Member States could tap into EUR 225 billion in loans under the RRF to support the net-zero technologies.

[89] Under certain conditions, the ERDF and the Cohesion Fund might support investments in enterprises other than SMEs. See in particular article 5.2 of the REGULATION (EU) 2021/1058 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 24 June 2021 on the European Regional Development Fund and on the Cohesion Fund.

6. Individual programmes' availabilities

Programmes centrally implemented by the Commission

Horizon Europe is the EU's key funding programme for research and innovation with a budget of EUR 95.5 billion for the period 2021-2027. Out of the total budget, a significant part, mainly under Cluster 4 Digital, Industry and Space and Cluster 5 Climate, Energy and Mobility of the programme, about EUR 12 billion[90], potentially allows support for research and innovation projects of companies in collaborating with other research and innovation entities on the development and, demonstration and deployment of net-zero technologies and their innovative use, on the basis of competitive calls for proposals, launched by executive agencies or by the Horizon Europe partnerships (Joint Undertakings have their own Work Programmes). EUR 10 billion are also available under the EIC, allocated through open calls for deep-tech companies (SMEs and small mid-caps for the Accelerator strand) developing breakthrough technologies in all sectors and through dedicated thematic challenges e.g. the 2021 Green Deal challenge addressing topics such as clean energy and smart mobility or 2022 challenge: Technologies for 'Fit for 55'. Around 70% of the EIC budget targets SMEs.

Example of Net-Zero technology projects already financed under Horizon Europe:

BatWoMan: EUR 4,85 million contribution from Horizon Europe under the Batt4EU co-programmed Partnership which develops new sustainable and cost-efficient Li-ion battery cell production concepts, paving the way towards carbon neutral cell production within the EU.

Example of a Net-Zero technology project financed under the EIC:

Brite Hellas, a Greek company, received a EUR 1.5 million EIC grant and an equity investment from the EIC Fund for a project named PanePowerSW. The project's technology consists of a transparent solar panel glass that can generate clean energy while allowing light to shine through greenhouses windows. On the one hand, PanePowerSW's technology leads to a significant reduction of energy operating costs in greenhouses. On the other hand, it enables the growth of crops due to its transparent surface. The equity financing contributes towards scaling up the company's manufacturing line.

Accessing to Horizon Europe funding: regular competitive calls based on the priorities identified in the work programme of Horizon Europe, EIC (open and challenge-related calls) and of European partnerships such as the Clean Hydrogen Joint Undertaking of the Clean Energy Transition Partnership.

The **Innovation Fund** is one of the world's largest funding programmes for the demonstration of innovative low-carbon technologies. It supports the development and first-of-a-kind deployment of technologies and solutions that decarbonise energy intensive industry, boost renewable energy and energy storage (including batteries and hydrogen) and

[90] For instance, the 2023/2024 Work Programme of Horizon considers the following parts/major activities under cluster 5: Cross sectoral solution for the climate transition (mainly batteries partnership), Sustainable, secure and competitive energy supply, Efficient, sustainable and inclusive energy use, Clean and competitive solutions for all transport modes (this includes for aircraft and shipping fuels), and joint undertakings for clean aviation and clean hydrogen.

strengthen net-zero supply chains by supporting the manufacturing of critical components for batteries, wind and solar energy, electrolysers, fuel cells and heat pumps. Over the decade 2020-2030, an estimated EUR 40 billion will be available under the Innovation Fund for both SMEs and large and manufacturing companies

Example of Net-Zero technology projects already financed under the Innovation Fund:

Holland Hydrogen (HH) plans to build a 400-megawatt (MW) electrolyser in the Port of Rotterdam to produce green hydrogen, using renewable electricity from offshore wind farms in the North Sea. The project (EUR 89 million) will demonstrate a complete end-to-end integrated renewable hydrogen system proof-of-concept at an industrial scale developed with world leading sustainability credentials. The green hydrogen will be supplied to a refinery and later on to the mobility sector, allowing for about 100% relative greenhouse gas emission avoidance over the first ten years of operation.

Accessing funding: regular competitive calls published by the Innovation Fund. A third call, with a budget of EUR 3 billion was launched in November 2022 with a special focus on decarbonisation, electrification, hydrogen and clean-tech manufacturing. The call was open for projects until 16 March 2023.

LIFE: the LIFE Clean Energy Transition sub-programme has a budget of nearly EUR 1 billion over the period of 2021-2027 and aims at facilitating the transition towards an energy-efficient, renewable energy-based, climate-neutral and resilient economy by funding coordination and support actions across Europe in support of the deployment of green energy solutions. These are actions of high EU added-value, which are targeted at breaking market barriers that hamper the socio-economic transition to sustainable energy, and typically engage multiple small and medium-sized stakeholders, multiple actors including local and regional public authorities and non-profit organisations, as well as consumers.

Example of Net-Zero technology projects already financed under LIFE:

- HP4ALL (All Heat pumps skills for nZEB construction): EU contribution EUR 996 million.

  The overarching objective of the HP4ALL project is to enhance, develop and promote the skills required for high quality HP installations within residential and non-residential buildings. Both the supply side (manufacturers, SMEs, installers etc.) and the demand side (building owners, public sector etc.) are engaged in the project.

  A core element is the development and implementation of tailored measures in three pilot regions: Ireland, Upper Austria, and Andalusia/Spain, aiming to address different HP market sectors, applications, and technology solutions:

  - In Ireland the main focus is on new-built residential houses;
  - In Andalusia/Spain: the focus is on the uptake of HPs in social housing; and
  - In Upper Austria: the primary focus is on developing the market for mid/large-scale HP applications for the tertiary and industrial sectors.

- COHEAT2 **-** Paving the way for energy renovations and the transition from fossil fuels to green, local heat supply in the Region of Southern Denmark: EU contribution EUR 1.4 million.

The objective is to change the heating sources of approximately 100,000 houses and buildings, and focuses specifically on deployment of heat pumps.

Accessing funding: Grants awarded following calls for proposals

The **InvestEU Fund** aims to mobilise at least EUR 372 billion of public and private investment through the backing of the EU budget guarantee (EUR 26,2 billion). InvestEU is the Union's flagship instrument for catalysing private investments in EU priority areas through repayable finance (guarantees, loans and equity financing). Through the EIB, the EIF, the EBRD and other implementing partners, the EU supports public and private investments in net-zero technologies and industrial innovation. The InvestEU envelope carries a 30% target to contribute to climate objectives which implies that at least EUR 110 billion of investments supported by the InvestEU Fund are meant to serve the climate objectives. While it is not possible to define precisely which share would be available for the net-zero technologies, since InvestEU is a demand-driven instrument, based on the detailed assessment of existing financial products and other policy objectives pursued, we expect that up to EUR 3 billion of EU budget guarantee could be used to support net-zero technologies, including around EUR 600 million for industry manufacturing capacities.

Example of Net-Zero technology projects already financed under InvestEU:

InvestEU supported French company Faurecia with a EUR 315 million loan from the EIB, which will co-finance research and development activities together with the industrial deployment of hydrogen technology for Faurecia's mobility applications. It will also finance Faurecia's research and development on advanced driver assistance systems. In the field of hydrogen storage and distribution, Faurecia produces (350 and 700-bar) carbon fibre storage tanks that aim to reduce weight and fuel consumption for different vehicle designs. The company has already been awarded major contracts to manufacture hydrogen-powered light commercial vehicles and for a large-scale project involving heavy commercial vehicles. Faurecia is also working on hydrogen fuel cell assemblies and production through its subsidiary Symbio, a joint venture with tyre manufacturer Michelin.

Accessing funding: through implementing partners and with the support of the InvestEU Advisory Hub which provides technical assistance and advisory support to project promoters.

Programmes implemented by the Member States

As part of the NextGenerationEU, under the **Recovery and Resilience Facility** (RRF), the current 27 adopted national Recovery and Resilience plans (RRPs) devote more than EUR 250 billion to the green transition, part of which goes to manufacturers of clean technology. Thanks to the agreement reached at the end of 2022 and adoption on 21 February 2023 modifying the RRF, the EU support to the transition will be increased with additional funding by the **REPowerEU** initiative: additional grants (EUR 20 billion) will be available to

Member States to increase the resilience, security and sustainability of the EU's energy system through the necessary decrease in dependence on fossil fuels and diversification of energy supplies at EU level, including by increasing the uptake of renewables, energy efficiency and energy storage capacity. Member States will be able to add a new REPowerEU chapter to their RRPs, to finance key investments and reforms to support the greening of industry, including net-zero industry manufacturing projects. Member States will also be able to dedicate grants of the Brexit Adjustment Reserve (EUR 5.4 billion) to these objectives[91].

Within Member States' currently adopted RRPs[92], EUR 37 billion are expected to be invested in the deployment of Renewable Energies and Networks (including hydrogen and storage), including EUR 5.3 million expected to be invested on energy efficiency measures supporting the transition from fossil-fuel based heating systems to decarbonized systems such as, but not exclusively, heat pumps.) Additionally, around EUR 13 billion are envisioned to be invested in climate-related research and innovation processes, including, but not exclusively, investments in hydrogen and the low carbon economy. At least EUR 2.3 billion are estimated to be invested in manufacturing capacities.

Examples of Net-Zero technology projects already financed under RRF:

- EUR 400 million for 'TANGO' project, i.e., iTaliAN Giga factOry, financing an increase from the current 200 MW/year to at least 2 GW/year in the production capacity for solar panels. The project includes investments in three different plants including EUR 70 million on the 3Sun Factory, an industrial-scale production facility for the manufacturing of innovative, sustainable and high-performance photovoltaic modules. To be noted, additional EUR 118 million under Innovation Fund.
- As part of the Belgian plan, a construction of a research and innovation facility dedicated to the manufacturing of electrolysers and of two industrial scale test production lines in Belgium and France are envisioned (as part of the IPCEI). One facility will be located in Seraing, Belgium (stacking parts, joints and assembly parts) and the second facility in Aspach, Alsace, France for the individual manufacture of electrolysis cells (cutting, welding, nickel plating) of large diameter parts. The objective is to reach 1GW production capacity per year in 2030. The investment for Belgium amounts to EUR 103 million.
- An investment of EUR 150 million is included into the Romanian RRP to develop the industrial value chain for manufacturing and/or assembly and/or recycling of batteries, with a total capacity of at least 2GW per year.

Accessing funding: Member States driven as projects financed must be included in MS RRPs

The European Regional Development Fund (ERDF) and the Cohesion Fund support investments in all the five policy objectives of the 2021-2027 cohesion policy. ERDF enables investments to make European Member States and regions *more competitive and smarter*, through innovation and support to small and medium-sized businesses, including

[91] This comes on top of the existing transfer possibilities of 5% from the cohesion policy funds to the RRF (up to EUR 17.9 billion).

[92] Situation at 6 March 2023

digitisation and digital connectivity; *greener*, low-carbon and resilient; *more connected* by enhancing mobility; *more social*, supporting effective and inclusive employment, education, skills, social inclusion and equal access to healthcare, as well as enhancing the role of culture and sustainable tourism; *closer to citizens*, supporting locally-led development and sustainable urban development across the EU. The ERDF supports the development of SMEs by enhancing their sustainable growth, competitiveness, and job creation in SMEs, including productive investments.

The Cohesion Fund[93] supports investments in *environment*, including sustainable development and energy presenting environmental benefits, with a particular focus on *renewable energy* and trans-European networks in the area of transport infrastructure (TEN-T).

The main priority considered in this context is the policy objective "Greener Europe", to which both funds contribute, namely 'a greener, low-carbon transitioning towards a net zero carbon economy and resilient Europe by promoting clean and fair energy transition, green and blue investment, the circular economy, climate change mitigation and adaptation, risk prevention and management, and sustainable urban mobility'.

The **Just Transition Fund** (JTF) is a key tool for supporting the territories most affected by the transition towards climate neutrality and for preventing an increase in regional disparities. Its main objective is to alleviate the impact of the transition by financing the diversification and modernisation of the local economy. Among the activities that the JTF can finance are productive investments in SMEs, including microenterprises and start-ups, but also in enterprises other than SMEs, provided that such investments have been approved as part of the territorial just transition plan and contribute to the transition to a climate-neutral economy of the Union by 2050. This includes the possibility to support deep decarbonisation projects in industrial plants under the EU Emissions Trading System that is in-line with a transformation to climate neutrality.

The planned support from these three cohesion policy funds to renewable energy and clean technologies amounts to EUR 85 billion, out of which EUR 10.1 billion is planned to support renewable energy, EUR 14.4 billion for clean technology, and the remaining EUR 60.5 billion goes for indirect support to renewables and cleantech.

Given that cohesion policy programmes are implemented in shared management, Member States are responsible for implementing the planned actions – including selecting concrete projects for funding. The Commission monitors implementation, reimburses expenditure certified by MS and verifies the MS control systems.

Example of Net-Zero technology projects already financed under the ERDF/CF/JTF:

- https://kohesio.ec.europa.eu/en/projects/Q3170611

[93] For the 2021-2027 period, the Cohesion Fund concerns Bulgaria, Czechia, Estonia, Greece, Croatia, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Portugal, Romania, Slovakia and Slovenia.

The JTF is a new fund and one of the first projects selected for funding is for investment of EUR 18.75 million in Estonia for the construction of a Rare Earth Magnet Manufacturing Plant. The JTF investment matches the EUR 81.25 million of the Neo Performance Materials company.

Accessing funding: Member States driven as the Managing Authorities of the programmes are responsible for launching calls for proposals and selection of projects.

The **Modernisation Fund** is a programme from which presently supports 10 Member States (increasing to 13 by 2024) to meet the 2030 energy and climate targets by helping to modernise energy systems and improve energy efficiency. It operates under the responsibility of the beneficiary Member States in close cooperation with the Commission and the European Investment Bank. The Modernisation Fund is funded from revenues from the auctioning of 2% of the total allowances under the EU Emissions Trading System (EU ETS) increasing 2.5% in 2024, and additional allowances transferred to the Modernisation Fund by beneficiary Member States. It targets investments in generation and use of energy from renewable sources, energy efficiency, energy storage, modernisation of energy networks, including district heating, pipelines and grids, just transition in carbon-dependent regions and support for low-income households to address energy poverty; and it can also fund investment in net-zero manufacturing capacities (even though this has not been the case yet)

2.1 Indirect support to infrastructures and skills

Among the abovementioned programmes, some provide support to net-zero industries in an indirect manner (e.g. EIT under Horizon Europe supports education and skills in net-zero industries; the RePowerEU Chapter of the RRF also finances green and digital skills).

In addition, there are other EU programmes that do not provide funding directly to net-zero industries but are providing support in an indirect manner.

The **Connecting Europe Facility** (CEF) is a key EU funding instrument to promote growth, jobs and competitiveness through targeted infrastructure investment at European level. It will address climate change and contribute 60% of its overall financial envelope to co-financing actions supporting climate objectives and moving fast towards zero-emission mobility. It supports the development of high performing, sustainable and efficiently interconnected trans-European networks in the fields of 1) transport, 2) energy and 3) digital services.

For the purpose of this document, the subprogrammes on transport and energy are relevant, where projects are selected on the basis of calls for proposals.

CEF Transport: It focuses on cross-border projects and projects aiming at removing bottlenecks or bridging missing links in various sections of the Core Network and on the Comprehensive Network (link), as well as for horizontal priorities such as traffic management systems. It also supports modernization of and innovation in the transport system in order to improve the use of infrastructure, reduce the environmental impact of transport and meet EU climate neutrality and zero pollution ambitions by 2050,. To this end, the CEF Regulation encompasses also the Alternative Fuels Infrastructure Facility, which funds alternative fuels infrastructure, namely electricity and hydrogen refuelling and recharging stations through a combination of CEF grants with a mandatory financing component (of min. 10%) from a financing institution, to increase investment support for relevant projects.

CEF Energy: The Trans-European Networks for Energy (TEN-E) policy, which focuses on linking the energy infrastructure of EU countries, has been instrumental in upgrading the EU's infrastructure cross-border energy since 2013. To address the energy infrastructure needs at regional and European level, the TEN-E policy identifies priority corridors and thematic areas and establishes a biennial list of Projects of Common Interest (PCIs) that help the EU meet its short and long-term energy and climate objectives. For 2021-2027, the budget of CEF Energy amounts to EUR 5.8 billion to help the transition towards clean energy and complete the Energy Union, making the EU energy systems more interconnected, smarter and digitalised. The focus is on cross-border renewable energy projects, interoperability of networks and better integration of the internal energy market.

Under the **Erasmus+ programme** (2021 – 2027) the action "Alliances for Innovation - Lot 2: Alliances for sectoral cooperation on skills", is the tool to implement sectoral cooperation on skills. Alliances gather key stakeholders from industrial ecosystems and can include businesses, trade unions, research institutions, education & training institutions, public authorities. The Commission selects the Alliances through the annual Erasmus+ call for proposals and supports their work with grants. Following the first call for proposals under the Erasmus+ programme 2021-2027 seven Alliances for sectoral cooperation on skills were selected in 2022, including one on renewable energy. Under the previous programming period an alliance on batteries for electro-mobility has been funded.

The **Social Climate Fund** will be financed by the new emissions trading system and its size will correspond to a dedicated share of the revenues from the auctioning of emission allowances. The total financial envelope of the Social Climate Fund for the 2025-32 period is expected to be EUR 72.2 billion, corresponding to approximately 25% of the expected auction revenues from the new system. The Social Climate Fund should provide funding to Member States to support measures and investments indirectly benefiting the net-zero industry by supporting vulnerable households, vulnerable micro-enterprises and vulnerable transport users, through temporary direct income support and through measures and investments intended to increase the energy efficiency of buildings, decarbonisation of heating and cooling of buildings, including through the integration of energy production from and storage of renewable energy sources, and to grant improved access to zero- and low-emission mobility and transport.

The **European Social Fund plus** (ESF+) is making EUR 5.8 billion available for green skills and green jobs, in particular for reskilling and upskilling people for the transition to a green economy. Funds are accessible through national and regional calls under National and Regional ESF+ Programmes. ERDF complements ESF+ with investments in skills, education, and training, including infrastructure (for a total of EUR 8.9 billion). In addition,

Just Transition Fund can support training and skills development of workers to adapt to the green transition (EUR 3 billion).

Annex 1: Fit-for-55 and REPowerEU deployment investment

Table 9: Average annual investment needs in the energy system and for transport, historical trend 2011-2020, and Fit-for-55 policy scenario 2021-2030, (EUR 2022, billion) (annual) [94]

Sector	**2011-2020 (annual)**	**Fit-for-55 policy scenario 2021-30 (annual)**	**Difference (annual)**
Supply side	**55**	**148**	**+93**
Power grid	15	55	+40
Power plants, incl. boilers and new fuels	40	93	+53
Demand side	**160**	**339**	**+178**
Industrial sector	12	34	+22
Residential	102	202	+100
Tertiary	46	103	+56
Total (Energy System)	**215**	**487**	**+272**
Transport sector[95]	549	754	+205
Total (energy and transport)	**764**	**1,241**	**+477**

[94] The investment needs for the fit-for-55 package have been derived from a variant scenario from the MIX and MIX-H2 scenarios published in SWD(2021) 621 final. They are reported in EUR2022 while for SWD(2021) 621 final, they were in EUR 2015. They are reported in EUR2022 with deflator 1.1588.

[95] Transport includes investment in vehicles and recharging and refuelling infrastructure. It does not include investment in infrastructure such as road or railways.

Table 10: Required installed capacity/output/investments/targets by 2030 to reach Fit-for-55 and REPowerEU Objectives.

	RePowerEU	**Fit-for-55**
Installed wind capacity GW	510	469
Installed solar PV capacity GW[96]	592	530
Installed heat pumps (million units)	41.5	39.9
Installed electrolyser capacity (GW hydrogen)	65	44
Net imports of hydrogen (Mt)	6.16	0.05
Biogas used in power plants (Mtoe)	12.3	11.8
Biogas as transformation input in industry/district heating (ktoe)	6.9	3.3
Electricity grid investments over the decade (EUR bn)	584	554
Annual renovation rate in 2030 (% of housing stock)	2.3%	2.0%
Annual renovation rate – medium and deep renovation in 2030 (% of housing stock)	2.1%	1.9%
EU binding ***RES Target***	45%	40%
EU Binding energy efficiency target	-13%	-9%
Heating & Cooling : RES Share- Average yearly increase for 2020-2030 at EU level	2.3 percentage point	1.5 percentage point*
District Heating & Cooling : RES Share- Average yearly increase for 2020-2030 at EU level	2.3 percentage point	2.1 percentage point
RES Share in Buildings in 2030 at EU level	60%	49%
RES-T share in 2030 / GHG intensity reduction in transport	32% / 16%	28% / 13%
Share of advanced biofuels in 2030 (single-counted)	2.2%	2.2%
Share of Renewable fuels of non-biological origin (“RFNBOs”) as hydrogen in 2030 (single counted)	5.7%	2.6%
RES share in industry - Average yearly increase for 2020-2030 at EU level	1.9 percentage point	1.1 percentage points
Renewable fuels of non-biological origin (“RFNBOs”) sharein industry	78% of hydrogen consumed in industry is renewable	50% of hydrogen consumed in industry is renewable

96 This is AC capacity and the actual PV installed (DC) will be approximately 25% higher.

Annex 2: Confidence indicators for net-zero industries and their upstream and downstream supply chains

The Commission carries out regular business surveys[97] to monitor changes in confidence levels across various EU industrial ecosystems.[98] Net-zero industries as proxied by the Energy Renewables industrial ecosystem[99] largely experienced four main phases.

First, when the pandemic crisis struck, confidence fell dramatically. Second, the bold policy action taken at the EU level in the summer of 2020 (notably NextGenerationEU - NGEU), with a clear focus on the green transition and digital transformation, contributed to a robust recovery, which kept on reinforcing business climate until the last months of 2021. Third, by the end of 2021, with global demand recovering thanks to the relaxation of sanitary restrictions but supply chains still compromised by the consequences of the pandemic, a gradual worsening of business sentiment was observed across the industrial ecosystems. The combination of high prices of raw materials (and inflation more in general), delays in deliveries, labour shortages, and the uncertainties linked to the Russia's unprovoked and unjustified military aggression against Ukraine, summed up to gradually offset the positive stimulus provided by the deployment of NGEU policy measures such as the Recovery and Resilience Facility (RRF). Finally, since the last months of 2022, the fall in commodity prices, normalisation in supply chains and the announcement of additional policy action, such as REPowerEU, provided new impetus to the business confidence in the net-zero industry, which is now still unfolding. Nonetheless, further changes in the EU regulatory framework that are favourable to the business and investment environment of EU manufacturers of net-zero industries are needed in order to sustain and further improve confidence levels.

There are however differences between the net-zero industries, as proxied by the Energy-Renewables ecosystem and the rest of their supply chain. One of its most important downstream ecosystems, Mobility-Transport-Automotive[100] suffered significantly from the pandemic and post-pandemic structural changes in the economy, but has later converged to its long-term average in business confidence. As for one key upstream ecosystem for the provision of inputs to NZI, Energy-Intensive Industries,[101] it proved more resilient than most other ecosystems during the pandemic and post-pandemic phase, but was hit harder by the

[97] The survey data is extracted from the "Joint Harmonised EU Programme of Business and Consumer Surveys", whose methodology, references and additional information can be found here

[98] Industrial ecosystems have been identified first in the "Annual Single Market Report 2021 (SWD/2021/351)", following the approach presented in the "March 2020 Industrial Strategy (COM/2020/102)".

[99] The Energy-Renewables ecosystem employs an estimated 1.2M people in the EU, working in 111 000 firms (99.4% SMEs) accounting for 1% of EU value added (based on 2018 EU input/output data). It includes sectors such as manufacture of equipment for wind energy, solar energy (photovoltaics, thermal and concentrated solar power), hydropower, bioenergy (including sustainable biofuels), geothermal energy, ocean energy, and heat pumps. Furthermore, sustainable energy storage solutions, smart infrastructure technologies and energy conversion technologies, including electrolysers, are also part of a clean energy ecosystem

[100] The Mobility-Transport-Automotive ecosystem employs an estimated 14.6M people in the EU, working in 1.8M firms (99.7% SMEs) accounting for 7.5% of EU value added (based on 2018 EU input/output data). It includes sectors such as automotive and rail production, transport and warehousing services.

[101] The Energy-Intensive Industries ecosystem employs an estimated 7.8M people in the EU, working in 548 000 firms (99.4% SMEs) accounting for 4.55% of EU value added (based on 2018 EU input/output data). It includes sectors such as chemicals, Steel, Paper, Plastics, Mining, extraction and quarrying, Refineries, Cement, Wood, Rubber, Non-ferrous metals, Glass, Ceramics.

supply chain and commodity/energy price shock in the course of 2022 and it is still suffering from global uncertainties, leaving its confidence below historical averages.

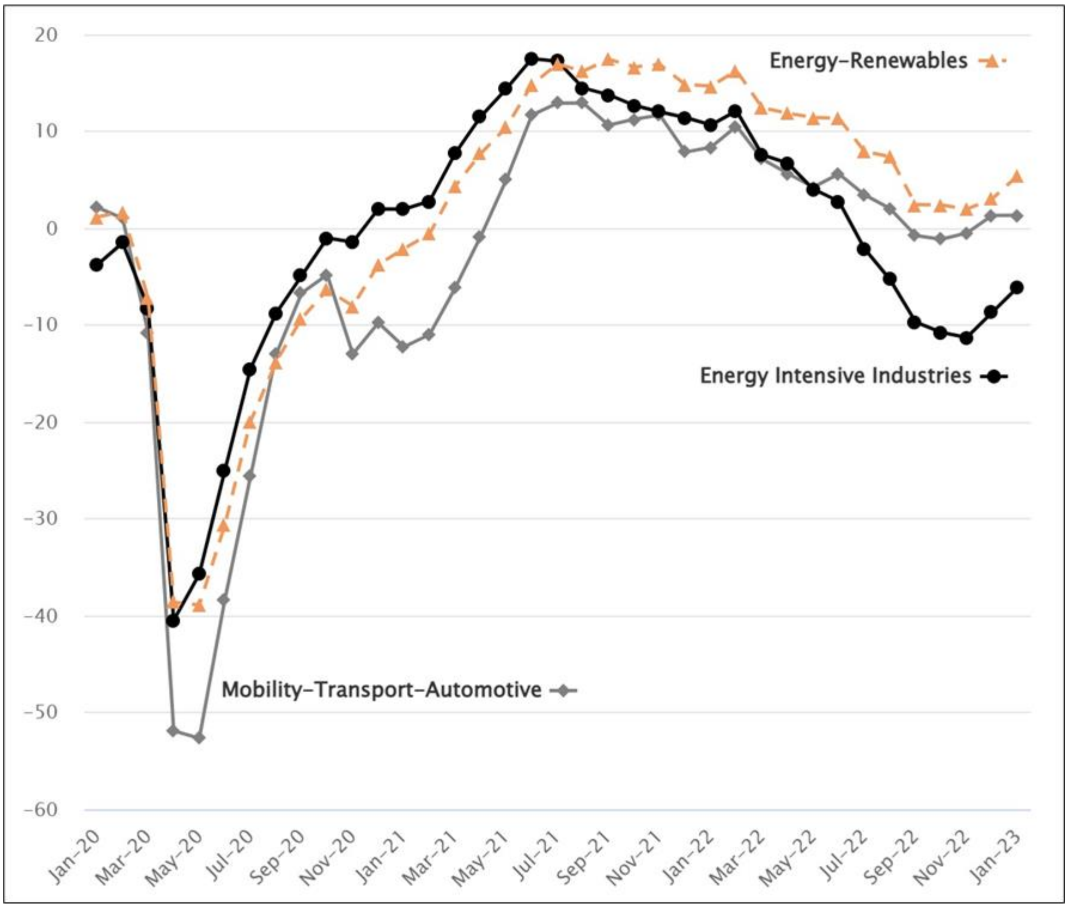


Figure 6: Evolution in confidence for the net-zero industry (proxied by the Energy Renewables ecosystem) and its upstream and downstream industries (proxied by the Energy Intensive Industries ecosystem and respectively the Mobility-Transport-Automotive ecosystem). Source: Source: European Commission services, DG GROW based on the Joint Harmonised EU Programme of Business and Consumer Surveys

Annex 3: Main funding/subsidies, tax incentives, support to investments, R&D etc., in specific sectors/values chains

- **US: The Inflation Reduction Act (IRA)**[102] puts forth major federal investments designed to reduce US greenhouse gas emissions and combat climate change (ISD 370 billion estimated at US Congress level, but potentially unlimited); catalyse US domestic clean energy, development, deployment, and expansion; and enhance US energy security (over $60 billion). To finance these new expenditures and USD 300 billion in deficit reduction, the new law imposes a new minimum tax on the income of larger corporations, creates a new excise tax on public corporation stock buybacks, and provides substantial additional funding for IRS enforcement, operations, and modernization. The bill has an (for some parts discriminatory) immediate and long-term supply chain impact on clean energy industries, notably for renewable energy industries – including clean hydrogen (up to USD 3 per kilogram to produce hydrogen in the US with a lifecycle greenhouse gas emissions not greater than 4 kg of CO_2), decarbonization activities (CCUS and direct-air-capture), energy intensive users -- and automobile manufacturers in the US and beyond, as well as their suppliers in third countries including the EU. The **Advanced Manufacturing Production Credit** (total estimated value of USD 31 billion) of is available for USD 35 per kilowatt hour of capacity for battery cells created for domestic production and sale of qualifying solar and wind components. In combination with the **Clean Vehicle Tax Credit**, the Advanced Manufacturing Credit can be a game-changer for the EU's battery industry and geographical mix of the supply chain.
- **US: Investment and Infrastructure Jobs Act** makes available **USD** 1.2 trillion investment in transport, power, and broadband infrastructure with domestic preference requirements (Buy America) attached
- **US: The Export-Import Bank** offers medium- and long-term loans and loan guarantees available for "export-oriented domestic manufacturing projects," with a particular focus on sectors such as semiconductors, biotech and biomedical products, renewable energy, and energy storage.
- **Canada**: In the fall economic statement, Canada announced **two clean energy tax credits to match U.S. subsidies** of the IRA and ensure that Canadian companies remain competitive: **a 30% refundable tax credit for capital investments in low-carbon energy generation and technology ($6.7 billion over 5 years)** and **a tax credit for hydrogen production**. The design of the hydrogen tax credit has yet to be determined, but the government suggested it would be modelled on tax credits in the IRA.
- **Japan: State-owned Japan Oil, Gas and Metals National Corporation** (JOGMEC) supports exploration and technological development by Japanese companies through equity capital and liability guarantees. Investment by JOGMEC in rare earth overseas projects involving Japanese companies to diversify supply. Its purpose, scope, structure, and obligations are defined in the JOGMEC ACT.

[102] IRA includes the following: Clean Electricity Production credit: tax credit to produce, sell, consume or store electricity by a production method with a net :greenhouse gas emission rate of not greater than zero in the US; Clean Electricity Investment Credit: tax credit for the construction or expansion of electricity production and storage facilities; Energy Credit: tax credit for the investment in a qualifying energy project in the US, which uses hydrogen, solar, geothermal, wind energy, waste energy recover, energy storage, biogas, or microgrid controller technology; Sustainable Aviation Fuel Credit: tax credit to produce aviation fuel in the US; Clean Fuel Production Credit: tax credit to produce transportation fuel in the US, which has a greenhouse gas emission rate of at most 50 kg of CO_2-equivalent per mmBTU; Production of Clean Hydrogen Credit: tax credit to produce hydrogen in the US; Clean Vehicle Credit: tax credit for the purchase of clean vehicles, equipped with a battery that has a minimum critical mineral share; equipped with a battery that has a minimum share of the components manufactured or assembled in North America, final assembly in North America; Advanced Manufacturing Production Credit: tax credit to produce in the US and sell: solar (thin film photovoltaic or crystalline photovoltaic cells; photovoltaic wafers; solar grade polysilicon; polymeric backsheets; solar modules); wind (wind energy components and offshore vessels), torque tubes; inverters), batteries (electrode active materials; battery cells; battery modules); and critical minerals.

- **China:** Significant amounts of state aid in strategic sectors – consumer subsidies and rebates, exemption from sales tax, expert support on R&D and public procurement are some examples of advantages received by New Energy Vehicle manufacturers over the past decade (estimated at more than USD 100 billion).
- **China:** The government directly or indirectly funnels credits and investment into 'strategic sectors', e.g., through so-called government guidance funds that combine public and private investment as well as lending by state-owned banks.
- **China:** The Implementation Plan for the Development of New Energy Storage Technologies during the 14th Five-Year Plan Period implements several investment measures to develop energy production and storage in emerging fields such as compressed air, hydrogen, battery, and thermal energy, with the goal of reaching self-reliance in those fields. The goal is notably to reach 100 GW of battery storage capacity by 2030.
- **China: China Hydrogen Alliance** is a public body charged with boosting hydrogen production in China. Hydrogen has been included as one of China's six industries of the future and has received important investments as part of the 14th Five Year Plan for a Modern Energy System.
- **India:** The Production Linked Incentive (PLI) Scheme managed by the Ministry of Heavy Industries provides subsidies and incentives under several national programmes to local industries to help develop local supply chains. Local governments participate by providing land and facilitating permitting for the benefiting companies. Benefitting industries have included the battery ecosystem (under the 'National Programme on Advanced Chemistry Cell Battery Storage') with US$ 2.49 billion over 5 years in subsidies to develop 50 GWh of battery capacity in India. Beneficiaries must ensure 60 percent domestic value addition within 5 years.
- **India:** An additional PLI scheme was launched to boost solar panel production in India as well, with a budget of US$ 600 million. The goal is to attract US$ 2.30 billion in private financing and to reach an additional 10,000 MW solar electricity production capacity in India. This project is managed by the Ministry of Renewable Energy. Additional PLI are being launched in the pharma sector, the steel sector the electronics sector and in the mobility sector
- **India:** The **National Hydrogen Mission** was launched in August 2021 as a blueprint for India's transition to a hydrogen-based economy. The goal is to reach a production of 5 million tons of green hydrogen by 2030. The Indian government is offering special manufacturing zones to produce hydrogen, with free energy transmission across state lines and priority connection to the grid. This is managed by the Ministry of New and Renewable Energy.

Annex 4: State of play and Technology market analysis for each of the eight technology groups

The net-zero technologies falling under the scope of the Net Zero Industry Act (NZIA) draw on three main criteria: 1) technology readiness level; 2) contribution to decarbonisation; and 3) security of supply risks. These were selected based on the overall NZIA objectives of scaling up the manufacturing capacity of net-zero technologies in the EU, particularly those that are commercially available and have a good potential for rapid scale-up, such that they support the Union's 2030 decarbonisation targets, improve the security of supply for net-zero technologies and their supply chains, and safeguard or strengthen the overall resilience of the Union's energy system.

The first criterion of technology readiness level (TRL) refers to a method of estimating the maturity of technologies and draws on the classification used by the International Energy Agency (IEA).[103] The scope of NZIA generally refers to those net-zero technologies that fall under TRL 8 (first-of-a-kind commercial – commercial demonstration, full-scale deployment in final form) or above. However, there are exceptions to this TRL threshold in NZIA, in that some articles from NZIA (particularly those targeting sandboxes) apply to those net-zero technologies having reached a TRL between 5 and 7 according to the IEA.

The second criterion of decarbonisation identifies those net-zero technologies that operationalise the low-carbon energy sources that are projected to deliver the most to reach the 2030 Fit for 55 target of reducing net greenhouse gas emissions by at least 55% relative to 1990 levels.

Finally, the third criterion relates to security of supply, ensuring the technological and industrial resilience of the Union's energy system by increasing the manufacturing capacity of a component or part in the net-zero technology value chain for which the Union heavily depends on imports, particularly those coming from a single third country.

Based on these criteria, 8 groups of net-zero technologies were selected in the Annex[104] of the Net Zero Industry Act. In addition, the respective net-zero technology groups refer not only to the final technological product or assemblies, but also to the main upstream components that are a central part of the respective technologies (e.g., ingots, wafers, solar cells, modules for solar panels; nacelles, towers, and blades for wind turbines, etc).

Several other technologies were not selected for an analytical discussion. While the NZIA legislative proposal has, as regards some of its provisions, a broad technological scope, the technologies listed in its Annex have been selected due to their particular relevance for

[103] IEA technology readiness level mapping for clean energy technologies available at: https://www.iea.org/data-and-statistics/data-tools/etp-clean-energy-technology-guide. Last updated 21 Sep 2022 based on 2020 data.

[104] COM(2023) 161 ANNEX

decarbonisation from an overall energy systems perspective and/or due to the identification of significant security of supply risks across their value chain.

A. Onshore and offshore renewable technologies

According the Renewable Energy Directive, "onshore and offshore renewable technologies" include wave and other ocean energy (offshore RES) as well as ambient energy, tide, hydropower, biomass, landfill gas, sewage treatment plant gas (onshore RES) according to RED.

Wind

Strengths	**Weaknesses**
- Strong presence in the EU with 31% of global manufacturing facilities. - EU is a global leader in wind technological development.	- Slow permitting process for new installations.
Opportunities	**Threats**
- Annual deployment rates need to increase significantly to reach ambitious 2030 targets. WindEurope is expecting Europe to install 116 GW of new wind farms over the period 2022-2026. - Increased recycling and circularity approaches could help optimise manufacturing processes.	- Supply chain bottlenecks might emerge in the EU if production needs to be ramped up in the short term - Rare earth elements used in the permanent magnets of the turbine generators are identified as critical raw materials and show a high supply risk as EU sourcing relies almost entirely on a single country

KPIs

The wind energy sector has strong presence in the EU. WindEurope/WoodMackenzie in 2020 identified about 800 manufacturing facilities, with the majority in China (45%) and Europe (31%) followed by India (7%), Brazil (5%) and North America (4.5%). In the EU, the leading markets, Germany, Spain, Italy, Denmark and France host a substantial number of manufacturers. More broadly, about 550 wind-related companies/entities are located in EU countries. The main manufacturers in the EU accounting for 85% of the EU market are presented in Table 11: KPIs of the 4 largest wind energy manufacturers in the EU (global figures), while the total production in the EU accounted for EUR 6.6 billion in 2020.

Table 11: KPIs of the 4 largest wind energy manufacturers in the EU (global figures)

		Vestas Wind Systems	Siemens Gamesa Renewable Energy	Nordex	Enercon
Company type		Publicly quoted company	Publicly quoted company	Publicly quoted company	Private company
Headquarters country		DK	DE	DE	DE
Total revenue in 2021 (billion EUR)		15.6	10.2	5.4	3.9 (in 2020)
Production cost (billion EUR)		14	9.9	5.2	3.9
Number of employees (in thousands)		29	26	9	N/A
Main production sites		DK, DE, IN, IT, UK, ES, SE, NO, AU, CN	ES, IN, CN, DK, UK, TR, TW	DE, ES BR, IN, MX, US	DE, PT
Market share	EU Onshore	40%	12%	22%	11%
	EU Offshore	28%	66%	-	-
	Global	18%	10%	6%	<1

Source: JRC based on Pitchbook, Vestas Annual Report 2022, Siemens Gamesa Annual Report 2021, Nordex Financial report 2022 and JRC CETO report "Wind energy in the European Union"

Technology status

In terms of technological development, the EU is leading in the wind energy sector. This is reflected in the share of private and public investments, as well as the share of high value inventions. In the period 2017-2019, the EU's share of high-value inventions was 59%, followed by the US (17%) and China (9%).

Bottom fixed offshore and onshore wind will likely remain the main technologies in the wind energy sector, but floating offshore wind will gradually increase. Given the variety of concepts, estimates are that the Technology Readiness Level (TRL) of offshore floating wind concepts range from TRL 4-9, with the highest being for Spar-buoy and semi-submersible concepts (TRL 8-9). According to WindEurope[105], Europe is expected to install 10 GW of floating wind by 2030. Floating hybrid energy platforms, that incorporate different types of marine renewables, are still at a lower TRL (6), but are expected to become mainstream by 2030.

Within the wind energy industry, several companies and original equipment manufacturers have announced ambitious targets with respect to recycling and circularity approaches. However, it is unclear how this will affect the manufacturing processes of the sub-components in the future.

To retain its technological leading position, further EU research and innovation will be needed. This is even more clear in the light of the increasing competition from Asian companies and the United States on the global market. Wind energy needs to meet its growth potential to deliver the ambitious Green Deal goals. This means further continuous support on R&I actions in several segments. Technologically, efficiency needs to be improved, be it at a

[105] https://windeurope.org/newsroom/news/europe-can-expect-to-have-10-gw-of-floating-wind-by-2030/

turbine level through new designs and materials or be it at a systems level through wind control and grid management.

The significant growth planned of wind energy installations requires major quantities and innovative materials (such as cement and steel), for example for new types of installations such as deep sea or floating wind parks. Floating wind offers possibility to kick off a new European industry and to reach currently untapped (or underdeveloped) geographic basins, such as the Atlantic, the Mediterranean Sea, and the Black Sea. Circularity and recycling will take centre stage as a main driver of innovation. Special attention will be given to topics such as composite recycling and strategic critical raw material substitution.

Even more critical is the supply of certain specific raw material used in wind equipment, for which the EU is critically dependent on third countries. R&I in this field is essential to identify resource efficiency solution, substitutive materials and support to circular solutions.

Market perception status

Both individual manufacturers and organisations estimate that the EU wind market will keep developing. WindEurope[106] is expecting the EU to install 98 GW of new wind farms over the period 2023-2027, 65 GW of which onshore and 33 GW offshore. In September 2022, Siemens Gamesa Renewable Energy published a white paper[107] analysing the importance of wind energy development for EU energy security and highlighted the need to account for high inflation, accelerate permitting, support construction of electrical infrastructure, invest in R&D and facilitate manufacturers' access to public funding to accelerate manufacturing and production.

Current production and expansion plans

Current manufacturing capabilities in the EU cover the demand for major wind energy components. However, as annual deployment rates need to increase to reach the ambitious 2030 targets, supply chain bottlenecks might emerge if components are sourced from EU Member States.

Based on current estimated manufacturing capabilities and assuming that EU manufacturers can follow the technological progress of wind turbines at their present factories, manufacturing might increase towards 2030 by 76%. Based on this estimate, manufacturing capacities match the average 2022-2030 build-out rate[108], although investments in the manufacturing supply chain will be needed to avoid new import dependencies and to match the accelerated deployment in the second half of the decade and from 2030 onwards.

[106] https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-2021-statistics-and-the-outlook-for-2022-2026/

[107] https://www.siemensgamesa.com/en-int/-/media/siemensgamesa/downloads/en/explore/journal/siemens-gamesa-europe-wind-energy-security-white-paper.pdf

[108] JRC CETO report " *Wind energy in the European Union*", November 2022

Obstacles

The wind industry relies on several raw and processed materials, for which high supply risks have been previously identified (e.g. 2020 Criticality Assessment, Carrara et al.[109]), and which are directly addressed in the Critical Raw Materials Act proposal of the Commission. For instance, rare earth elements used in the permanent magnets of the turbine generators are notably identified as critical raw materials in the wind sector, whereas Niobium, used for iron-alloy metals in the main frame of the wind turbine, shows a high supply risk as the EU sources 85% of it demand from Brazil. Blade manufacturers experience a strong resource dependency as most balsa wood is sourced from Ecuador[110].

International competitiveness of EU production and trade

The European Original Equipment Manufacturers (OEMs) in the wind energy sector have held a leading position (Figure 7 and Figure 8). In 2021, the leading European OEMs supplied about 90% of the turbines installed in Europe, 56% in North America, 91% in Latin America and 87% in Africa and the Middle East.

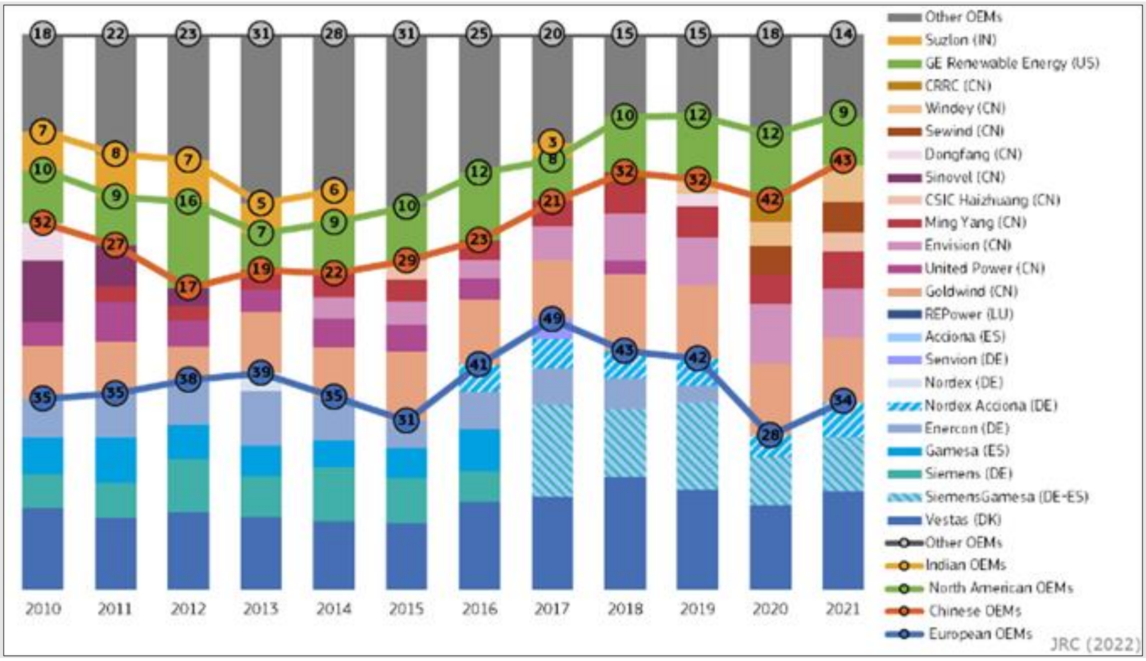


Figure 7: Market share (%) of all top OEMs over the period 2010-2021 and their origin. Source: JRC, 2022

[109] Carrara S, Alves Dias P, Plazzotta B and Pavel C: Raw materials demand for wind and solar PV technologies in the transition towards a decarbonised energy system. EUR 30095 EN, JRC119941. Luxembourg

[110] A detailed analysis of the material needs for wind energy, under different scenarios and in combination with the demands from other renewable energy technologies is presented in the 'Critical raw materials for strategic technologies and sectors in the EU – A foresight study'Critical raw materials for strategic technologies and sectors in the EU – A foresight study'.

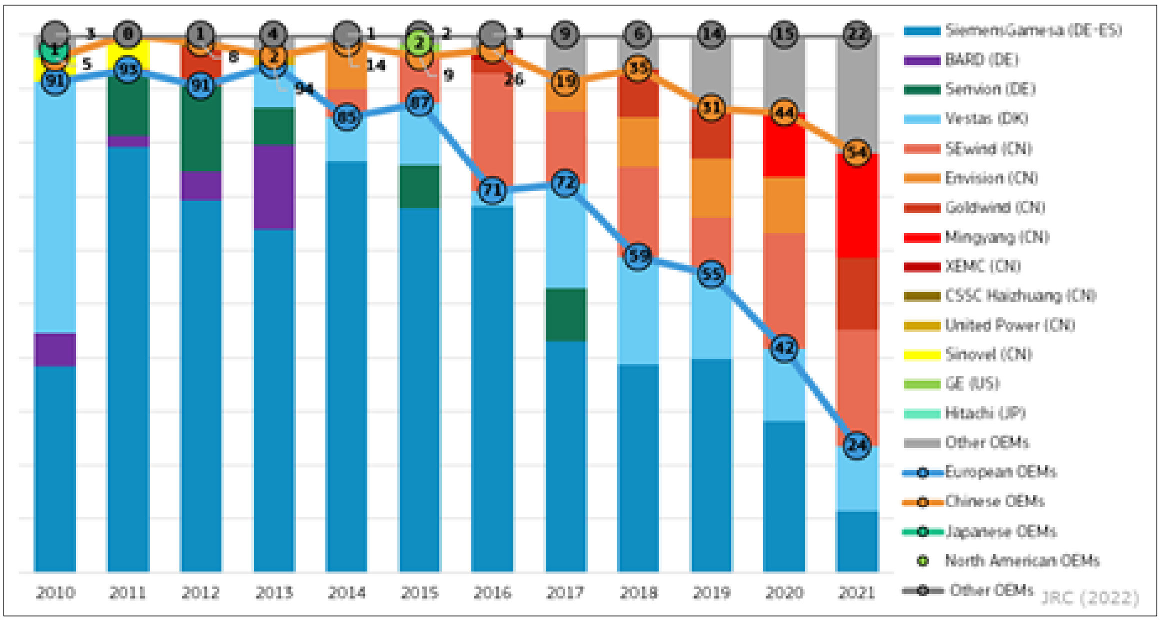


Figure 8: Market share (%) of offshore top OEMs over the period 2010-2021 and their origin. Source: JRC, 2022

Specifically for the offshore market there has been a pronounced development driven by the Chinese market. In 2021, China installed in one year the same offshore wind capacity as the EU did in cumulative terms. The increased deployment activity in China led to a strong increase in the market share of Chinese OEMs (54%), ahead of the European manufacturers (24%) when assessing their cumulative market share. Yet the European offshore wind OEMs rank among the Top 5. Vestas ranks fourth place (12%), closely followed by SiemensGamesa RE (11%), losing its top spot of 2020.

In Figure 9, the performance of the EU wind rotor industry in terms of production, imports, exports and trade balance is presented. As also described ain the first section, the wind rotor industry is strong in the EU, with low amounts of imports, mainly from China.

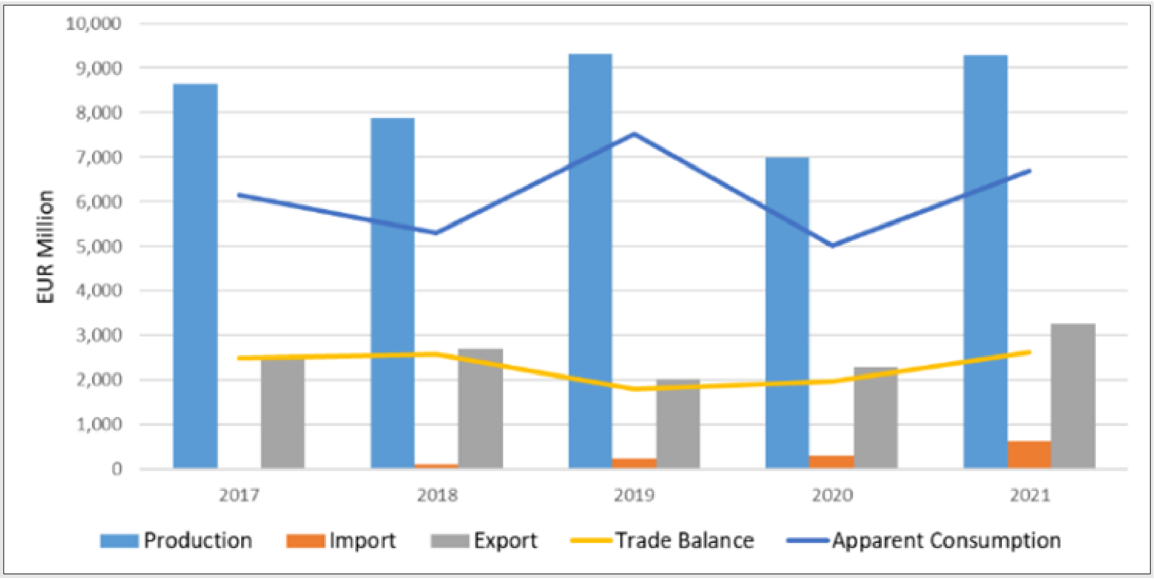


Figure 9: Wind rotor production and extra-EU trade trends. Source: JRC based on PRODCOM and COMEXT data, adapted from CIndECS 2022 (2023)

Ocean Energy

Strengths	Weaknesses
• Reduced visual impact, leading to increased public acceptance • Large number of projects in the pipeline • Multiple European companies have project experience and knowledge • EU is in a good position in terms of publications, patents, private and public R&I.	• Due to the immaturity of the sector there are still high initial cost (CAPEX) which is expected to decrease as deployments increase • Maintenance can be costly/ difficult, leading in higher operational costs (OPEX) • Limited data on the length of lifetime leads in conservative assumptions of the lifetime for the calculations of coast. • Geographically limiting factors
Opportunities	**Threats**
• Due to their capabilities both for energy production but also for alternative uses (desalination, aquaculture etc) they have the potential to drive blue economy • EU companies are leading the field so there are substantial export opportunities for both technology and knowledge • Co-development of ocean energy sources with other renewable sources of energy or other activities in common platforms	• The number of commercial projects in the pipeline has increased but more is needed to achieve ambitious targets. • Administrative barriers. Due to not well defined procedures and environmental impacts, licensing procedures are often long and complicated • Ocean energy technologies are more costly compared to other marine renewables

KPIs

Wave energy and tidal stream energy are the two ocean technologies that dominate deployments, technological advancements and potential in the EU.

Tidal energy is the most advanced form of ocean energy, with companies developing projects globally. Tidal energy developers based in the EU account for 41% of developers with TRL>5, leading with Netherlands, France and Ireland. Non-EU players are predominantly based in the UK (18%), Canada (14%), USA (9%) and China (7%)[111].

Similarly to tidal energy, the majority of companies developing wave energy devices are located in the EU. Wave energy developers located in the EU account for 52% of all active developers with TRL>6. Denmark has the highest number of developers, followed by Italy

[111] JRC CETO report " Ocean energy in the European Union", November 2022

and Sweden. Outside the EU, countries hosting wave energy developers are the UK (14%), the USA (12%) and Australia (9%)[112].

Since 2010, cumulatively, 30.2 MW of tidal and 12.7MW have been installed in European waters. In 2022 installations have slowed down significantly in the EU with only 55kW of tidal and 33.5kW of wave energy being installed[113].

EU holds a leading position in terms of publications and patents, while in terms of private investments, EU companies are the second largest investors in ocean energy following China[114]. Due to the large investments in China, the gap between EU and China in terms of high-invention patents is decreasing.

Technology status

The ocean contains a vast renewable energy potential, which could support economically sustainable long-term development and can be a crucial component in the world's emerging blue economy. Currently, multiple designs of both tidal and wave energy devices are being considered, with tidal energy having full-scale, one of a kind commercial deployment (maximum TRL 8- 9) and wave energy having one of a kind, full-scale applications (maximum TRL 8).

The number of commercial projects in the pipeline has increased with 1.4MW of tidal and up to 450kW of wave energy slated for installation in European waters. However, more is needed to achieve the targets set by the offshore renewable energy strategy[115].

Market perception status

Both individual manufacturers and organisations estimate that the EU market will keep developing, however there are concerns about the eroding leadership position of EU companies. According to Ocean Energy Europe[116], competitive markets have increased their activities, with new devices hitting American and Chinese waters, alongside substantial funding and new policy measures. That resulted in shrinking of Europe's competitive advantage. IEA - Ocean Energy Systems[117] highlighted that the industry is shifting from small-scale demonstrations and pilot projects to higher technology readiness levels. The accumulated operational hours of some devices demonstrate increased reliability and availability, giving confidence to scale-up the technology.

Obstacles

Currently, the number of commercial projects in the pipeline has increased but more is needed to achieve ambitious levels. Due to the immaturity of the sector, there are multiple

[112] JRC CETO report " Ocean energy in the European Union", November 2022
[113] Ocean Energy Europe, Ocean Energy - Key Trends and Statistics 2022, 2023.
[114] JRC CETO report " Ocean energy in the European Union", November 2022
[115] (COM(2020)741)
[116] Ocean Energy Europe, Ocean Energy - Key Trends and Statistics 2022, 2023.
[117] IEA-OES (2023), Annual Report: An Overview of Ocean Energy Activities in 2022

obstacles in the uptake of the technologies. High initial and maintenance costs, especially compared to other marine renewables, are slowing the market uptake. Moreover, due to not well-defined procedures and environmental impacts, licensing procedures are often long and complicated.

While public and private investments are substantial and help ocean energy technologies develop, longer-term support is necessary for devices to reach commercialization.

B. Solar PV and solar thermal

Solar Photovoltaics (PV)

Strengths	Weaknesses
- The EU is a technology leader in polysilicon as well as manufacturing equipment. - The EU has advanced manufacturing techniques. - Strong EU support (under REPowerEU policy) and global markets.	-Energy and labour costs in the EU are significantly higher than for trading partners. - Financing is a major issue to build PV manufacturing plants along the value chain. - Shortage of skilled workers in case of strong development of manufacturing in the EU.
Opportunities	**Threats**
- The EU has several world-leading R&D clusters for silicon PV and thin film technologies. - PV manufacturing in the EU could be competitive under the double condition that i) it is done in very large gigawatt-scale factories, and ii) these factories are fully integrated across all stages of the value chain (ingot, wafer, cell and module).	- The supply of critical raw materials used in current module designs may be a limitation. - The overconcentration of supply from China poses a risk for supply security and resilience.

Solar PV is a modular technology both for deployment (systems range from a few W and multi-GW[118]), and along the manufacturing value chain. The main steps are polysilicon production, ingot pulling and wafering, solar cell production and module production, with this last step requiring, in addition to solar cells specific glass, backsheets and contacting materials. Additional system components are inverters and mounting systems.

KPIs

The global PV market is booming and creating a wealth of industrial opportunities in a highly competitive environment. The global PV market increased from USD 155 billion to USD 235 billion (EUR 220 billion) between 2020 and 2022[119], reaching approximately 300 GW of module production. The EU market has been growing since 2015 and between 2020 and 2022 more than doubled from 20 GW to over 41 GW. The most complete market data is from 2020, when the EU accounted for EUR 21 billion of sales or 14% of the global total. In manufacturing, the EU had a minor share (9% of total Gross Value Added) of global annual PV cell/module production, which was around 140 GW globally[120]. The weakness of the

[118] Important note: PV manufacturing capacity is expressed in terms of the DC power of the cells or modules produced. On the other hand, power scenarios such as PRIMES use the maximum AC power at the grid connection, higher by a factor of approximately 1.2. This needs to taken into account when calculating the necessary manufacturing capacities (nominal DC power) from power scenarios (expressed in terms of AC current).

[119] Fortune Business Insights, 16 January 2023 Fortune Business Insights, 16 January 2023

[120] Overview of the Global PV Industry, A. Jaeger-Waldau, https://doi.org/10.1016/B978-0-12-819727-1.00054-6 Jaeger-Waldau, https://doi.org/10.1016/B978-0-12-819727-1.00054-6

EU's manufacturing base is also shown in the supply chain schematic below[121] (Figure 10), with the GVA per segment and the EU share. A notable exception is for polysilicon production, where the EU's share is 21%. Manufacturing of wafers and of solar glass is almost completely lacking. In value terms, EU production (based on Prodcom group for semiconductor devices and photovoltaic cells) was approximately EUR 2 billion in 2021, with a compound annual decrease of 3% between 2015 and 2021.[122]

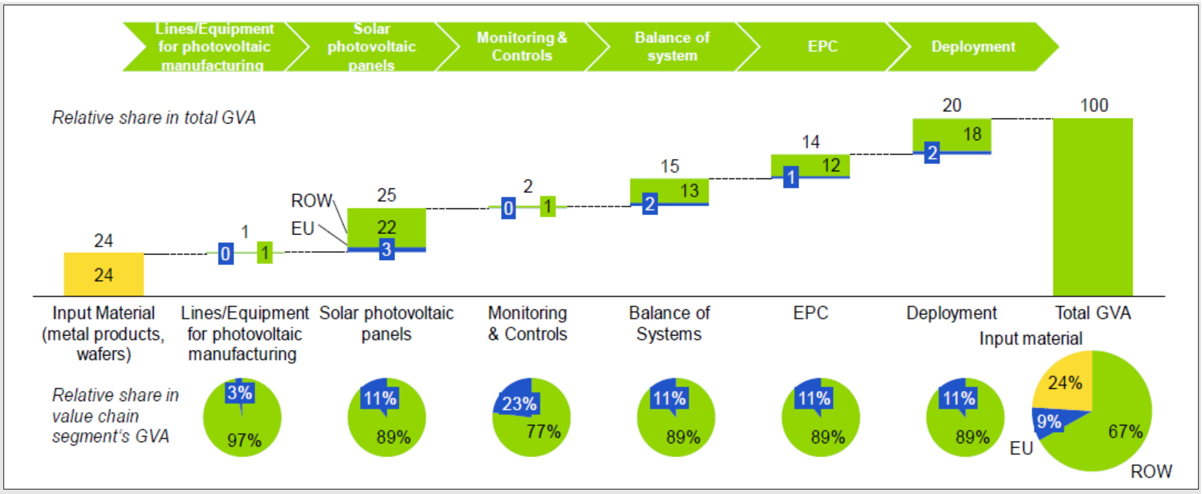


Figure 10: 2020 breakdown of GVA throughout solar PV value chain. Source: Guidehouse Insights.

A key issue has been China's lower (up to -35%) manufacturing costs compared to Europe. Manufacturing costs in China are also 10% lower than in India and 20% lower than in the United States.[123] Other studies show smaller differences, *e.g.* advanced manufacturing techniques can help, but at present EU locations are penalised by high energy and labour costs, lack of an integrated supply chain and regulatory restrictions. This is also important because the downwards trend of PV manufacturing costs (20% learning rate) is set to continue. For the EU, the levelised cost of PV electricity is expected to decrease from 2020 values of EUR 0.050/kWh to 0.020/kWh, to the range EUR 0.020/kWh to 0.010/kWh in 2050.[124] Another aspect of the cost reduction is the resulting pressure on margins for PV producers. These are historically below 10% and this deterred investment in the EU and USA in the last decade.

---

[121] Progress on competitiveness of clean energy technologies 4 & 5 - Solar PV and Heat pumps Progress on competitiveness of clean energy technologies 4 & 5 - Solar PV and Heat pumps

[122] CETO: Photovoltaics in the European Union – 2022 Status Report on Technology Development, Trends, Value Chains and Markets CETO: Photovoltaics in the European Union – 2022 Status Report on Technology Development, Trends, Value Chains and Markets

[123] IEA Special Report on Solar PV Global Supply Chains', Special Report on Solar PV Global Supply Chains IEA Special Report on Solar PV Global Supply Chains', Special Report on Solar PV Global Supply Chains

[124] ETIP-PV PV the cheapest electricity source almost everywhere (https://etip-pv.eu/publications/fact-sheets/)

Looking at employment, PV-related jobs in the EU have steadily increased to above 200 000 in 2021[125] and are expected to further increase significantly.[126] Installation jobs lead the way (80%), with manufacturing at 9%, O&M at 4% and end-of-life/recycling at 3%.

In term of location, Germany remains a focal point (Table 12). Module production is more widely distributed.

Table 12: European PV manufacturing landscape in 2022127

	GWp/a	Country (Company)
mg-Si	38.2	Iceland (Stakkberg, pcc SE), Norway (Wacker Norway, ELKEM)
Poly-Si	22.1	Germany (Wacker, Silicon Products), Norway (REC Solar Norway)
Ingot/wafer	1.4	Norway (Norwegian Crystals, NorSun), France (EDF PW)
Cell	0.8	Germany (MeyerBurger), Hungary (Ecosolifer), Lithuania (Solitek/Valoe), Italy (ENEL)
Module	8.3	Over 20 EU locations, generally at modest scale (average approx. 200 MW per plant.)

Technology status

Crystalline silicon is the predominant technology (with a 95% market share) and this is expected to continue until 2030 and beyond, albeit with a continuous stream of innovations. Along the supply chain, the EU is a technology leader in polysilicon (Wacker Chemie), as well as manufacturing equipment. The EU has also been a leader for equipment manufacturing and inverters. The EU has several module manufacturing sites, but few at the GW-scale that is now the industry norm. The EU also has several world-leading R&D clusters for silicon PV.

Thin-film PV technologies are the other main technologies for PV, and some can be a promising alternative to crystalline silicon in the medium term. There are only a few European producers (mostly branches of Asian companies) for CIGS (copper indium gallium selenide) technology and none for CdTe (cadmium telluride) technology. The EU has a high expertise in perovskite PV technology. Several companies are starting pilot lines of production lines (Evolar, Saule Technologies, OxfordPV and Solaronix). China is also developing the technology (GCL Photoelectric Materials plans 1 GW production). Tandem technologies and in particular perovskite-silicon, characterised by very high efficiency, are expected to enter the market in 3-5 years.

The average efficiency of silicon cell-based modules has increased from 15.1% in 2011 to 20.9% in 2021. This is thanks to the use of larger cut wafers and higher efficiency solar cells,

[125] IRENA/EurObserv'ER

[126] CETO: Photovoltaics in the European Union – 2022 Status Report on Technology Development, Trends, Value Chains and Markets
CETO: Photovoltaics in the European Union – 2022 Status Report on Technology Development, Trends, Value Chains and Markets

[127] Fraunhofer ISE

including multi-junction cells designs. Europe has notable expertise and a lead in the promising perovskites technology, for which several EU companies such as Evolar (Sweden), Saule Technologies (Poland) and Solaronix (France) are currently setting up production lines. Continued technological progress in solar Photovoltaics is critical to achieving cost-effective grid decarbonisation and greater economy-wide decarbonisation. Research and innovation (R&I) can play an important role in keeping photovoltaic technologies on current or accelerated cost-reduction trajectories. For example, a 60% reduction in PV energy costs by 2030 could be achieved via improvements in photovoltaic efficiency, lifetime energy yield, and cost Further advances are also needed in areas including energy storage, load flexibility, generation flexibility, and inverter-based resource capabilities for grid services. With the requisite improvements, PV technologies may proliferate in novel configurations associated with agriculture, waterbodies, buildings, and other parts of the built environment.

Innovation is also needed in PV materials and manufacturing processes to ensure that a TW annual market is sustainable. The supply of critical materials used in current module designs may be a limitation to some options.[128] Here circularity can also play a role and the EU is leader in pilot plants for recycling.

Market perception status

Global Venture Capital (VC) investments increased sharply in 2021 to EUR 1.35 billion (EU share was about 10%). JRC analysis for 2016-2021 showed that the scaling-up phase is preferred over start-up investment. China saw a large increase in VC investments to EUR 890 million in the period 2016-2020.

Current production and expansion plans

With the annual EU potential market set to grow from 50 to 100[129] GW by 2030, a status quo approach would leave EU manufacturers supplying less than 5% of the EU PV module market and the EU being almost completely reliant on imports for the rest. By contrast, the REPowerEU strategy foresees growing EU manufacturing capabilities to supply 25 to 35% of the EU market, along the full supply chain. This is supported by the new European Solar Photovoltaic Industry Alliance, and stakeholder initiatives and estimates such as from the European Solar Manufacturing Council.[130] At the same time a series of expansion plans was announced in Europe by 2025. These include 30 GW for polysilicon, 15-20 GW for ingots and wafers, about 20 GW for cells and about 20 GW for modules.[131] Turning all these into operating plants remains a challenge, but it does confirm significant investor interest in building a new solar PV industry in Europe.

[128] JRC Briefing Note, Criticalities in Supply Chains for the REPowerEU Plan, Ares(2022)8706058 - 15/12/2022

[129] Strategic Research and Innovation Agenda   Strategic Research and Innovation Agenda

130 https://esmc.solar/wp-content/uploads/2020/08/Press-release_ESMC-delivers-backbone-proposals-for-the-European-Solar-PV-Industry-Alliance-before-its-launch.pdf

[131] McKinsey, Rebuilding Europe's solar supply chain, December 2022, online

Obstacles

The high electricity prices in the EU are a commercial risk for polysilicon manufacturers, *e.g.* Wacker consumed about 6 TWh of electricity in 2020, about 1.2% of German demand[132].

The lack of financing has been a major obstacle to the setting-up of PV manufacturing plants along the solar value chain. Measures to reduce market risk can also play a role.

The dominance of Chinese companies along the supply chain poses a risk for supply security. It also poses a competitiveness threat, as products manufactured in the EU may struggle to match the cost of imported wafers and modules. However, PV manufacturing in the EU could be competitive under the double condition that (i) it is done in very large gigawatt-scale factories, and (ii) manufacturing targets high-efficient, innovative technologies that are fully integrated across all stages of the value chain (ingot, wafer, cell & module).[133]

International competitiveness of EU production and trade

While the global market has grown strongly over the last decade, the EU share in PV installed capacity has dropped from 68% in 2012 to approximately 17% in 2022. In 2012, the EU accounted for approximately 7% of the global PV module production (40 GW), i.e. around 2.5GWp, while in 2020, the EU's share decreased to 3%, i.e. around 4.5 GWp out of 140 GW globally.134 In 2012 the average PV module price was around EUR 0.80/Wp, and in December 2022, the spot price for mainstream crystalline PV modules was EUR 0.30/W135.

The EU has been a leader in production equipment and in manufacturing. However, the two main EU-based inverter manufacturers, SMA (Germany) and Power Electronics (Spain), have gradually seen their market share reduced (from 14% in 2018 to 11% in 2021). The EU's share in global export for the period 2019-2021 was 13%. The trade balance has been in deficit since 2012, reaching EUR -9.2 billion in 2021. The EU is importing mainly from China (82%), but also from Malaysia (7%), Japan (5%), Korea and Taiwan.

The EU's solar strategy[136] aims to reverse the declining trend observed in public and private funding in the PV industry. It addresses the main bottlenecks and barriers to investment with a view to accelerating deployment, ensuring security of supply and maximising the socio-economic benefits of PV energy throughout the value chain. The European Solar PV Industry Alliance, one of the concrete initiatives of the EU solar energy strategy, was formally endorsed by the Commission in October 2022, and it aims at scaling up manufacturing technologies of innovative solar photovoltaic products and components.

---

[132] Wacker, Sustainability report 2019/20

[133] https://www.ise.fraunhofer.de/en/press-media/news/2019/study-european-solar-industry-could-be-ready-for-a-comeback.html https://www.ise.fraunhofer.de/en/press-media/news/2019/study-european-solar-industry-could-be-ready-for-a-comeback.html

[134] Fraunhofer ISE, Photovoltaics Report -2022

[135] https://www.pvxchange.com/Price-Index

[136] COM(2022) 221 final

The EU remains a strong innovator in the field, with a significant number of publications and patent applications recorded in 2017-2019. Germany alone ranks fifth in the world in the patenting of high-value inventions in PV.

Solar Thermal for Power and Heat

Concentrated solar power (CSP) plants incorporating thermal storage offer a dispatchable suply of renewable elctricity. Global installed capacity is approximately 7 GW. In the EU, plans to add 6 GW by 2030 are moving forward slowly for now. CSP technology has made big steps forward on cost reduction and reliability. However to become more competitive, further standardisation in design and manufacturing can be key to attracting the levels of investment needed to bring deployment rates back on track. Several EU companies are traditional leaders for this technology but now face stiff competition from China. [137]

Solar thermal collectors are installed in over 10 million EU households, representing just over 40 GWth. The market returned to modest growth (+2.4%) in 2021. There are several European manufactures and ten are in the world top 20[138]. There is also a large EU market for industrial process heat in the range 150 to 400 °CoC, a part of which can be addressed by concentrated solar heat systems. EU companies are in a good position as technology suppliers, but challenges include availability of space at the potential industrial locations, the need for integrated system concepts customised to user load profiles and access to financing appropriate to industry needs. Solar thermal is also an option for supplying district heat systems.

137 Taylor, N., et al, *Clean Energy Technology Observatory: Concentrated Solar Power and Heat in the European Union - 2022 Status Report on Technology Development, Trends, Value Chains and Markets,* European Commission, 2022, doi:10.2760/080204, JRC130811

138 EUR'Observ'RE Solar Thermal and Concentrated Solar Power Barometer, July 2022

C. Batteries

Strengths	Weaknesses
- Strong EU demand for batteries, accounting for almost quarter of the entire global demand. - EVs are currently the main application for batteries. The significant size of the EU car industry, as well as new CO_2 emission standards and the mandatory phase-out of the internal combustion engine in the EU ensures a sustained source of present and future demand for batteries in EVs. - IPCEI batteries is promoting battery production.	- EU head-quartered companies don't have extensive experience in the mass production of Li-ion batteries and battery cell production equipment is mainly imported from Asia. - Battery packs produced in the EU (and the US) are 40% to 60% more expensive than the similar size packs produced in China.
Opportunities	**Threats**
- Global demand for batteries, which is expected to increase six-fold from 2022 to 2030. - New battery technologies are emerging, such as sodium-ion and redox-flow, which do not require critical raw materials and are safer and have the potential to be cheaper.	- Critical raw materials account for 50-70% of battery costs, so future prices are sensitive to CRM prices and cannot be reliably predicted - The EU battery industry is highly dependent on third countries for sourcing of raw materials and the EU has no lithium refining capacity In addition, this supply is often concentrated in countries/regions with high geopolitical risks.

Batteries are a key enabling technology for the electrification of economies and the transition to renewable energy sources, with the main applications being batteries for electric vehicles (EV) and stationary batteries for energy storage.

KPIs

The market for batteries is developing fast. The current EU lithium-ion battery demand is approx. 140 GWh per year, and this is expected to grow fast in the next years, although 2030 demand projections vary considerably: from around 362 GWh per year to about 1000 GWh per year.[139]

Battery deployment is dominated and is expected to remain dominated for the foreseeable future by electric vehicles, while stationary applications are also a growing market.[140] This summary focuses on these two main markets, although other applications, e.g. 12 V car batteries and portable electronics batteries should not be forgotten.

EV batteries & car sales

The EU has a strong position in car production accounting for almost 8 % of gross domestic product[141] and due to the shift to electric vehicles, battery cell production is ramping up close to automotive manufacturing clusters, often in collaboration with or (co-)owned by OEMs.

In the EU, just over 2 million electric vehicles (pure electric and plug-in) were sold in 2022, which corresponds to a market share of 21.5 %.[142] In 2021 the corresponding number was 1.75 million in the EU, and for comparison, 3.3 million in China and 0.63 million in the US. The rate of growth of both the Chinese and US EV markets are higher than in the EU. The capacity of all EV batteries deployed worldwide in 2021 was 278 GWh and is expected that annual deployment will exceed 2 100 GWh by 2030.[143]

Stationary application batteries

In comparison to EV batteries, deployment of stationary batteries was much lower, globally at 22 GWh in 2021 with an expected increase to around 250 GWh in 2030 (150 GWh grid scale plus 99 GWh behind-the-meter).[144] In the EU, installation of energy storage systems of about 3.7 GWh in 2021 is lagging behind installations in US or China.[145] While Europe outpaces both China and the US for renewable energy capacity growth, this is not the case for stationary battery deployment: the EU has a much more robust and dense electricity grid as compared to other regions, limiting dependence on storage.

Battery prices

According to the BloombergNEF's annual battery price survey, in 2021 global battery prices fell by 89% in real terms from above USD 1 200/kWh in 2010 to USD 132/kWh.[146](Figure 11). These prices represent a weighted average across all regions and applications, including different types of EVs, buses and stationary storage. Battery packs were cheapest in China, at USD 111/kWh while in the U.S. and Europe the cost was

[139] A 2030 lithium-ion battery annual demand range for the EU of 362 GWh/year to 754 GWh/year is provided byVDI/VDE Innovation and Technik GmbH (Market Analysis Report Q4 2021), whereas BNEF estimates 744 GWh/year (dataset "Localising clean energy supply chains comes at a cost") and EBA 1000 GWh/year (European Battery Alliance Discussion Paper for the 7th High-Level Meeting of the European Battery Alliance. Published 1 March 2023)").

[140] CETO; RhoMotion, EV & Battery Quarterly Outlook Q4 2021; Battery Energy Stationary Storage Outlook Q1 2022, 2022

[141] ACEA Economic and Market Report State of the EU auto industry

[142] ACEA Fuel types of new cars: battery electric 12.1%, hybrid 22.6% and petrol 36.4% market share full-year 2022

[143] CETO, RhoMotion, EV & Battery Quarterly Outlook Q4 2021

[144] CETO, RhoMotion, EV & Battery Quarterly Outlook Q4 2021

[145] [EASE/EMMES 6.0]

[146] BloombergNEF, Nov 2021

respectively 40% and 60% higher. This also reflects wider use of cheaper LFP (lithium iron phosphate) cells in recent years, especially in China.

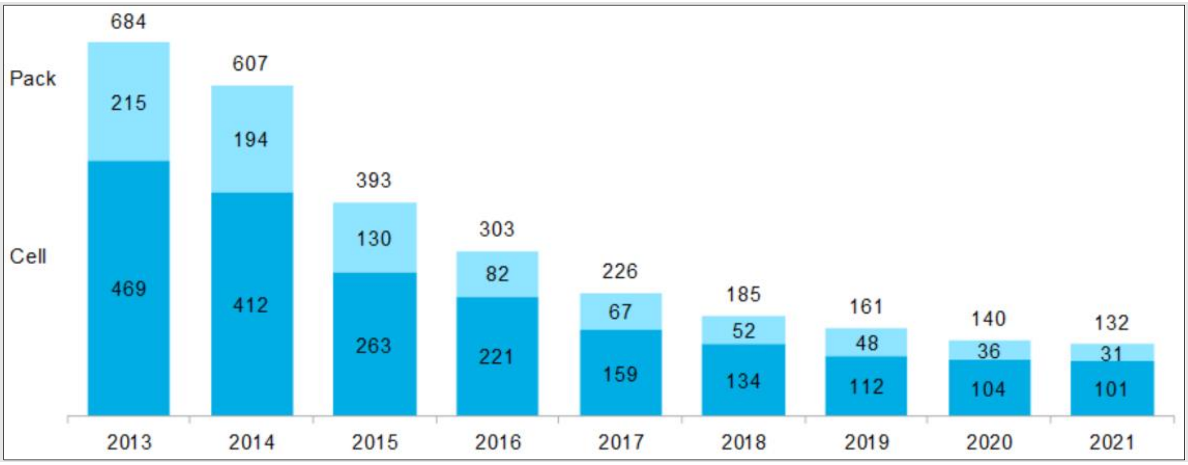


Figure 11: Volume weighted average pack and cell price split (real 2021 USD/kWh). Source: BloombergNEF, Nov 2021

In 2022 in the EU, the price for EV batteries at system level varied between 125 EUR/kWh for LFP batteries and 150 EUR/kWh for NMC622 or NMC712 (nickel manganese cobalt mixed oxide, numbers depict ratios of the metals). Those prices are expected to decrease to 95 to 110 EUR/kWh, respectively in 2030.[147]

Worldwide, Li-ion batteries make up about 90% of the stationary battery storage market. The prices for stationary Li-ion systems are dropping, but the cost reduction has been slower than in electric vehicles. In 2022 the whole system costs between 300 and 400 EUR/kWh (for grid-scale applications,[148] depending on configuration of the storage system, which the cost of the Li-ion battery system is between 100 and 140 EUR/kWh depending on the chemistry. The cost of other types of battery storage systems varies depending on the technology from 150 to 400 USD/kWh, for lead-acid and zinc-bromine redox flow batteries, respectively.[149] Home batteries with a storage capacity of ~10 kWh cost 600–2000 USD/kWh, i.e. are considerable more expensive per kWh than grid scale installations.[150] BESS market solutions are less developed than EVs, so it may be expected that the potential for cost reduction is relatively higher than in mobility applications. Increasing market maturity will reduce cost.

Technology status

Currently the main driver of battery development is the EV sector and in stationary applications usually the same cells are used. However it is however expected that in the

[147] RhoMotion, EV & Battery Quarterly Outlook Q4 2021, 2021

[148] Aurora Energy Research, How high can battery cost get?, 2022

[149] RhoMotion Battery Energy Stationary Storage Outlook Q1 2022, 2022

[150] RhoMotion, Battery Energy Stationary Storage Outlook Q1 2022, 2022

future, development of EV and stationary batteries will decouple, as both applications focus on different aspects. The currently dominant battery chemistry is Li-ion (LFP, NCA and NMC622). In the future, Li-ion will still dominate (LFP, NMC811+), but competition will arise from other technologies offering typically either higher energy density or lower cost. The role of sodium-ion, redox-flow batteries and high temperature sodium-based technologies will significantly increase, while lead acid batteries will remain on the market with a reducing share. Sodium-ion batteries have already been commercialised in China, are comparably safe, cheap and do not require critical raw materials. These properties make sodium-ion competitive, even though offering a lower energy density than high performance lithium-ion chemistries (but remaining above the energy density of lithium-ion LFP batteries). China is aiming to build the whole sodium-ion batteries supply chain by 2024 and is planning to use sodium-ion cells in EV hybrid (lithium-ion + sodium-ion) battery packs from the same year. Redox-flow batteries are flexible in power and energy scaling, potentially suitable for seasonal energy storage. The most developed chemistry is based on vanadium, but many chemistries e.g. relying on cheap, non-toxic and non-critical materials are possible. Non-vanadium redox-flow batteries are starting to appear on the batteries market on commercial conditions. High temperature sodium-based batteries are well-established, particularly sodium-sulphur and sodium metal halide batteries. They combine high energy and power densities, long lifetimes, longer storage duration than lithium-ion and use of low-cost materials. With these characteristics, they are most suitable for grid scale storage, and most of the recent deployments come from this sector.

The battery ecosystem has developed strongly in the EU, ramping up technology development and production capacities. Car manufacturing is currently the dominant force in battery development, however the highest growth rate expected in batteries is for stationary energy storage. However, further investment in R&I for batteries is required if Europe and European industry is to become net-zero.

Market perception status

Considerable research is on-going to develop higher energy density technologies, such as lithium-ion batteries employing silicone rich (durability issues, first solutions already on the market) or lithium metal (difficult production, expected by 2030) anodes, solid state (high costs, difficult production, commercial for some niche applications) or lithium-sulphur batteries (durability issues).

At battery-pack level the development focusses on increasing energy density, reducing costs and combining energy storage and structural functions (incremental improvements). At application level the significant change is a shift in EV industry interest to LFP lithium-ion cells for application in economic EV models. Similar interest might be expected for sodium-ion cells.

Current production and expansion plans

Currently, the leading cell producers in the EU are mostly the local subsidiaries of Far East companies The estimated production capacity in the EU was approximately 75 GWh/year in 2022 (not to be confused with actual production; also reaching the nominal production capacity needs up to five years for optimisation of processes). Numerous enlargements of existing and new production plants have already been announced.

EU companies are also active and are preparing a significant number of battery cell production facilities (Figure 12).[151] It is projected that the EU will have a manufacturing capacity of some 886 GWh per year by 2030, sufficient to cover 89% of the expected EU demand for batteries (Figure 13).[152]

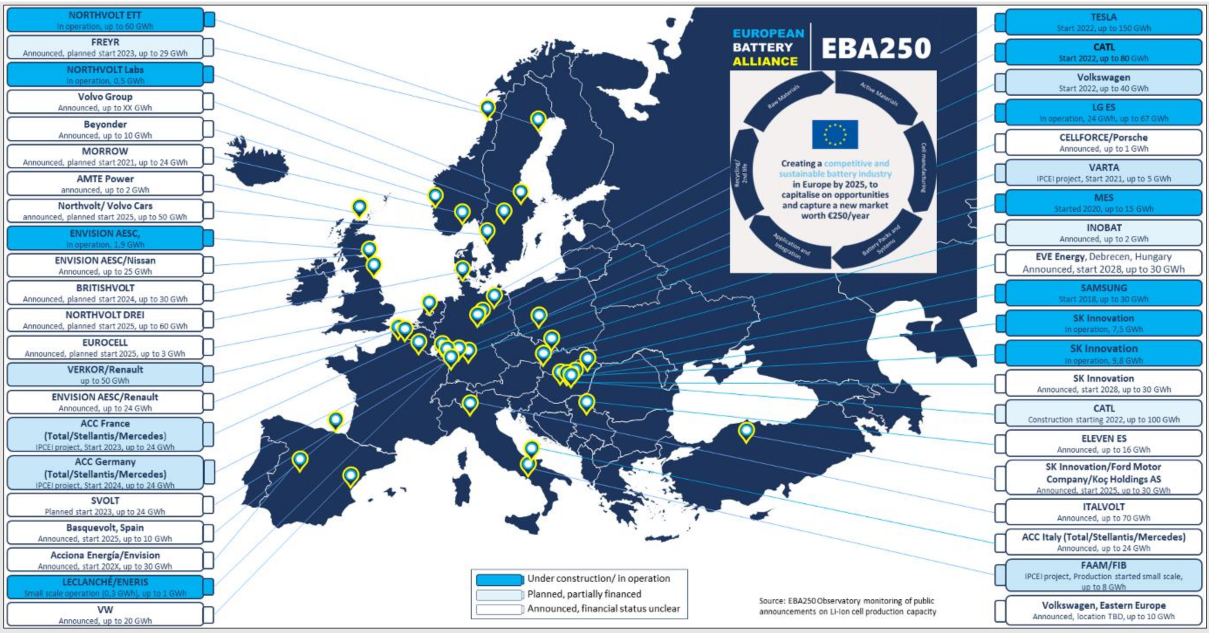


Figure 12: Existing and announced battery cell production plants in Europe. Source: EBA250, 2021

---

[151] EBA250, 2021

[152] EIT Innoenergy, Contribution for High-Level ministerial meeting on batteries, February 2022 and https://www.eba250.com/].

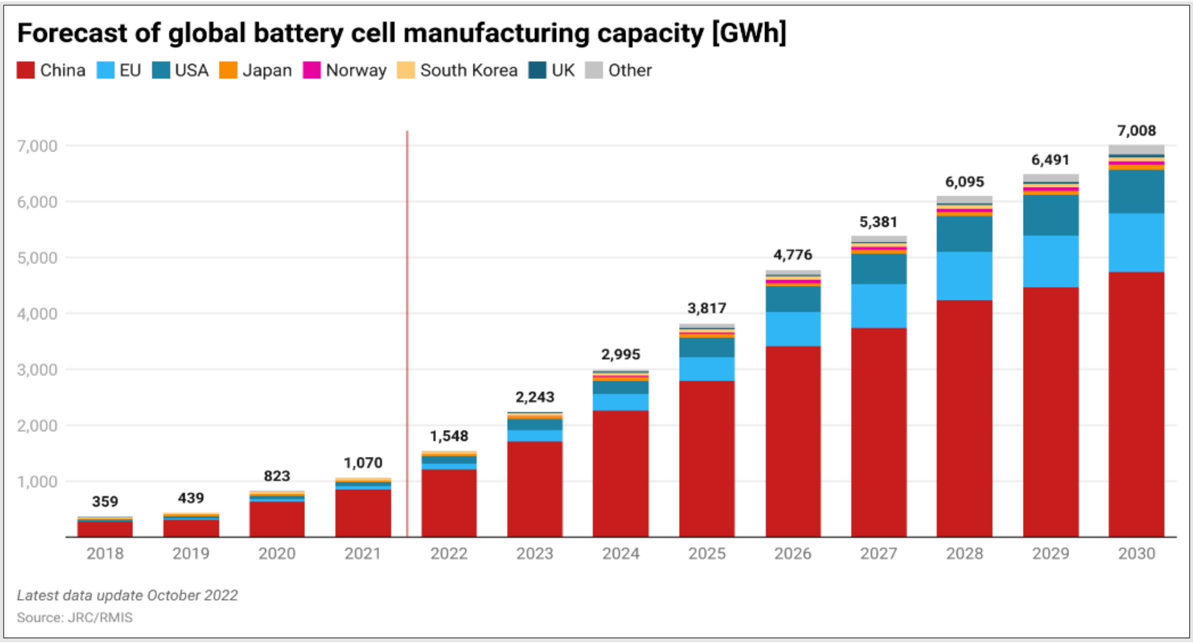


Figure 13: Forecast of global battery cell manufacturing capacity. Source: JRC/RMIS

EU companies face several challenges: the EU battery industry is highly dependent on third countries for sourcing of raw materials (Figure 14) and EU has no lithium refining capacity.

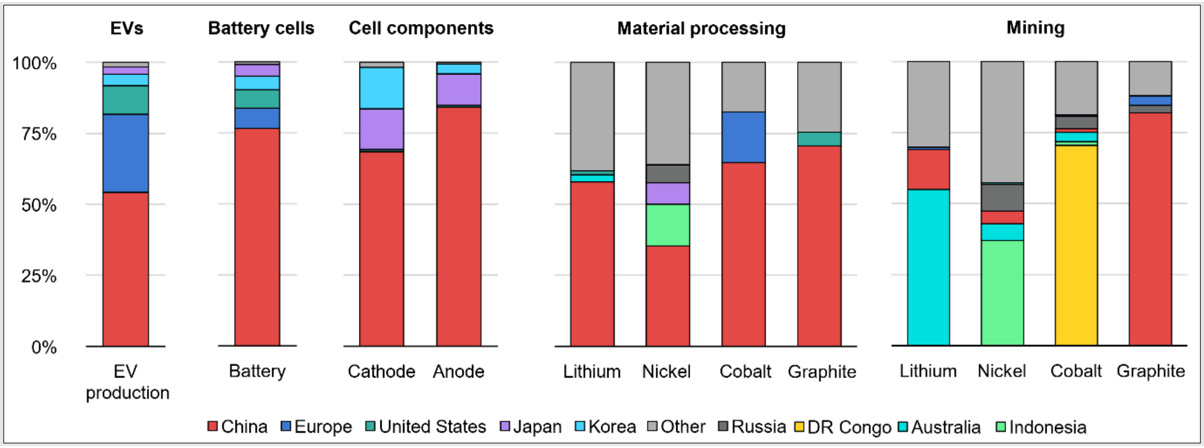


Figure 14: Geographical distribution of production/capacity by element of the supply chain in 2021. Source: IEA Global Electric Vehicle Outlook 2022.

EU head-quartered companies do not yet have extensive experience in the mass production of Li-ion batteries and battery cell production equipment is mainly imported from Asia. EU head-quartered companies face a big challenge to be able to mass-produce battery cells at globally competitive prices.

Currently, the EU is focusing on the development and setting up the production of high-performance cells and batteries, like nickel-rich NMC as they are targeted by EV companies. The less well performing chemistries, like LFP, sodium-ion or redox-flow are not in the focus of European players.

International competitiveness of EU production and trade

Around USD 300 billion of investment in new lithium-ion battery gigafactories has been announced over the last four years and USD 131 committed last year, with the global production of lithium of lithium-ion batteries projected to increase five-fold by 2030 (dominated by China with 70%) as a result of these investments and the world adding last year 102 gigafactories with 31 TWh of potential new capacity.[153]

Overall, the cost of raw materials contribute significantly, usually 50-70%, to total battery cost. so future prices are rather sensitive to the prices of key raw materials and cannot be reliably predicted, given the volatility of raw material markets. Battery materials supply is often concentrated in specific countries/regions

In 2020, the global market of Li-ion batteries exceeded that for lead-acid batteries in value USD 47 billion vs USD 37.5 billion. In terms of storage capacity, lead-acid battery sales were still ahead in 2021 with 410 GWh vs 305 GWh for Li-ion respectively, but if the trends continue, in 2022 the Li-ion should have outpaced lead-acid batteries reaching about 490 GWh.[154]

Currently the EU focusses on development and setting the production of high-performance cells and batteries, like nickel-rich NMC as they are targeted by EV companies. The less performing chemistries, like LFP, sodium-ion or redox-flow are not in focus of European players.

The EU has a strong position in the lead acid battery market, with a turnover of over EUR 7 billion, and is a net-export. Europe accounts for ~20% of global supply, which is about 75 GWh/year.[155,156,157] For lithium-ion battery cells production the EU's ~7% of global supply is competing mainly with China's ~77% of global supply, and the US ~5% of global supply.

Even if the EU is strong in the segment of integration/final products (EVs and stationary storage), it is rather weak when it comes to raw materials, advanced materials (although cathode materials, electrolyte, separator are improving) and equipment for manufacturing of Li-ion cells.[158]

[153] Benchmark Mineral Intelligence "Investment in battery gigafactories near USD 300 billion since 2019 as China extends battery dominance", 4th of January 2023

[154] https://www.eurobat.org/images/Avicenne_EU_Market_-_summary_110321.pdf

[155] Avicenne energy, EU battery demand and supply (2019-2030) in a global context, 2021: https://www.eurobat.org/images/Avicenne_EU_Market_-_summary_110321.pdf

[156] Statista, 2021

[157] Markets and Markets, Battery energy storage system market, 2020.

[158] JRC Clean Energy Technology Observatory Report on Batteries for Energy Storage in the European Union, November 2022

D. Heat Pumps and geothermal energy technologies

Heat pumps

Strengths	Weaknesses
- Rapid sales growth (+38% in 2022, +34% in 2021[159]) sustaining high revenues. - High market share of EU manufacturers (73%). - Relatively common raw materials; few heat pump-specific components; relatively straightforward assembly. Like other EU manufacturing sectors in terms of energy and resource consumption, processes, labour costs, etc. - No specific supply risk, high degree of component commonality with other products, and lifetimes of around 17 years. - Manufacturing sites in several Member States; mix of EU ownership/headquarters (e.g. Viessmann, Bosch) and some local subsidiaries (e.g. Daikin). - Very mature technology, no breakthroughs needed in short term; high activity in incremental innovation, e.g., cost, efficiency, size, noise, refrigerants. - Strong investment pipeline to 2025 (~ EUR 5 billion) on track to deliver projected sales in the medium term (i.e. 2030). - High local content in the sector: renovation and construction workforce are highly local	- In the short-term customers in several countries are experiencing delays. - General shortage of labour in the EU for both manufacturing and installation (gas boiler phaseout might help somewhat). - Beyond manufacturing, a general shortage in the EU of specialised profiles needed for installation and maintenance (e.g. plumbers, electricians, engineers, architects). Integration of heat pump-specific skills in curricula for such trades and better recognition of qualifications also needed.
Opportunities	**Threats**
- Strong technological lead of EU companies. The EU is particularly strong in geothermal and large heat pumps, for which development of district heating represents an opportunity. - Experience of EU manufacturers with refrigerants alternative to F-gases. The phaseout of such refrigerants may represent an opportunity for the EU heat pump value chain overall in the medium term. Under the Montreal Protocol, all countries have binding obligations to reduce HFCs that are used in heat pumps. Heat pumps avoiding these substances will also find markets outside the EU. - Early integration with smart grids would increase interoperability and benefits for users. - Entry of heat pump manufacturers from outside the EU could be a threat (see right), but via acquisitions or creation of subsidiaries new entrants could also bring capital investment, innovation and economies of scale.	- An increasing share of extra-EU imports is a threat for EU manufacturing. Imports from China have been rising for the past two years but from a low base and in the context of very rapid deployment overall. EU manufacturing capacity is adjusting, and extra-EU manufacturers may create subsidiaries in the EU, if they have not already, threatening current leaders.

[159] Note that EHPA data is for 18 Member States, Norway, Switzerland and the United Kingdom. See www.ehpa.org/press_releases/heat-pump-record-3-million-units-sold-in-2022-contributing-to-repowereu-targets/.

KPIs

Around 3 million heat pumps for heating and hot water were sold in Europe in 2022 (Figure 15) and there were around EUR 14-17 billion[160] in revenues (for the full value chain including installation), with heat pump price falling significantly in recent years (Figure 16). The market share of EU manufacturing in EU sales is between 60% and 73% (according to different sources). In 2021, 117 000 employees worked in the heat pump value chain, with around 37% (44 000) in manufacturing. Location and ownership of companies is a mix of SMEs and several large companies with manufacturing sites in several Member States (more than 170 manufacturing sites in total), with a small number of recent examples of consolidation in the sector.

Manufacturing sites are present in at least 18 Member States, with Germany and Italy in the lead; manufacturing of components is more diffuse – including from outside the EU.

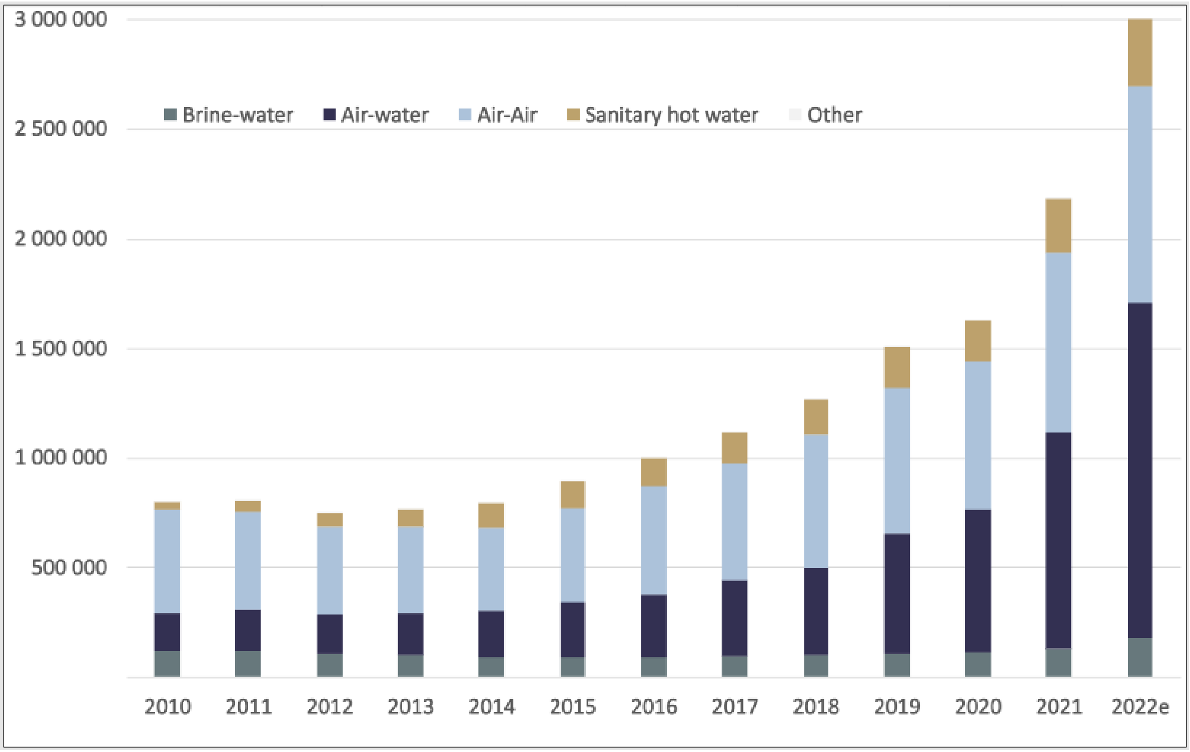


Figure 15: Heat pumps sold in Europe (source EHPA, 2023).

[160] Based on EHPA data.

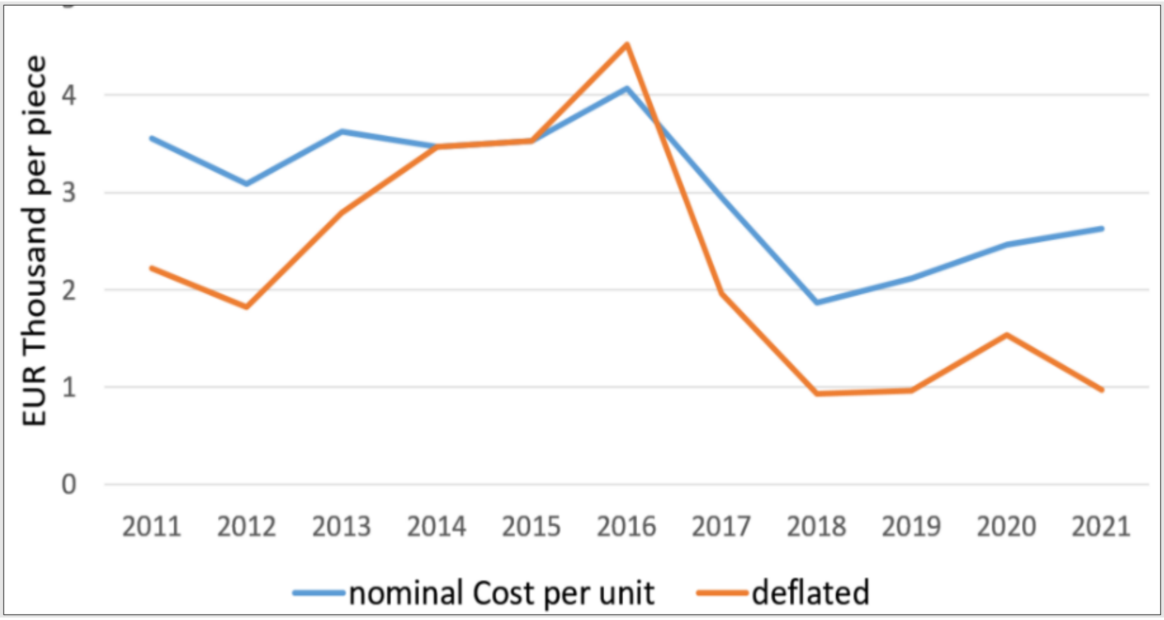


Figure 16: Cost per heat pump (excl. air conditioning). CIndECS, JRC, forthcoming 2023.

Technology status

EU manufacturers of heat pumps are technological leaders in all areas, especially in larger heat pumps for the commercial and district heating segments. EU manufacturers are technology leaders in air-water, ground-water and brine-water heat pumps. Within air-water heat pumps, European manufacturers lead in monoblocs while Asian manufacturers lead in split systems. The EU is also a technology leader in use of natural refrigerants, in noise reduction and energy efficiency, and in sorption heat pumps.

There is no clear next generation of heat pumps as such. Heat pumps are very mature technology. That said, there are important areas of incremental innovation, aimed notably at increasing efficiency; reducing cost, size, noise and installation time; fostering systems integration; and shifting to natural refrigerants. By far the dominant type of heat pump (>95%) is the electric compression heat pump. Thermally driven (i.e., gas-fired) heat pumps are also available, but sales are counted in the thousands rather than the millions. There are also small but growing numbers of hybrid heat pump systems, combining a heat pump with a boiler. These alternatives are also mature technology. No major breakthrough is expected to reach widespread deployment by 2030. Alternatives that are not yet mature are: Magneto-caloric heat pumps (TRL 2-4); Thermo-acoustic heat pumps (TRL 4); Transcritical thermal compression heat pumps (TRL 4); Membrane heat pumps (TRL 5-6).

The new generation of technology will be characterised by a phasing-in of alternative (natural) refrigerants to F-gases. The adoption of new refrigerants is underway and they are expected to be in widespread use within a few years.

Market perception status

From the customer's perspective, the up-front cost, the need to have a well isolated house and lack of financing options is still a major barrier. Market concentration is not a specific risk for heat pumps.

Current production and expansion plans

Current production and expansion plans appear to be on track to meet demand to 2030 and beyond. However, lags in delivery are being experienced in several countries in the short term, due also to shortage of installers and semiconductors. The average annual growth rate of heat pump sales in Europe during 2019-2021 was 20%. According to the European Heat Pump Association (EHPA), there are at least EUR 5billion of investment in the pipeline to 2025.[161]

The EU heat pumps sector is established, innovative and well positioned to benefit from increasing deployment. Heat pump manufacturers commonly also manufacture other heating equipment such as gas boilers. Development of manufacturing in the EU could include a combination of addingion of production lines at existing sites, conversion of production lines at existing sites (e.g., from boilers to heat pumps) and some new sites. There are no particular factors limiting new industrial capacity in Europe for heat pumps other than those applying to manufacturing in the EU in general.

Obstacles

The most pressing short-term bottleneck in terms of materials or components has been in semiconductors, as part of the global shortage. In general, heat pumps contribute positively to security of supply – perhaps more than for any other technology in this assessment due to their direct displacement of gas.

International competitiveness of EU production

It is not possible to compare unit costs with third countries without defining what should be included (raw materials, labour costs, manufacturing cost, energy costs, taxes, etc.). In general, factors in the international competitiveness of manufacturing businesses include things like local demand for the products in question, local economic growth, availability and cost of labour, government incentives to industry in general, tax, distance to market in the case of exports, supply chain of components, etc. Since, extra-EU imports remain relatively small, we can deduce that EU production should be currently competitive.

Extra-EU imports increased from EUR 455 million in 2020 to EUR 902 million in 2021 (Figure 17). However, the reasons behind that jump are not clear so it is too soon to confirm a

[161] As of December 2022, source EHPA.

medium-term trend. Following that increase, extra-EU imports are 27% of EU apparent consumption (production and net imports).

The EU itself has a strong presence in global trade as extra-EU exports accounted for 37% of world exports during 2019-2021.[162] Over the same period, 68% of imports by Member States came from other Member States.

Thus, there is a very recent trend of rising imports, in particular from China, but from a small base and it is unclear if the trend will continue. Most (73%) heat pumps sold in the EU are manufactured in the EU and that situation is likely to continue. The heating market, as part of the buildings sector, has strong local characteristics; potential for disruption might come from large air conditioning manufacturers from outside the EU who are targeting the EU market, or EU manufacturers marketing their more innovative, sustainable models outside the EU. It is unclear how easy either development would be.

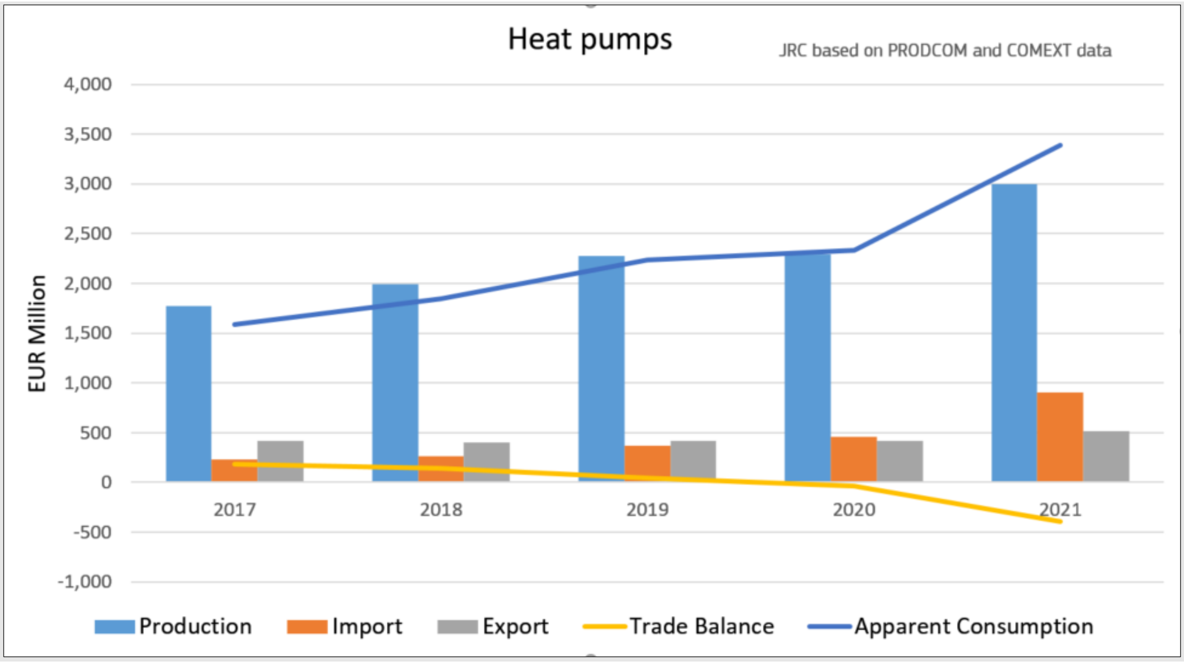


Figure 17: Heat pump production, imports and exports. Source: Adapted from CIndECS, JRC, forthcoming 2023.

Factors influencing investment decisions in heat pump manufacturing facilities are common to other equipment industries. A possible exception is perhaps the local nature of heating markets due to differences in climate, building stock, standards and installers' practices. Based on announcements by EU heat pump manufacturers expanding their capacity, it seems that three years are necessary on average to completely disburse the investments This might vary depending on whether they are considering greenfield investment or conversion of an existing production line.

[162] CIndECS (forthcoming).

Geothermal energy technologies

Ground-source heat pumps use geothermal energy and are included in the analysis above. To reiterate, such heat pumps have higher up-front costs but often greater efficiency and exhibit strong EU technology leadership, yet they have not experienced as rapid sales growth as other types. Other geothermal energy technologies operate at larger scales (and depths) in office buildings, groups of dwellings, industry, power generation, and district heating and cooling (DHC).

Technology status and next generation

Geothermal energy technologies are very mature. The European Geothermal Energy Council (EGEC) reports 142 geothermal power plants, with six added in 2021, and 364 geothermal DHC networks, with 14 new in 2021 (in addition to more than 2 million ground-source heat pumps).[163]

The Horizon Europe project PUSH-IT started in January 2023 with the aim of demonstrating the use of high-temperature geothermal reservoirs to provide energy storage. There is also an ongoing call for integration of geothermal heating and cooling in industry. Geothermal is already providing competitive and stable heat supply at scale to industries that need temperatures up to 200°C: agri-food, paper, plastics, etc. (for more information and examples, see the relevant SET Plan working group).

Deep geothermal energy for *electricity* generation has seen steady growth in a number of countries, reaching a total installed capacity of around 14.4 GW in 2021. The EU's net capacity was 877 MWe in 2021, but growth is well below the global trend. For geothermal *heat* production in the EU, the outlook is more promising, with EurObserv'ER expecting growth from 870.5 ktoe in 2020 to 1 000 ktoe in 2030. In particular the geothermal DHC sector has shown a growth rate in installed capacity of 6% (JRC CETO, 2022). Deep geothermal projects still face high up-front costs and often complicated licensing issues. In addition, availability of subsurface data is often limited. With a general focus on electricity in the energy discussion, geothermal projects are often at a competitive disadvantage. However, the new urgency for measures to decarbonise heating in national or European energy debates may change this. The EU maintains a strong position in R&D investment, high-value patents and scientific publications in this field. Nonetheless, public R&D funding for geothermal energy in general has usually been far below that for other technologies.

Current production and expansion plans, and international competitiveness

Current production has been growing, although more slowly than some other clean energy technologies and remains very low compared to the potential, which is large in almost all

163 EGEC Geothermal Market Report 2021.

Member States. In France for example, geothermal is only 1% of final energy for heating and 5% of district heat.164

Geothermal energy – and district heating in general – involves multiple actors and significant up-front investment. This can be a disadvantage in terms of rapid deployment scale-up but perhaps an advantage in terms of international competitiveness relative to a value chain with a traded good at its heart, such as heat pumps. A new district heating project with geothermal can be deployed in as little as three years, but often takes considerably longer from planning to connection.

As with other clean energy technologies, geothermal also provides competitiveness benefits to end users, through lower and more stable energy bills. Moreover, its use in a district heating network can also help to unlock the off-site use of unavoidable waste heat.

164 Géothermie: un plan d'action pour accélerer, Ministère de la transition énergétique, 2 February 2023.

E. Electrolysers and fuel cells

Electrolysers

Strengths	Weaknesses
- Strong momentum in the European and Global markets. Ambitious targets at EU level - Europe's (EU, EFTA and UK) cumulative deployments are accelerating. Deployment pipeline is for now still the largest globally. Plans are growing year after year and if announcements are materialised EU targets can be reached by 2030 if not before. - Important public finance pipeline for hydrogen projects (IPCEIs, Innovation Fund, Recovery and Resilience Plan, etc.) incentivising electrolyser production - Europe is most advanced technologically with good presence in the PEM electrolysers market and is dominating the Solid Oxide electrolysers one. - Electrolysers manufacturing capacity can be called up relatively fast and new production built relatively quickly.	-.At current scale, European manufacturing costs for the electrolyser systems are high compared to those in China. - Lack of standardisation and international trade dimension. - Lack of fully mature markets and solid deployment drivers in Europe for electrolysers and clean hydrogen production. - Electrolysers manufacturing capacity can reach full potential only if demand is secured. - Hydrogen value chains are strongly dependent on investments in infrastructure and renewable electricity generation.
Opportunities	**Threats**
- Completion of the EU regulatory framework for renewable and low carbon hydrogen and gasses, including sub targets for use in industry and transport. - Momentum reached with manufacturing industry announcing the establishment of gigawatt factories in Europe. - Research and Innovation initiatives should pursue opportunities to substitute CRMs and define recycling solutions. - There is a strong interest to develop the scale of the European electrolysers manufacturing and deployment industries. - IPCEI hydrogen paves the way for a clean hydrogen value chain.	- Lack of official international codes and monitoring exercises for hydrogen and hydrogen technologies able to capture the technological complexity of the current markets. - At current scale, European costs of production and assembly of stacks seems currently not to be competitive compared to other economies. Strong international competition can partly arise due to local subsidies abroad. - While labour for electrolysers will only be a fraction of that necessary for developing renewable energy production, competition among sectors for securing workforce is possible due to a shortage of relevant available skilled workforce. - Strong EU dependence on concentrated supplies of critical raw materials and components necessary for the development of electrolysers manufacturing at scale.

KPIs

Electrolysers are for now divided into three main technologies: alkaline, proton exchange membrane (PEM) and solid oxide. Due to the different features of these technologies, the SWOT analysis can differ depending on the electrolyser technologies. In Europe and America, alkaline electrolysers costs are estimated around 1 100-600 EUR/kW, PEM electrolysers costs around 1 300-900 EUR/kW and solid oxide electrolysers costs are estimated at more than 2 000 EUR/kW. Overall CAPEX for system deployment have already been significantly reduced in the last ten years –especially for PEM. Even higher CAPEX reductions are expected for solid oxide electrolysis. Production costs for alkaline and PEM electrolysers are expected to roughly halve in 2030 compared to today thanks to economies of scale, automation and manufacturing expertise gains. The relative cost of electrolyser systems will also be impacted not only by increased manufacturing volumes, but also by producing larger and larger units. A range of EUR 60-150 million has been estimated for setting up, or upgrading a plant with a capacity of 1 GW/y. Some estimates[165] quantify the amount of employment linked with the manufacturing capacity of 1 GW of electrolysers per year as 500 – 1000 FTE. Developing European hydrogen production capacity of 10 million tons/year would imply the creation of roughly 440000 jobs, of which the majority will be linked with renewable electricity generation[166]. Production, deployment, operation and maintenance of hydrogen value chains in general and water electrolysis in particular will required the availability of a dedicated workforce with the right technical skillset, which should encompass not only general engineering expertise, but also specific competences require for dealing with hydrogen technologies.

Technology status

The three technologies mentioned above are currently dominating the market, with alkaline being the most mature, PEM being the second technology widely commercially available and solid oxide having reached the market last[167]. Currently it is difficult to have accurate figures for hydrogen and electrolysers markets and investments. Clear official classifications codes and monitoring exercises able to distinguish the sources of hydrogen flows or the different hydrogen technologies, such as electrolysers, are missing. Reporting is based on available press releases or business insight.

Market perception status

Hydrogen is perceived as an important technology for the decarbonization of hard-to-abate sectors such as heavy industries and electrolysers represent an essential component of the renewable hydrogen production infrastructure. However, due to the hydrogen market being in

[165] IEA (2023), Energy Technology Perspectives 2023, IEA, Paris https://www.iea.org/reports/energy-technology-perspectives-2023

[166] European Commission. Joint Research Centre. “Clean Energy Technology Observatory, Water Electrolysis and Hydrogen in the European Union: Status Report on Technology Development, Trends, Value Chains and Markets : 2022.” LU: Publications Office, 2022.

[167] Anion Exchange Membrane electrolysis (AEM) is an emerging technology which could penetrate markets in the medium term, but it is still at a much lower TRL than the other three options and will not be considered here.

its infancy, in Europe and globally, for now there is little knowledge in terms of sales and revenues.

IEA estimates[168] the funding needed to establish a European infrastructure able to achieve the production of 10 million tonnes of hydrogen per year and import of the same magnitude from outside of the EU by 2030 at USD 72-87 billion (54% of total investments are on EU territory and 19% are needed for electrolysers development). This is in line with Commission estimates[169] for reaching the targeted deployment of electrolysers by 2030 in the range EUR 50 - 75 billion. Funds for producing and deploying electrolysers will always be a fraction of those needed for deploying sufficient renewable electricity capacity and bringing hydrogen value chain to their full maturity. According to recent estimates[170], in 2021, global venture capital for hydrogen-related activities reached almost EUR 2 billion with a significant increase from previous years in the size of agreed deals. It is estimated that around a fifth of the total investments has been aimed at developing or targeting electrolysers or hydrogen production.[171]

Current production and expansion plans

Global manufacturing capacity at the end of 2022 was estimated[172] at 15.2 GW/y, which is more than double a 2021 estimate[173] of 6.7 GW/y (of which about two third alkaline and one-third PEM). It is expected[174] to double again at the end of 2023, reaching 31.1 GW/y. It seems that production capacity is significantly underutilised especially in Europe and the US[175]. This is probably caused by a mismatch between manufacturing capacity and deployment demand. According to Hydrogen Europe[176], the most cited reasons for recent delays in deployment of European capacities include “regulatory uncertainty”, “lack of financial incentives”, and “supply chain/ pandemic delays”. Regulatory uncertainty is also perceived as one major issue hindering the scaling up of hydrogen deployment. Final investment decisions have reportedly been put on hold in late 2022.[177]

168 IEA (2022), World Energy Outlook 2022, IEA, Paris https://www.iea.org/reports/world-energy-outlook-2022

169 COMMISSION STAFF WORKING DOCUMENT IMPLEMENTING THE REPOWER EU ACTION PLAN: INVESTMENT NEEDS, HYDROGEN ACCELERATOR AND ACHIEVING THE BIO-METHANE TARGETS, 2022, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022SC0230&from=EN

170 Hydrogen Europe. “Clean Hydrogen Monitor 2022.” Hydrogen Europe, October 2022.

171 European Commission. Joint Research Centre. “Clean Energy Technology Observatory, Water Electrolysis and Hydrogen in the European Union: Status Report on Technology Development, Trends, Value Chains and Markets : 2022.” LU: Publications Office, 2022.

172 BloombergNEF, Energy Transition Investment Trends 2023, Tracking global investment in the low-carbon energy transition, January 2023.

173 Bloomberg NEF, 1H 2022 Hydrogen Market Outlook.

174 BloombergNEF, Energy Transition Investment Trends 2023, Tracking global investment in the low-carbon energy transition, January 2023.

175 Bloomberg NEF, 1H 2022 Hydrogen Market Outlook.

176 Hydrogen Europe. “Clean Hydrogen Monitor 2022.” Hydrogen Europe, October 2022.

177 https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/electric-power/122322-europe-struggles-to-maintain-hydrogen-momentum-into-2023#

Obstacles

One of the main obstacles the European deployment of electrolysers will be facing is the availability of raw materials. More than 40 raw materials and 60 processed materials are required for the production of electrolysers. Across all electrolyser technologies, the major suppliers of raw materials for electrolysers are based in China (37%), South Africa (11%) and Russia (7%).[178]

Iridium supply is a significant bottleneck for the deployment of PEM electrolysers at large scale. South Africa dominates the supply of platinum group metals, providing 94% of global iridium production. Alkaline electrolysers mainly require steel, aluminium and nickel. The main supply of these raw materials comes from China. The EU seems to dominate the processed materials, components and electrolyser stacks manufacturing in terms of number of companies, but falls behind China when it comes to final electrolyser manufacturing capacity volumes. Europe seems to maintain a strongly dominant position in the still relatively marginal solid oxide electrolyser stacks manufacturing and components. However, China still dominates the raw materials supply for this technology. Overall, the EU share in supplying the raw materials is only 2%. European shares increase the closer to the final product in the electrolyser value chain is considered. Finally, a push for hydrogen deployment will marginally increase the pressure on materials supply for the renewable electricity sector.[179] [180]

International competitiveness of EU production and trade

As of August 2022, European electrolysers manufacturing capacity amounts to about 3.3 GW/y. Europe accounts for roughly 20% of current world manufacturing capacity, with China undisputedly dominating the current production market, especially for alkaline electrolysis. Estimates for 2021-2022[181] allocate around a half of worldwide alkaline electrolysis manufacturing capacity to Chinese companies, and most of the production capacity for PEM electrolysers to American companies. Chinese manufacturing companies can offer installed system costs for alkaline electrolysis which in 2021 were assessed to be from half, to up four times lower than those of western companies.[182] [183] The lower cost of Chinese electrolysers is due to the availability of cheap workforce, the presence of more developed local supply chains and the possibility of cheaper designs linked to less stringent performance requirements. According to electrolyser manufacturers, differences in technical

[178] European Commission. 2020. "Critical Raw Materials for Strategic Technologies and Sectors in the EU - A Foresight Study". LU: Publications Office, 2022

[179] IEA (2023), Energy Technology Perspectives 2023, IEA, Paris

[180] European Commission. Joint Research Centre. “Clean Energy Technology Observatory, Water Electrolysis and Hydrogen in the European Union: Status Report on Technology Development, Trends, Value Chains and Markets : 2022.” LU: Publications Office, 2022.

[181] Bloomberg NEF, 1H 2022 Hydrogen Market Outlook

[182] Bloomberg NEF, 1H 2022 Hydrogen Market Outlook.

[183] IEA (2022), Global Hydrogen Review 2022, IEA, Paris https://www.iea.org/reports/global-hydrogen-review-2022

norms and standards regarding the grade of steel used in electrolysers may constraint the trade of Alkaline electrolysers from China[184].

At the moment, Europe has a clear lead in terms of Solid Oxide electrolysis and also hosts a very large number of companies producing electrolyser stacks or systems across every technological platform. Europe is also expected[185] to catch up in terms of market shares for electrolysers manufacturing capacity in the following 2-3 years and reach around 40% of the market, more or less equalling the share of Chinese manufacturers. This is partly explained by a mix of higher local demand (gauged by keeping track of announcements issued by manufactures in the recent past) and proximity of manufacturing capacity close to deployment markets. It does not take into account initiatives such as the incentives granted under the USA IRA, which could significantly alter the relative weight of American market share. By 2030 European manufacturing capacity is expected to reach 53 GW/y, provided that all the announced plants are realised and exploited at full capacity.

Shipping of full electrolyser systems is not expected to be economically viable due to their weight. Electrolysers manufacturing is usually located in relative proximity to deployment sites, since large electrolysers installations will have to be tailored to the needs of a specific project. This does not imply that smaller, but crucial system components could be traded and distributed towards assembly lines. Lack of standardisation for stacks and balance-of-plant components hampers the development of trade and more open value chains.

Installations costs for setting up manufacturing production capacity for electrolysers are not expected to be different in the USA with respect to the EU. However, recent US policy measures (the Defence Production Act of June 2022, the Infrastructure Investment and Jobs Act and the American Inflation Reduction Act) impacting hydrogen value chains could foster a shift in manufacturers investment decisions. One possible risk is that Europe will receive significant imports of cheap renewable hydrogen from the USA, undercutting European players. However, this does not seem likely since the US market for hydrogen should absorb most of its production in the long term. Moreover, the trade of hydrogen and hydrogen carriers might add a significant cost premium, partly because transporting hydrogen over long distances increases the costs for hydrogen at the point of delivery. A second risk is that electrolysers manufacturing companies will divert investments from the EU to the USA to profit from the incentives, slowing down investment in EU capacity. Ultimately, the incentives for electrolysers manufacturers to move to the USA are linked more to the expected growth in demand triggered by the IRA. Evidence for this trend is weak at the moment and no shift in manufacturing investments have been announced to date.

In order to drive the cost of electrolysers down there is a strong push from European companies towards a higher degree of automation of the whole manufacturing processes. Development times for new electrolysers manufacturing sites are estimated to be between 2

[184] HydrogenInsight “Cheap Chinese hydrogen electrolysers will not flood global markets or damage Western suppliers”, December 2022

[185] Bloomberg NEF, 1H 2022 Hydrogen Market Outlook.

and 3 years. Most manufacturers are currently in the design/pre-operation phases and expect to enter full-scale operation of their manufacturing capacities between 2025 and 2030.

Fuel Cells

Fuel cells are a downstream component of hydrogen value chains and can be used to transform a hydrogen[186] input into an electricity output. Fuel cells can be used for portable, stationary and mobility applications and therefore play a key role in developing hydrogen demand.

The overall global shipment of fuel cells in 2021 was estimated at around 2.3 GW[187] with a potential manufacturing capacity of around 19 GW/y[188]. This would imply a significantly underutilised global manufacturing capacity. Setting up a new fuel cells manufacturing plant takes between 1.5 and 2.5 years.

As regards trade in fuel cells, it is worth noting that most of the worldwide markets and manufacturing capacity are located in Asia (roughly 65%), followed by the US (41%) and Europe (9%). Europe is a net importer, with Japan clearly outlined as a net exporter due to its dominance in the development and production of fuel cells cars. China and the USA are close to a net zero trade balance.

As in previous years, the 2021 market was dominated by fuel cells used in the transport sector and almost three quarters of fuel cells shipments were linked with fuel cells electric cars which are mainly produced by two Japanese companies. Adding other vehicles such as buses and material handling vehicles like forklifts increases the market share for mobility application to roughly 85% of shipped capacity[189]. [190] This implies that around four fifths of the market currently relies on the production and the integration of PEM fuel cells systems, which are heavily dependent on platinum and sulfonated polymer membranes supplies. New mobility applications such as maritime, train transport and especially trucks could increase the market even further, provided that battery-based alternatives will not become more economically competitive.

More than 20% of deployed fuel cells are used for stationary applications[190]. Europe significantly lags in the stationary fuel cells market since it has a stable electrical grid, less generous support schemes and combined heat and power applications that offer lower thermal efficiencies than heat pumps. The European market is also integrating fuels cells rather than producing them, and fuel cells markets remain quite small.

[186] Fuels other than hydrogen are possible, but they will not be considered in this document..

[187] E4tech (2022), The Fuel Cell Industry Review 2021, E4tech, https://fuelcellindustryreview.com/

[188] IEA (2023) “Energy Technology Perspectives 2023”, International Energy Agency

[189] E4tech (2022), The Fuel Cell Industry Review 2021, E4tech, https://fuelcellindustryreview.com/

F. Carbon capture and storage (CCS)

Strengths	Weaknesses
- Significant share (24%) of key players are European or are active in the field through their European subsidiaries - Leading position of the EU in CCS in industry and CO_2 capture technologies	- Long lead times for CCS projects, low actual investments in the value chain up to today - Lack of developed storage sites blocks investment across the whole value chain - Costs of components are highly variable - Strong opportunity costs for aging gas fields
Opportunities	**Threats**
- Rapidly growing sector in the near future - Strong EU Research and Innovation landscape - CCS projects profitable with forecasted carbon prices, allows hard-to-abate industries to decarbonise - Large industrial base in the EU with significant potential for capture - New revenue streams for oil and gas companies in transition	- Lack of EU CO2 storage and transport infrastructure leading to coordination problems with capturing projects, risking underdevelopment of the EU value chain. - Risk of reduced access EU industry to CCS as an abatement option, which for some sectors is still the only deep decarbonisation option - Lack of public acceptance or national legal barriers

KPIs

CO2 capture, transport and storage (CCS) technology components are commercially available for most industries but there are only very few commercial projects in operation worldwide. The global market was worth USD 6.4 billion in 2022 with Europe being a leader in industrial CCS.[190] When looking at the value chain of CCS, Czechia (0.048%), Ireland (0.046%) and Italy (0.031%) show the highest value added (in % of GDP) for CCS in the EU.[191]

Market research identified 186 key companies worldwide with activity in CCS.[192] 24% of the key players are European or are active in the field through their European subsidiaries. The US is leading with 42% of the key companies being American or based in the US. In the EU, companies have been mostly involved in project development in the energy-intensive industries (steel, cement, chemicals). In North America, most of CCS development is in ethanol production, natural gas processing and power generation. A lot of projects in the US also mostly use the injected CO2 to increase oil production from aging oil fields, a practice

[190] BloombergNEF, Energy Transition Investment Trends 2023, Tracking global investment in the low-carbon energy transition, January 2023.

[191] It is important to notice that there is also economic activity related to CCS in countries without actual projects in operation (or in planning and construction).

[192] However, depending on the boundaries set for the value chain, other research suggests about 17 000 companies involved in all aspects of the CCUS supply chain including technology providers, services, legal aspects (Kapetaki, 2022).

known as enhanced oil recovery.[193] This puts the EU in a leading position when it comes to developing a climate mitigation-focused CCS in industry.

Technology status

While in the mid-2000s it was primarily the power sector that was involved in CCS, the focus has now shifted to industry such as cement, steel and chemical as well as oil & gas.

Today, two technology approaches are being used to capture CO2 from the air: liquid and solid systems. Key technology vendors include EU companies, both for commercially available technologies and for technologies at lower readiness levels. In addition to CO2 capture from point sources, direct air capture is one set of technologies to extract CO2 directly from the atmosphere.

In general, first-generation capture technologies are currently commercially available but research and development on necessary improvements is ongoing. Second generation capture technologies are currently in the R&D phase and third generation technologies are at very early stages of development. Some of those technologies have not evolved in the last 10 years, perhaps indicating some fundamental challenges to further development (e.g., material stability, extreme operating conditions). In addition to CO2 capture from point sources, direct air capture is one set of technologies to extract CO2 directly from the atmosphere.

When looking at investments in research and innovation from 2015, six EU companies (Air Liquide, Shell, Linde, Sabic, Merck, and Maersk) were amongst the top 20 global companies. Other leading EU companies are Anheuser Busch Inbev, BASF, Solvay, and Haldor Topsoe[194]

Overall CCS is less exposed to critical raw material risks than other technologies. Materials used for injection wells include corrosion resistant alloys. Depending on their composition, they may contain critical materials, such as titanium and cobalt, but also other materials such as nickel. The latter may become subject to shortages or price volatilities due to geopolitical and/or environmental conditions.[195] Supply chain risks of CCS have not been subject to a thorough assessment yet.

Market perception status

According to the Global CCS Institute, there are 16 major technology providers of commercially available CO_2 capture technologies worldwide and 5 of them are EU companies (Air Liquide, Axens, Leilac Group, Saipem, Shell).[196] For CO_2 transport, 2 out of 5 key companies are in the EU (MAN Energy Solutions, Svanehøj). On CO_2 storage, none of the companies listed are in the EU. On the full value chain, 1 company is an EU company

[193] https://sgp.fas.org/crs/misc/R44902.pdf

[194] Specific Report (2022) Carbon Capture, Utilisation and Storage in the European Union, European Commission, JRC130663

[195] See also: Parker, M., Meyer, J., Meadows, S., 2009. Carbon Dioxide Enhanced Oil Recovery Injection Operations Technologies. Energy Procedia 1, 3141–3148. https://doi.org/10.1016/j.egypro.2009.02.096 and

ZEP, 2011: The costs of CO2 storage. Zero Emission Platform.

[196] State of the art: CCS technologies 2022. Global CCS Institute.

(Linde). In summary, the EU is well positioned on CO_2 capture technologies but is behind compared to the US and Canada when it comes to transport, storage and the full value chain.

JRC analysis shows that the USA is the leader in early-stage venture capital investments with investments amounting to EUR 277 million between 2016-2021.[197] In the EU, Sweden ranks highest in CCS venture capital with EUR 4.5 million between 2016 and 2021. It is interesting to note that in some countries (e.g. Germany) investments between 2010 and 2015 were notable but strongly decreased in 2016-2021.

Current production and expansion plans

Less than 2 million tons of CO2 per year are currently being stored geologically in the EEA while the CO2 capture projects already selected for support from the ETS Innovation Fund will require 4.6 million tons of CO2 storage capacity per year by 2029.

Industrial sectors whose process emissions are hard to abate (e.g. cement) increasingly develop investment plans to capture CO2, to either reuse the CO2 to produce fuels/chemicals (CCU), or permanently store the CO2 (CCS). Such investments are expected to give positive economic returns before 2030 based on current and projected carbon prices. Industry stakeholders have estimated that up to 80 Mtpa[198] of capture capacity can be expected to be online by 2030, which will require similar amounts of annual storage capacity. In addition, the Commission’s impact assessment for reaching climate neutrality by 2050, indicates that annual storage capacities will need to increase substantially after 2030.

The central bottleneck for CCS investments is the (un)availability of operating CO2 storage sites in Europe[199]. In January 2023, the next 1 Mtpa of storage capacity put on the EU market was oversubscribed close to 20 times. The projects supported by the Innovation Fund have so far not been able to secure CO_2 storage capacity.

Several storage projects are currently in different stages of the permitting process in Europe. The most advanced projects respond to, or are a part of, national support schemes for CO2 value chains, which address the cross-chain risks. No project has so far taken a final investment decision.

Obstacles

The main cost components of a complete CCS value chain are CO2 capture and purifying; $CO2_2$ dehydration and compression/liquefaction; transport; injection, monitoring, reporting and verification of stored CO2. The costs for the various components are highly variable, depending on the purity of CO2 in exhaust streams, transportation distance and CO_2 mass. Indicative unit costs in EUR/ton CO2 range between 28-55 for capture, 4-11 for transport,

[197] Kapetaki, Z., 2022. Carbon Capture Utilisation and Storage in the European Union – 2022. Clean Energy Observatory Status Report on Technology Development Trends, Value Chains and Markets (No. JRC130663). European Commission.

[198] According to needs calculation by CCUS Forum stakeholder CCUS Forum coalition (industry, NGOs); no Final Investment Decisions (FID) taken – pending availability of storage sites.

[199] The development of the storage sites in Europe is also hampered by the unavailability of storage data.

and 8-30 for storage.[200] Some important cost factors for CCS in Europe are gas prices (influencing the economic viability of further exploiting gas fields, fuel, and energy costs), accessibility and costs of materials, labour (similar skillsets needed for oil and gas production and CCS). Overall these cost estimates match current and projected carbon prices, and thus in principle would allow for a viable supply chain to be developed. Therefore the different participants in the value chain have the prospect of making a net profit from these investments, if developed in a coordinated manner.

The first entrants on the CO2 storage market are expected to be oil and gas companies as they are best placed to deal with subsoil assets, considering their knowledge and experience. Often they already have the rights to typical storage sites linked to oil & gas exploration and exploitation. Also by developing storage sites they create opportunities for their own long-term business strategies (e.g. the production of blue hydrogen, natural gas processing). The first service offers on the market will be strongly driven by oil & gas companies that have an inherent comparative advantage to develop such projects. This is further confirmed by the fact that they are already competing against each other to secure rights for exploration of other future storage sites. Still uncertainty remains in place if the oil & gas sector will develop and implement sufficient projects in a timely way and at a scale that allows the value chain to develop in a coordinated manner considering competing demand for capital and resource allocation. While developing storage sites will significantly depend on assets, skills and know-how in the oil & gas industry, it is a sector that is accustomed to revenue models with higher returns on shorter time frames than in CCS.

However, investments needed to develop an EU a storage capacity by 2030 equal to 50 Mtpa are limited. Estimates give a broad range depending on the characteristics of the storage site with onshore storage cheaper than offshore, depleted Oil & Gas Fields (DOGF) cheaper than deep saline aquifers (SA), larger reservoirs/sites cheaper than smaller ones and high injection volumes cheaper than lower injection volumes. Estimates range as low as EUR 300 million or as high as EUR 10.5 billion[201]. Important, this capacity will likely be in operation for several decades, and thus will continue to operate and generate revenues after 2030 towards 2050.

The fossil fuel industry will collectively benefit if investments into storage capacity are made, allowing the creation of corresponding market demand in hard-to-abate industries. Investments of CO2 capturing industries need to be de-risked and made bankable based on a market of storage capacities that is line with the aggregated needs in Member States/regions.

Another obstacle to develop the theoretical geological storage capacities, which are identified by Geological Services in Member States[202], into operational CO2 injection capacities in

[200] Reference year 2020. From draft ENTEC study, modified after Danish Energy Agency and Energinet (2021). Technology Data – Carbon Capture, Transport and Storage, 151p. http://www.ens.dk/teknologikatalog.

[201] Based on estimates as presented in: The Costs of CO2 Storage Post-demonstration CCS in the EU, Zero Emissions Platform (ZEP) 2011, https://zeroemissionsplatform.eu/wp-content/uploads/CO2-Storage-Report.pdf. Estimated investment costs for 50 Mtpa of CO2 injection capacity in 2030 by type of storage site with 40-year lifetime, adjusted for inflation up to 2022.

[202] http://www.co2geonet.com/state-of-play/

permitted storage sites is the often missing awareness of this vital decarbonisation option for hard-to-abate industrial companies, while public concerns often focus on safety aspects of storage sites. Concerns that carbon capture and storage would prolong the use of fossil fuels have also contributed to underdeveloped political support in promising regions and the lack of necessary implementing legislations or insufficient administrative capacities for permitting procedures in accordance with Directive 2009/31/EC.

International competitiveness

The US Inflation Reduction Act of 2022 includes important enhancements to tax credits available for CCS. They support deployment until 1 January 2033 with corporate projects receiving direct pay for the first 5 years after the carbon capture equipment is put into operation: Industrial and power facilities - USD 85/tonne; enhanced oil recovery - USD 60/ton; direct air capture and storage - USD 180/tonne; direct air capture and utilization - USD 130/tonne. This important financial support might weaken the EU position in the global CCS sector.

G. Biomethane

Strengths	Weaknesses
- Strong EU position in the global biogas and biomethane market - anaerobic digestion technologies are available and demonstrated from small to large scale - Many biogas and biomethane plant manufacturers exist in the EU - Several biogas upgrading technologies to biomethane available developed by EU companies - EU technology providers have a strong market position with some competition from North America - Biomethane can replace natural gas on short term in hard to electrify industries, such as chemical and steel, as well as in transport	- High capital cost and operation cost - Economic viability depends mostly on investment cost but also on the availability of low-cost feedstock - Grid injection is not always possible, as biogas and biomethane plants are built in areas where feedstock is available - Biogas and biomethane facilities are often at small to medium scale, due to the availability of feedstock, leading to high costs of biomethane - Additional CAPEX for grid injection - High biomethane cost compared to natural gas - Small scale facilities, but complex logistics
Opportunities	**Threats**
- The REPowerEU target represents a good opportunity for the development of the sector -strong synergies with other sectors such as the chemical industry and Carbon Capture, Storage and Utilisation - CO_2 captured can be used in several sectors such as in the food and beverage industry, as a feedstock in the chemical industry or for power-to-X to produce synthetic methane. - A wide range of feedstocks and organic wastes are available - Digestate is a co-product that can be used or sold as low-GHG emissions fertilizer - Biomethane can replace natural gas in existing infrastructure to be used in many sectors (industry, transport, etc.) - Driver of agriculture and industrial development in rural areas and diversification of the rural & circular economy	- High investment costs related mostly to the manufacturing of the biogas production plant and upgrading section - Limited availability of waste feedstock also due to sustainability constraints and competition with alternative uses of feedstock - Low public acceptance, public perception (due to smell of biogas plants, additional traffic, etc.) - Lack of viable business case without incentives for biogas production and lack of competitivity with fossil energy - High market volatility, lack of long term predictability of natural gas prices

Note*: Currently, nearly all biomethane is produced from biogas upgrading, which is what this text is covering. Other alternatives would be synthetic biomethane made from hydrogen, a RFNBO, so please consult the CETO report "RFNBO"*[203] *for the specific SWOT analysis; if it is synthetic biomethane made of syngas from biomass, it is an advanced biofuel, so please consult the "advanced biofuels" CETO report*[204] *for the specific SWOT analysis.*

[203] Buffi M, Scarlat N, Hurtig O, Motola V, Georgakaki A, Letout S, et al. Clean Energy Technology Observatory: Renewable fuels of non-biological origin in the European Union – 2022 Status Report on Technology Development, Trends, Value Chains and Markets. Luxembourg: 2022. https://doi.org/10.2760/76717.

[204] Hurtig O, Scarlat N, Buffi M, Motola V, Georgakaki A, Letout S, et al. Clean Energy Technology Observatory: Advanced Biofuels in the European Union – 2022 Status Report on Technology Development, Trends, Value Chains and Markets. Luxembourg: 2022. https://doi.org/10.1201/b18526.

KPIs

Biogas and biomethane sector has a strong presence in the EU. Further development of the biomethane sector will create good opportunities for the industry, for rural development and the circular economy. Biomethane is produced through upgrading of biogas. Biogas is produced nowadays through anaerobic digestion of agro-residues or organic wastes, manure or crops in agriculture-based biogas plants (agricultural residues and energy crops), industrial biogas plants (food and beverage industry waste, organic municipal solid waste, and sewage sludge) and landfill gas recovery. Although anaerobic digestion is well established technology, some improvements and cost reduction could be expected from improved biological processes. New pre-treatment technologies are being developed to extend feedstock basis to increase feedstock biodegradability to include lignocellulosic biomass (crop residues, straw, etc.). Biogas is used mostly for heat and power production. There are several technologies for biogas upgrading to biomethane, already in use or with high TRL, based on separating CO_2 from biogas stream. There are other technologies to produce biomethane, including gasification followed by methanation to produce a synthetic biomethane, which are expected to become commercial in the future, but that are not considered here due to the low TRL.

The European market for biogas is highly fragmented due to the presence of numerous players, addressing the manufacturing of the equipment for biogas plants and the design and the construction of the biogas and biomethane plants. The market size is currently still small. The main market players in the biogas value chain are European companies. Companies in the European biogas industry are Planet Biogas Global GmbH (Germany), WELTEC BIOPOWER GmbH (Germany), Scandinavian Biogas Fuels International AB (Sweden), EnviTec Biogas AG (Germany), AB HOLDING SPA (Italy), RENERGON International AG (Switzerland), Strabag (Austria), Thoni (Austria), Naskeo Environnement S.A. (France), IES BIOGAS S.r.l (Italy), Zorg Biogas (Switzerland), CombiGas (Denmark), DSM (Netherlands), Yara International ASA (Norway), GM-Green Methane (Italy), etc.

A range of technologies are available for the upgrading of biogas to biomethane that operate commercially[205][206]. Most of the biomethane plants use membrane separation (39% of installed plants in Europe), water scrubbing (22%), chemical scrubbing (18%) or pressure swing adsorption (12%), with a limited number of biomethane plants using cryogenic separation (1%) and physical scrubbing (1%)[207]. Upscaling biomethane upgrading could significantly change those shares. The trend in recent years is to install membrane separation systems whereas chemical scrubbing was initially the most frequently installed technology at new plants[208]. The main differences of the technologies are: separation efficiency (also determining the amount of lost biomethane), heat and electricity needed and CAPEX.

[205] Kirchmeyer F, Stürmer B, Hofmann F, Sainz Arnau A. Categorization of European Biogas Technologies 2020:1–127.

[206] Bioenergy I. Biomethane – factors for a successful sector development Synthesis Report of WP1 of the IEA Bioenergy Intertask project Biomethane – factors for a successful sector development 2021.

[207] European Biogas Association (EBA). EBA Statistical Report 2021 2021.

[208] Bioenergy I. Biomethane – factors for a successful sector development Synthesis Report of WP1 of the IEA Bioenergy Intertask project Biomethane – factors for a successful sector development 2021.

Various European companies provide technologies for biogas to biomethane upgrading, benefitting from the strong technology basis from the chemical industry that developed various solutions, such as reactors, scrubbers and other gas separation systems. Several providers offer Pressurised Water Scrubbing (PWS) solutions where carbon dioxide is separated from the methane through dissolution in water at low temperatures and high pressures (5-10 bar) such as Wärtsilä Biogas Solutions, Carbotech, Flotech Sweden AB, HAASE and Malmberg Water. Pressure Swing Adsorption (PSA), where carbon dioxide is separated from the methane molecules by adsorption on solid surface, is being provided by CarboTech, Gasrec and Greenlane Renewables (Canada). Providers for chemical absorption technologies, where carbon dioxide from biogas dissolves in a chemical solvent (such as amines, sodium hydroxide, potassium hydroxide) for biogas upgrading, especially for high-capacity biogas plants and include several European companies such as Wärtsilä Biogas Solutions, Airco Process Technology and Tecno Project Industriale. Several European companies developed innovative membrane technologies for upgrading biogas into biomethane that include AirLiquide, Evonik, Pentair, UGS, Gruppo AB and Bright Renewables. Companies such as GtS BV and Waga Energy offer cryogenic separation solutions, which uses the different boiling points of various gases, particularly for the separation of carbon dioxide and methane.

According to Eurobserver, the biogas sector in EU employed (directly and indirectly) 65 000 persons in 2016, dropping to 49 000 employees in 2020 (of which 25 000 in Germany). The turnover was steady at around annual 6 bn € from 2018 to 2020, of which almost 4 bn € in Germany[209].

Technology status

In terms of technological development, the EU is leading in biogas and biomethane production. The biogas and biomethane plants in Europe are fed by local feedstock which can be a combination of many typologies and vary by share used in different countries. Recent policies shifted feedstock use away from the use of energy crops towards the use of manure and biowaste and the capture of methane from landfill sites, due to the concerns about the competition for food and feed and land use.

Biogas can be upgraded to biomethane which can be used either to replace natural gas either as a fuel in transport, or for the injection in the natural gas grid for further uses. The production of bio-LNG is growing rapidly in the European Union for the use in heavy duty road transport and in maritime transport. There were 10 bio-LNG plants in Europe in 2020, and this number increased to 23 plants in 2021 with a capacity of 1.2 TWh[210].

The EU biomethane market includes many smaller biomethane plants, with an average plant size of about 400 Nm3/h, as well as plants with larger production capacities. Biomethane plants are larger in size than biogas to electricity plants, although nowadays an increasing

[209] EurObserv-ER. Employment & Turnover 2020 2022. https://www.eurobserv-er.org/online-database/.

[210] Jens J, Gräf D, Schimmel M. Market state and trends in renewable and low-carbon gases in Europe. 2021.

share of smaller biomethane plants are being built[211]. Also, there is a trend of converting small scale biogas electricity plants into biomethane plants. About half of the biomethane plants are connected to the natural gas grid, the rest are fuelling stations.

CO_2 captured can be used in several sectors such as in the food and beverage industry, as a feedstock in the chemical industry or for power-to-X. Cryogenic separation might be of growing importance in case of higher use of biomethane as LNG, benefitting from the integration of methane separation with liquefaction units for the methane. The direct use of CO_2 in the biogas stream through methanation process with the addition of H_2 could also become interesting if hydrogen production becomes cheap enough.

Market perception status

Global VC investments in bio methane ventures amount to € 193.6 million over the 2016-21 period and are growing (+43 %) as compared to the previous half-decade[212]. Since 2016, the EU has attracted 22.5 % of global VC investments (37 % and 19 % of early and late-stage investments respectively) and significantly improved its lagging position over the 2010-15 period. The lower levels of early-stage investments over the recent years and the drop of later stage investments in 2021 however indicate that this is not a generalised trend.

To support the implementation of the REPowerEU Plan, the European Commission initiated a Biomethane Action Plan setting out measures to be taken at both national and European levels to scale up biomethane production and consumption. The plan includes the establishment of the Bio-methane Industrial Partnership (BIP) which promotes participatory multi-stakeholder engagement between the Commission, EU countries, industry representatives, feedstock producers, academia and NGOs. The European Commission proposed a dedicated programme for a new EU framework to decarbonise gas markets, promote hydrogen and reduce methane emissions according to the EU Methane Strategy launched in October 2020.

Current production and expansion plans

The European biogas production has increased 6 folds from 2005 to 2020, although the biogas market stagnated during the last years, accompanied by an important shift from biogas to biomethane production. Today the production of biomethane is still low (3 bcm or 32 TWh) compared the overall biogas supply (18 bcm). However, recently the REPowerEU set a specific target for biomethane production at 35 bcm by 2030, so it is of fundamental importance to ramp up its production in the short-term scenario, both installing new plants and retrofitting existing CHP-based biogas plant. The number of biomethane plants in Europe reached 880 in 2020 in 21 European countries.

---

[211] European Biogas Association (EBA). EBA statistical report 2021. 2021. European Biogas Association (EBA). EBA statistical report 2021. 2021.

[212] Motola V, Scarlat N, Hurtig O, Buffi M, Georgakaki A, Letout S, et al. Clean Energy Technology Observatory: Bioenergy in the European Union – 2022 Status Report on Technology Development, Trends, Value Chains and Markets. Luxembourg: 2022. https://doi.org/10.2760/577104.

The potential biogas and biomethane production estimated for 2030 is between 35 and 42 bcm according to EBA[213]. Other estimates of the biomethane production potential indicates a potential for 2050 of 91 bcm from biogas and 60 bcm from gasification[214] while the International Energy Agency (IEA) calculates a Europe's overall biomethane potential of 125 bcm for 2040 [5]. The current (2020) EU natural gas consumption is around 400 bcm.

RePowerEU can boost the manufacturing capacity and related industries producing the materials, machineries and components and making sure that this part of the value chain stays in Europe. EBA estimates that to reach the RePowerEU targets, around 5,000 additional biogas plants with biomethane upgrading are needed in Europe (with 83 bn € investment)[215], up from around 880 in 2020[216]. Current manufacturing capabilities in EU cover the demand in major biomethane plant components. The need to reach the ambitious 2030 targets requires high annual deployment rates of biomethane plants and equipment supply and a significant annual increase in biomethane production.

Obstacles

The main obstacle for biomethane development rely on high capital cost and operation cost in particular for the biogas production step; in addition investment cost is needed for upgrading and grid injection (compressors, pipeline to the grid, etc.). Biogas and biomethane facilities are at small to medium scale, due to the availability of feedstock, leading to high costs of biomethane compared to natural gas. The deployment of biogas and biomethane production depends in the first place on low-cost and abundant feedstocks close to the plant. The trend to move away from crops (such as silage maize) to wastes limits the amount of available feedstock. Also, grid injection is not always possible, as biogas and biomethane plants are built where feedstock is available while the gas grid is not well developed in all regions of the EU.

According to EBA the biomethane production cost in the EU ranges from 55 €/MWh and 100 €/MWh, depending on plant size, location, feedstock and setup of the plant, which puts it at disadvantage when compared to natural gas.

As most operators are farmers or small companies and the investment costs are quite high (in general between 1 and 2 M€ for the upgrading part[217]) compared to the average benefits, they depend on a stable business case, which currently requires incentives. In countries like Germany where the incentives have been reduced, the number of newly installed plants has decreased sharply. Also, the German biomethane production is growing at a lower rate than that of Denmark, France, the Netherlands and Italy. Biomethane upgrading is still a niche

[213] European Biogas Association. Statistical Report 2022 Tracking biogas and biomethane 2022.

[214] Alberici S, Grimme W, Toop G. Biomethane production potentials in the EU - Feasibility of REPowerEU 2030 targets, production potentials in the Member Biomethane production potentials in the EU. 2022.

[215] European Biogas Association. Breaking Free of the Energy Dependency Trap – Delivering 35 bcm of biomethane by 2030. EuropeanbiogasEu 2022.

[216] European Biogas Association. Statistical Report 2022 Tracking biogas and biomethane 2022.

[217] Ardolino F, Cardamone GF, Parrillo F, Arena U. Biogas-to-biomethane upgrading: A comparative review and assessment in a life cycle perspective. Renew Sustain Energy Rev 2021;139:110588. https://doi.org/10.1016/j.rser.2020.110588.

market, and installations have to be adapted to each plant considering plant size, heat availability and other factors.

International competitiveness of EU production and trade

The EU is the largest producer of biogas today, with a share of more than two thirds of the global biogas production, followed by North America with a share of about 15%. In the United States, biogas is produced mainly through landfill gas recovery, which accounts for nearly 90% of its biogas production, with a trend for increasing biogas production from agricultural waste. In China, biogas production increases as result of policies supporting the installation of household-scale digesters in rural areas. The biogas market development depended in the EU on the various support schemes due to the low economic viability and competition with other energy sources. The biogas market stagnated over the last years in the EU.

The EU has a leading place in electricity production and installed biogas electricity capacity, with almost 12 GW, in comparison to 20 GW installed capacity worldwide. The development of the CHP units emerged as a need to increase the economic viability of biogas plants through the use of heat.

The EU is the largest producer of biomethane worldwide, with a production of 3 bcm in 2030 and a number of 880 biomethane plants. In comparison, there were 1,161 biogas upgrading facilities operating in the world at the end of 2020, with a production capacity of 6.7 bcm per year[218]. EU has been a leader in biogas and upgrading equipment manufacturing. Since there is a fragmented market, statistics on equipment biogas manufacturing and trade are hardly available.

[218] Cedigaz. GLOBAL BIOMETHANE MARKET 2022 ASSESSMENT + DATABASE. 2022

H. Grid technologies: Smart grids and smart electricity meters

The uptake of renewables and distributed and flexible demand is posing enormous challenges the electricity networks. Rapid network expansion is needed to cope which energy systems largely based on variable generation and electrified demands such as EVs or heat pumps. A substantial amount of new lines at all voltage levels (from HVDC and HVAC transmission lines, high-voltage distribution lines, down to low and medium voltage power cables) are therefore required. Moreover, with a more digitalised economy, grids shall rapidly evolve to incorporate more optimal capabilities, especially through the large deployment across Europe of smart electricity grids and applications that enable a more efficient operation of the networks. In addition, offshore renewable energies, for which EU Member States have expressed in 2023 the so-far largest global ambitions in the medium and long terms[219], are driving an unprecedented growth in hybrid interconnector HVDC lines. The demand for substations, power converters and other power components is likewise increasingly rapidly, both onshore and offshore.

All the above are pre-requisites to achieve the energy transition. Investing in manufacturing and deployment of renewable and clean technologies without a parallel investment in cables and substations, will lead to electricity grids becoming bottlenecks and showstoppers of the energy transition, instead of enablers. That is why electricity grids are increasingly becoming a key part of the total supply costs, understanding supply as the compound of generation, transmission and distribution costs: power grids share of such costs has evolved from 27% in the decade of the 2020s, to 37% in the decade of the 2030s. Motivated by the trends in the sector, this trend will only grow towards the 2050s.

Already by 2030, the EU requires EUR 584 billion investments to cover the needs in electricity grids. In contrast, the current budget available for energy under the Connecting Europe Facility for the period 2021-27, of EUR 5.84 billion, shows how the current potential for the EU instrument to support the network development pursuant to the TEN-E Regulation, which covers cross-border energy infrastructure projects in not only electricity, offshore grids and smart electricity grids, but also other carriers such as hydrogen networks and CO2 networks, therefore being able to cover a very limited amount of EU projects; the budget allocated to the Connecting Europe Facility could therefore require considering an upwards revision.

[219] https://energy.ec.europa.eu/news/member-states-agree-new-ambition-expanding-offshore-renewable-energy-2023-01-19_en

Smart grids and smart electricity meters

Strengths	**Weaknesses**
- The smart electricity meter technology is mature and continuously evolves to reduce costs and increase functionalities. - The market is highly competitive. The larger companies are based in the USA and Europe, with the former being the majority. European companies operate worldwide. - Several EU programmes exist both for innovation (e.g., NER300) and for implementing projects (e.g., TEN-E smart electricity, and gas, grids). The digilitilisation of the European energy sector remains high on the EU agenda.	- Deployment has high costs and these are mostly passed onto the consumer. The cost of installing a smart meter in the EU is on average between EUR 180 and EUR 200.[220] - Functionalities of smart meters differ across European systems, fragmenting the market. - There are technical issues with the installation and maintenance of smart meters in older buildings and areas with limited connectivity. - Smart meters produce significant amounts of data. Managing and analysing this data is challenging and costly. - Lack of standardisation and interoperability between different smart grid technologies.
Opportunities	**Threats**
- There will be a strong demand in Europe over the next years as the rollout of smart electricity meters in Europe has been slow and delayed. The mandatory 80% target by 2020 envisioned in the relevant Directive was only half met in 2022 (¬43%). Close to 225 million smart meters for electricity and 51 million for gas will be rolled out in the EU by 2024. This represents a potential investment of EUR 47 billion. - Increase of electricity demand fostered by electrification of end-uses and regional availability of considerable potentials for renewable energy sources support the development of new electricity transmission projects. - There are significant opportunities for energy companies both for the production, installation, and use of smart meters, but also for innovations in the context of smart homes and the Internet of Things. - Further demand is expected worldwide, especially in Southeast Asia.	- Smart meters are not always compatible with existing energy systems, which can create problems for consumers and energy companies. - Some consumers may be resistant to the installation of smart meters due to concerns about data privacy and security, given the amount of data collected and the perceived vulnerability to cyber-attacks. - New costs may incur from upcoming legislation regulation on Data and security protection - The digitalisation of the energy sector relies on a series of technologies and materials where the EU is not the leader (e.g., chip manufacturing). - China is the major producer of refined metal used for grids, Chile and Peru are the major producing countries of copper. - Climate change and extreme weather events can pose risks to transmission infrastructure, increasing capital and O&M costs[221].

220 European Commission, Directorate-General for Energy, Alaton, C., Tounquet, F., Benchmarking smart metering deployment in the EU-28: final report, Publications Office, 2020, https://data.europa.eu/doi/10.2833/492070

221 Climate resilience – Power Systems in Transition – Analysis – IEA.

The increased use of renewable energy will make electricity flows more variable while decentralising sources.[222] This will require a better management of electricity transmission and distribution networks, including congestion management, especially as the electrification of various sectors will progress (e.g., transport).[223] In this context, digitalisation 'will help to unleash the potential of distributed flexibility'[2] while allowing consumers to better manage their consumption leading to efficiency gains.[224]

The smart electricity grids sector encompasses several technologies. To provide a practical example we focus on Advanced Metering Infrastructure systems, and in particular, smart meters. Advanced Metering Infrastructure systems can offer advantages to both energy service providers and consumers, including reduced electricity bills through better management of consumptions, better grid observability, reduced costs for grid updates and electricity peaks, better customer control through the usee of advanced customer infrastructure, i.e., smart applications, web portals.[225] These systems comprise different components, with smart meters being the core part, complemented by communication networks and data management systems.[226] The rollout of intelligent metering systems is progressing in the EU, although at a slower pace than envisaged in the electricity Directive.[227] Instead of the targeted 80%, by 2020 only 43% of consumers had been equipped with a smart electricity meter (corresponding to approx.. 123 million units in the EU and UK).[228]

However, market analysts estimate that by 2024 almost 77% of European consumers will have a smart meter for electricity.[229]

<u>The role of manufacturing and process industry in the smart grid:</u> An increasing trend for industrial installations is the autonomous production of part of the energy they need for their operations using net zero technologies. This energy can provide a positive contribution to the energy grid whenever the entire energy production of the installation is not needed to power the industrial operations, which is often the case for industries not working h24, e.g., in the discrete manufacturing sector. It is important that such installations can be fully integrated in the energy grid as producers, both from a technical and regulatory point of view.

[222] https://energy.ec.europa.eu/topics/markets-and-consumers/smart-grids-and-meters_en

[223] https://www.edsoforsmartgrids.eu/images/publications/20210315_SGI_Report_DSO_Only_final.pdf

[224] https://energy.ec.europa.eu/topics/energy-systems-integration/digitalisation-energy-system_en

[225] Prettico, G., De Paola, A., Thomas, D., Andreadou, N., Papaioannou, I., Kotsakis, E., Clean Energy Technology Observatory: Smart Grids in the European Union – 2022 Status Report on Technology Development Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/276606, JRC130710. https://publications.jrc.ec.europa.eu/repository/bitstream/JRC130710/jrc130710_ceto-a2-smartgrids-energy-report_20221024.pdf

[226] For an overview of other relevant technologies such as transmission innovation, grid-scale storage services, electric vehicles smart charging, and others, please see rettico, G., De Paola, A., Thomas, D., Andreadou, N., Papaioannou, I., Kotsakis, E., Clean Energy Technology Observatory: Smart Grids in the European Union – 2022 Status Report on Technology Development Trends, Value Chains and Markets,Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/276606, JRC130710 https://publications.jrc.ec.europa.eu/repository/bitstream/JRC130710/jrc130710_ceto-a2-smartgrids-energy-report_20221024.pdf

[227] Directive 2009/72/EC concerning common rules for the internal market in electricity.

[228] Italy, Sweden, Finland, Estonia and Spain: 90%; Malta, Slovenia, the Netherlands, Luxembourg, France, Denmark: 70-90%; Latvia and Portugal: 50-70%; Austria, Greece and the UK: 20-50%. See in: Vitiello, S.; Andreadou, N.; Ardelean, M.; Fulli, G. Smart Metering Roll-Out in Europe: Where Do We Stand? Cost Benefit Analyses in the Clean Energy Package and Research Trends in the Green Deal. Energies 2022, 15, 2340. https://doi.org/10.3390/en15072340

[229] https://energy.ec.europa.eu/topics/markets-and-consumers/smart-grids-and-meters_en

KPIs

Deploying both offshore wind generation and the necessary infrastructure is estimated to lead to economic benefits between EUR 1.4 bn and 1.6 bn annually (total CAPEX of EUR 65 bn), additional renewables integration between 13.5 TWh and 19.2 TWh per year and a reduction of CO_2 emissions between 12,260 Mt and 15,900 Mt by 2030[230]. A major risk related to missing grid capacity is the creation of congestions in the grid, often resolved via expensive and CO_2-emission intensive re-dispatch measures, which would undermine the achievements of climate targets.

Only five EU Member States have reached a smart meter rollout of more than 90%, namely: Italy, Sweden, Finland, Estonia, and Spain. Countries between 70% and 90% are Malta, Slovenia, the Netherlands, Luxembourg, France, and Denmark. On the other hand, Latvia and Portugal are at a good stage, having reached 50-70% of their smart meter rollout. Austria and Greece have reported reaching between 20-50% of their national smart meter rollout. For example, in Greece, the progress is mainly in the industrial sector and little has been done in the residential sector. Additionally, the smart meter rollout is in its infancy in Croatia, Hungary, Ireland, Poland, and other countries.

Smart meters can be components of larger smart electricity or gas grids, which can obtain EU support through NER300 and other support programmes. An example is the energy Projects of Common Interest, where both smart electricity grids and smart gas grids can benefit from accelerating permitting, funding from the Connecting Europe Facility, etc.[231]

Technology status

Network expansion measures and upgrades need to be complemented with emerging technological solutions. Currently the Technopedia webpage of ENTSO-E reports 65 different technologies with a different Technology Readiness Level (TRL) that TSOs are considering for further development and integration into transmission grids[232].

Smart meters can be considered as an advanced type of utility meter that allows for two-way communication between the meter and the utility company. Smart meters, and Advanced Metering Infrastructure systems in general, can be considered a mature technology with continuous development. For example, many smart meters use wireless communication where technological developments continue to rapidly advance. However, one must note that the functionalities of smart meters differ across systems and markets. In some places, smart meters offer real time data on energy usage while in others they may provide single observations every 15 minutes.

Other potential technical issues concern the installation and maintenance of smart meters especially in older buildings or areas with limited connectivity. Furthermore, data privacy and cybersecurity concerns can provoke adoption resistance. Finally, the storage, management, and analysis of the enormous amounts of data produced from smart meters remains a challenge for many energy companies.

Market perception status

[230] Smart Grids in the European Union (europa.eu)

[231] A list of smart electricity grids Projects of Common Interest and their descriptions can be found in Vasiljevska, J.; Efthimiadis, T. Selection of Smart Grids Projects of Common Interest—Past Experiences and Future Perspectives. Energies 2022, 15, 1915. https://doi.org/10.3390/en15051915

[232] A subset of the most mature technologies (with TRL between 8 and 9) is briefly discussed in the Clean Energy Technology Observatory: Smart Grids in the European Union, 2022 Status Report.

The transformation of the power system will rely on both increased cross-border cooperation and stronger adaptation to local needs. This will entail a shift in the tasks of Transmission System Operators (TSOs). Although traditional CAPEX-intensive investments towards expanding and maintaining the grid infrastructure will still predominate, TSOs will face a number of new challenges for which riskier, more OPEX-oriented activities must be adequately considered.

On the demand side, the rollout of smart meters continues worldwide. In Europe, most Member States will achieve the 80% installation target before 2024.[233] However, costs remain high and installations in older buildings and in areas where connectivity is sporadic provide additional challenges.

On the supply side, the market for smart metering solutions in Europe is highly competitive, and there are many companies that offer comparable products and services. One can mention the following smart meter vendors:[234] Itron, IBM Corporation, Siemens AG, Schneider Electric SE, and Honeywell International In., Mueller Systems LLC, Iskraemeco, General Electric, Tieto Corporation Trilliant Inc., Elster Group, Kamstrup, KELAG, GMBH, Landis+Gyr, Aclara Technologies LLC, Secure Sensus Solutions, and Cisco Systems Inc. Several of these companies are based in Europe with operations worldwide: Iskraemeco, Siemens, Landis+Gyr, Kamstrup, and others.

The 2022 revised Trans-European Energy Infrastructure Regulation refers to smart electricity grids and smart gas grids as priority thematic areas.[235] Five relevant projects are included in the 5th (2021) list of Projects of Common Interest.[236]

Current production and expansion plans

Electricity network expansion requires significant volumes of copper and aluminium (cables, lines and transformers). Moreover, an increasing number of chips (silicon) will be needed to digitalise further the system.

To meet the European energy policy goals and the targets of the EU Recovery Plan, the TYNDP1 for year 2020 highlighted a total CAPEX of EUR 135 billion for projects[237]. Looking at the commissioning year, the median value corresponds to 2027, but there are some projects which can reach up to 2040.

While the rollout of Advanced Metering Infrastructure systems is progressing, driven mostly by utilities' interest in access to better consumer data, taking full benefit of their functionalities will require further integration with home energy management systems, smart appliances, smart electrical vehicle charging, and other new energy services.

International competitiveness of EU production and trade

An analysis from the KU Leuven shows that 35-45% of the total amount of copper and aluminium needed for the energy transition comes from electricity networks and solar PV production. In a base

[233] ACER (2021). Annual Report on the Results of Monitoring the Internal Electricity and Natural Gas Markets in 2020 - Energy Retail Markets and Consumer Protection Volume. Retrieved from ACER: https://www.acer.europa.eu/electricity/market-monitoring-report

[234] Main source: Allied Market Research. (2021). Advanced Metering Infrastructure (AMI) Market by Product Type (Smart Metering Devices, Solutions, and Services) and End User (Residential, Commercials, and Industrial): Global Opportunity Analysis and Industry Forecast, 2021–2030. Retrieved from Allied Market Research: https://www.alliedmarketresearch.com/ami-metering-market-A12092

[235] https://energy.ec.europa.eu/topics/infrastructure/projects-common-interest/key-cross-border-infrastructure-projects_en

[236] European Commission, Joint Research Centre, Vasiljevska, J., Flego, G., *Projects of common interest in the priority thematic area of smart grids deployment : evaluation of candidate projects under EU Regulation 347/2013 on trans-European energy infrastructure*, Publications Office, 2021, https://data.europa.eu/doi/10.2760/235790

[237] This includes only transmission projects which amount to a total of 154.

case, total copper mine output could grow from 20.5 Mt in 2020 to 23-24 Mt in 2030, and in a full potential case, just over 30 Mt. Chile and Peru are the major producing countries, and this is expected to remain by 2030. Refining copper capacity is expected to grow from 25 Mt in 2020 to 29 Mt in 2024. China is the major producer of refined metal. Chile, Japan, and the DRC are the top 3 non-China producers. There are no major changes expected in this supply profile. Note that in terms of materials needs, silicon will be also relevant given its importance in the semiconductor and power electronic devices.

According to the IEA (IEA, World Energy Investment 2022, 2022), after declining for the fourth consecutive year in 2020, spending on electricity grids is expected to go up substantially starting in 2021. Most of the 2020 decline stemmed from a reduction in China and several emerging markets and developing economies, which more than outweighed increases in the United States and Europe. In China, the majority of the drop came in the distribution sector, as targets for rural power grid expansion had been met and focus shifted to transmission, which represents a smaller share of grid investments. However, there are large expansion plans expected for 2021 – especially in China and Europe – which are set likely change this trend.

Annex 5: Employment in Net-Zero industries

Wind

The wind energy sector in Europe employed more than 300,000 people directly and indirectly in 2020, with 77,000 jobs related to offshore wind. These figures are expected to experience significant growth as the EU strives to increase its installed capacity. The industry requires skilled workers, including engineers, project managers, technicians, and skilled tradespeople. To achieve this, transferring skills from the oil and gas sector to the wind industry may be required since roughly 70% of jobs (in FTE) in the oil and gas sector display good or partial overlap with the offshore renewable segment.[238]

Approximately 28% of the EU's direct jobs in the wind sector are situated at turbine and component manufacturers, followed by service providers (15%), developers (8%), and offshore substructure manufacturers (3%).[239] Wind energy employment in the EU accounts for roughly a quarter of the estimated global employment in the wind energy sector, with the majority of wind-related jobs located in China (44%).[240] Future scenarios predict a nearly fivefold increase in global wind energy jobs to around 5.5 million jobs by 2050, necessitating the recruitment, training, and retention of skilled workers.

Solar

The solar sector employed around 240,000 people in Europe in 2020[241], and this number is also expected to grow significantly as the EU aims to achieve 600 GW of installed solar capacity by 2030. The sector requires a range of skilled workers, including engineers, project managers, technicians, and installers. According to IRENA and SPE, in 2021, the EU had a 5.5% share of the PV job market.[242]

Data from different sources show that most PV jobs in the EU are related to deployment activities (79%), of which half are direct and half are indirect jobs. In 2016, 25% of EU employment supported by the PV industry was for the upstream (i.e. production) and 75% for the downstream (i.e. installation) PV sector.[243] A 2022 report from Fraunhofer ISE suggests that 7,500 FTEs are needed for the production of 10 GW from silicon ingot via wafer and cell

[238] T., Georgakaki, A., Letout, S., Kuokkanen, A., Mountraki, A., Ince, E., Shtjefni, D., Joanny Ordonez, G., Eulaerts, O. and Grabowska, M., Clean Energy Technology Observatory: Wind Energy in the European Union – 2022 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/855840, JRC130582

[239] WindEurope/Deloitte: Wind energy and economic recovery in Europe How wind energy will put communities at the heart of the green recovery - October 2020

[240] IRENA/ILO: Renewable Energy and Jobs – Annual Review 2021, International Renewable Energy Agency, International Labour Organization, Abu Dhabi, Geneva

[241] Employment data vary significantly based on the data source. In 2020, the total number of (direct and indirect) PV jobs in the EU was approximately 166,000 according to EurObserv'ER, while IRENA estimates the total number to be 195,000. SolarPower Europe (SPE) reports a total of 357,000 PV-related jobs in the EU, of which 150,000 (42%) are direct and 207,000 (58%) are indirect jobs.

[242] Chatzipanagi, A., Jaeger-Waldau, A., Cleret de Langavant, C., Letout, S., Latunussa, C., Mountraki, A., Georgakaki, A., Ince, E., Kuokkanen, A. and Shtjefni, D., Clean Energy Technology Observatory: Photovoltaics in the European Union – 2022 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/812610, JRC130720.

[243] Dodd, N. et al. (2020) Preparatory study for solar photovoltaic modules, inverters and systems. doi:10.2760/852637

to module, whereas the installation of 10 GW of PV requires 46,500 FTEs, suggesting a standard ratio of 14% for upstream versus 86% for downstream activities.[244] According to SPE, PV jobs related to manufacturing activities account for 9%, with most of these jobs being direct jobs. These relate to manufacturing of inverters (70% of manufacturing jobs in 2021), polysilicon production (10%) and module production (18%). Regarding gender balance in solar PV jobs, women account for 40% of the global PV related jobs.[245]

Heat pumps

The heat pump sector in Europe is expected to grow significantly in the coming years as the EU aims to decarbonise its building sector. The European heating sector as a whole accounts for about 1.8 million direct and indirect jobs.[246] In 2020, the broad EU heat pump value chain (i.e. including all air-air heat pumps including those used mainly for cooling), employed 318,800 people directly and indirectly – an increase of 26% from 2019.[247] Focusing on heat pumps used for heating and hot water, employment is around 117 000 in Europe[248] (including installation that accounts for a significant share of total employment while heat pump manufacturing and component manufacturing consist of more than half of the jobs approximately).

The sector of heat pumps encompasses various roles, such as research and development, manufacturing, installation (which involves drilling in the case of ground-source heat pumps), and maintenance (which includes annual checks), providing employment opportunities to individuals with diverse skill sets e.g. heating engineers, HVAC technicians, and electricians, as well as specialists in areas such as system design and integration.[249]

Batteries

The EU is setting its sights on creating a strong domestic battery industry to support the transition towards electric vehicles and renewable energy storage. As a result, the battery sector is expected to grow significantly in the coming years. However, despite the potential for job creation, there is currently no sufficiently granular data on the industry available.

Skilled workers will be essential to the growth of the battery industry, including engineers, chemists, and technicians. The development of a robust battery value chain in the EU has the potential to create over one million new jobs.[250] This increase in employment is expected to

---

[244] Fraunhofer ISE (2022) Photovoltaics Report -2022- Fraunhofer ISE. Available at: https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf

[245] IRENA, Solar PV: A Gender Perspective 2022

[246] Heating Market Report (2021), EHI, Brussel

[247] Kuokkanen, A., Georgakaki, A., Mountraki, A., Letout, S., Telsnig, T., Kapetaki, Z., Quaranta, E., Czako, V. and Pasimeni, F., European Climate Neutral Industry Competitiveness Scoreboard (CINDECS) - Annual Report 2021, EUR 31183 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-55804-0, doi:10.2760/5869, JRC129336.

[248] European Heat Pump Association (EHPA), Mass rollout of rooftop solar and heat pumps, presentation at IEA workshop, 13 July 2022

[249] Lyons, L., Georgakaki, A., Kuokkanen, A., Letout, S., Mountraki, A., Ince, E., Shtjefni, D., Joanny, G., Eulaerts, O.D. and M. Grabowska, Clean Energy Technology Observatory: Heat Pumps in the European Union – 2022 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/372872, JRC130874.

[250] Batteries Europe General Assembly 21/06/2022

occur despite the ongoing digitalisation and automation of production processes, including the development of machine learning algorithms.[251]

Electrolysers

The development of the electrolysers industry is expected to create significant employment opportunities across a range of skill levels, including engineers, technicians, chemists, and process operators. In addition to direct job creation, the development of the electrolysers industry is also expected to create a range of indirect employment opportunities in related industries, such as renewable energy generation, energy storage, and transportation.

Carbon Capture and Storage (CCS) The Global CCS Institute estimates that CCS deployment could create up to 1.4 million jobs globally by 2040, with a significant portion of those jobs being in Europe. The report highlights the need for a skilled workforce that is trained in various aspects of CCS, including capture, transportation, and storage. The Zero Emissions Platform identifies the specific skills and training needed for CCS workers in the power sector, including knowledge of geological storage, pipeline construction & maintenance, and emissions monitoring & verification. The global CCS industry may need to grow by more than a factor of 100 by 2050, to achieve the Paris Agreement climate targets. This would imply building 70 to 100 facilities a year, requiring up to 100 000 construction jobs and ongoing jobs for 30000 to 40000 operators and maintainers.[252]

Bio-methane

According to the IEA, boenergy supply accounts for 300,000 jobs in Europe253 three-quarters of which are connected to operating existing supply chains while most of the employment in the bioenergy sector is concentrated in rural areas and requires workers with specialized skills in operating agricultural machinery and performing manual labour for processing feedstock. The production of liquid biofuels is typically linked to existing refinery operations and utilizes the existing expertise and employment base of the petrochemical industry. A similar situation applies to the production of biomethane, where a significant portion is integrated with existing gas businesses.

Grids

The IEA estimates that power grids (including transmission, distribution, and storage) account for 1, 200,000 jobs in Europe.[254] The construction of new grids accounts globally for 40% of the power transmission and distribution jobs. The majority of employment related to grids is centered on the operation of distribution systems, which includes tasks such as

[251] M. Bielewski, A. Pfrang, S. Bobba, A. Kronberga, A. Georgakaki, S. Letout, A. Kuokkanen, A. Mountraki, E. Ince, D. Shtjefni, G. Joanny, O. Eulaerts, M. Grabowska, Clean Energy Technology Observatory: Batteries for energy storage in the European Union - 2022 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/808352, JRC130724.

[252] Global Status of CCS 2021 report, Available at: https://www.globalccsinstitute.com/wp-content/uploads/2021/10/2021-Global-Status-of-CCS-Report_Global_CCS_Institute.pdf

[253] IEA (2022), World Energy Employment, IEA, Paris https://www.iea.org/reports/world-energy-employment, License: CC BY 4.0

[254] IEA (2022), World Energy Employment, IEA, Paris https://www.iea.org/reports/world-energy-employment, License: CC BY 4.0

maintaining power lines and providing customer support for meter reading and billing. The increasing adoption of smart metering and digitalisation of grids is decreasing the labour-intensive nature of operating and maintaining grids, while simultaneously increasing the demand for IT skills. At the same time, an increasingly electrified and digitalised energy network and economy means that the overall staffing needs of transmission and distribution system operators, cable manufacturers and HVDC and other power system developers, are likely to increase.

Developments in grids and system operation have substantial impacts on skills and staffing needs. For example, network operators and dispatchers, highly skilled specialists that maintain a secure flow of electricity in the transmission and distribution network systems in real-time, need to acquire further advanced digital and technological skills, such as automation, controlling, big data and advanced analytics, to detect and control network challenges[255.]

255 Skills needs developments, vocational education and training systems in the changing electricity sector, by industriAll European Trade Union, the European Public Service Union (EPSU) and Eurelectric, with support from the EU.

Annex 6: Women's participation in the net-zero industry

Table 13: Women's' share in key energy transition sectors.

Sector	Unit	Women share
Battery	(total workers)	32.2%
Hydrogen	(total workers)	31.7%
Wind	(total workers)	26.0%
Solar	(total workers)	27.0%
Heat pump	(total workers)	16.0%
Carbon capture, use and storage		26.2%
engineering, manufacturing, construction § ICT higher education Students		25%
Innovation	(Patents)	3.4%-11%
Women on Boards		30.4%
Women-led/Mixed Start-Ups		6% /15%
Investment in women-led/Mixed companies		2% / 9%

Notes:

- Female inventors are heavily under-represented in patent-intensive fields such as Computer technology, Machinery and Transport. Overall, 20% of all patents of top European R&D investors have at least one woman inventor.
- Women in Europe and North America are less present in the solar sector than at global level (40%).
- Women representation in large energy-related companies may be slightly higher in the EU (the IEA estimates that women make up just under 14% of senior managers).
- Women are between 10 and 25% less likely to apply for a loan and have a 10% lower probability of obtaining credit than their male peers in the same industry.

Success Stories

- **European Innovation Council Fund:**

ROSI SAS is a French company led by female CEO Yun Luo. Rosi has established a recycling line to recover high-purity silicon, silver and copper and reintegrate them into advanced industrial uses. In 2022, the company raised EUR 7.4 million from the EIC Fund, the ITOCHU Corporation group and InnoEnergy. The money, complemented by other funds, will be used to set up Rosi's first industrial line.

Doris Hafenbradl is a CTO and Managing Director of Electrochaea, Munich-based start-up. Electrochaea offers a proven, safe, and efficient solution to store renewable energy in the form of renewable methane. Thanks to an EIC grant of EUR 2.49 million and an equity investment of €14.98 million, the company completed the standardized design for a 10 MWe plant and is ready for commercial development.

- **Horizon Europe: Women TechEU pilot**

Malin Alpsten and **Anna Carlsson,** founders and CEO and CTO of Bright Day Graphene, a company developing a high quality graphene from biomass to be used in energy storage and other high tech applications. The company produces large volumes of a type of graphene optimised for energy storage and other applications. Their graphene has high conductivity and a large specific surface area. They call their graphene "green" because it is made from a renewable raw material (instead of graphite) and they don't use toxic chemicals in their production process.

Farnaz Sotoodeh, founder and CEO of C2CAT B.V., a Dutch company specialised in catalysis for hydrogen production, storage and recycling of CO2. Contribution to the hydrogen economy will be achieved at C2CAT via the design, development and commercialisation of cost-effective alternative catalysts suitable for sustainable processes.

EU ACTION

- DG GROW: A project to support women investors and improve the representation of women in the investment community, facilitate learning and networking and raise awareness of the gender financing gap in order to facilitate more investments into women-led and gender-diverse companies, including start-ups and scale-ups.

- **Women TechEU 2023-2024 programme (180 companies funded in 2021-2022)**:
  - Financial support to women-led, early-stage deep tech start-ups (the received proposals cover a wide range of deep-tech areas, including technologies such as clean tech and biotech). Grant of EUR 75 000 for the initial steps in the innovation process, and the growth of the company,
  - Activities needed to grow up the business to be funded i.e. business model upgrade, certifications, IP strategy, market analysis, prototyping and developing a product.
  - EUR 15 million budget for 2023 and 2024

- The EU Prize for Women Innovators is awarded every year to women entrepreneurs that have founded a successful company (three EUR 100,000 "Women Innovators" prizes and three EUR 50,000 “Rising Innovator” prizes) – to be run jointly with EIT in 2023

- **InvestEU supporting women**

  The indicative objective by the end of the implementation period is that at least 25% of the funds invested by the European Investment Fund (EIF) under the InvestEU-by the end of the implementation period- comply with the gender smart criteria, which have been designed to focus on the role of women in decision making and leadership bodies relevant for the Venture Capital (VC) and Private Equity (PE) industry. These investments should also be focused on the thematic and sectorial priorities relevant for the EU, incorporated in different InvestEU equity products of the EIF.

  In order to consider a fund complying with the EIF Gender Criteria, it has to fulfil at the time of the EIF commitment, at least one of the following criteria:

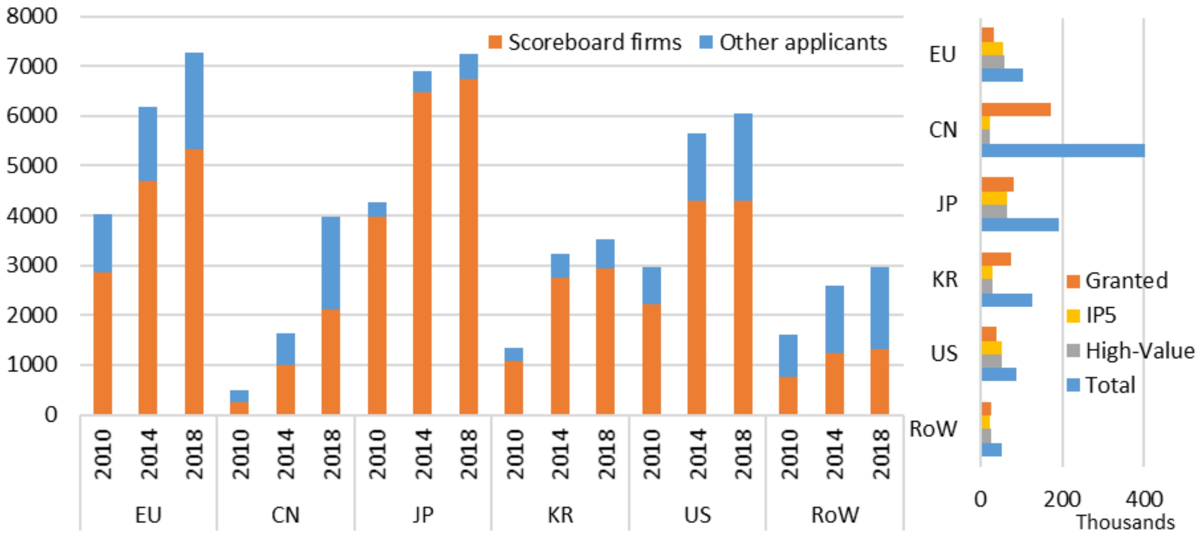
  - At least 1/3 of female partners in management team,
  - At least 40% of female representation in senior investment team, or
  - At least 40 % of female representation in investment committee.

  Additionally, market development and capacity building activities are foreseen to be implemented by the EIF, jointly with the EIB Advisory Services (as the EIB is InvestEU’s Advisory Partner), in order to provide with networking and training opportunities among mixed and female-led VC/PE teams and, in general, to raise awareness on the importance of gender equality in the VC/PE industry.

Annex 7: The EU's position and preparedness to lead in next generation technologies

The global share of patents in climate change mitigation technologies (otherwise referred to as 'green' and encompassing all renewable technologies and solutions for a 'net-zero' carbon economy) has been increasing, accounting for and 10% of all high-value filings. The EU and Japan lead in these high-value patents, with the US in third place. At 58%, the US and the EU have the highest shares of high value patents (patents filed at several patent offices, indicating international protection) among their filings. The EU and the US also have a more diverse contribution to green innovation from applicants beyond the major investor included in the R& I Industrial Scoreboard. Energy and transport remain as the most prominent areas in the EU portfolio of inventions (33% and 28%, respectively), and the EU had highest specialisation index on climate change mitigation patents. The EU also leads in inventions relevant to circularity both in absolute terms and as a share of patents in climate change mitigation technologies[256] and in high-value patents relating to climate change mitigation from industrial production processes[257]. The majority (85-90%) of patents for these technologies from EU corporates are filed by EU-based subsidiaries.

Figure 18: Trends in high-value patents in climate change mitigation technologies: Scoreboard firms and other applicants, 2010-2018



Note: On the left: trend of annual fillings in climate change mitigation technologies for major economies for the years 2010, 2014 and 2018. On the right: Summary over the period 2010-2018: total number of inventions, high-value inventions, IP5 inventions and granted inventions for major economies. Source: JRC, The 2022 EU Industrial R&D Investment Scoreboard

[256]Grassano, N., Hernandez Guevara, H., Fako, P., Nindl, E., Georgakaki, A., Ince, E., Napolitano, L., Rentocchini, F., Tubke, A. The 2022 EU Industrial R&D Investment Scoreboard, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/485748, JRC132035.

[257] Grassano, N., Hernandez Guevara, H., Fako, P., Tübke, A., Amoroso, S., Georgakaki, A., Napolitano, L., Pasimeni, F.,Rentocchini, F., Compaño, R., Fatica, S. and Panzica, R. The 2021 EU Industrial R&D Investment Scoreboard, EUR 30902 EN,Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-44399-5, doi:10.2760/559391, JRC127360

The EU's leadership in science, its strong industrial base and its ambitious clean energy framework conditions provide a good technology base for the anticipated market development of several clean energy technologies. The EU has maintained its good position in internationally protected patents since 2014[258]. The EU remains second only to Japan overall in high-value inventions[259], it leads in renewables, and shares the lead with Japan in energy efficiency, thanks mainly to the EU's specialisation in materials and technologies for buildings. The EU remained the top worldwide patent applicant in the fields of climate & environment (23%), energy (22%) and transport (28%). The EU's patenting data also show its leadership in renewable fuels; batteries and e-mobility; and carbon capture, storage and utilisation technologies.

In heating & cooling networks, wind and offshore operations for renewable energy, the EU accounts for over half of all high-value filings. In solar PV and cooling & air-conditioning, Chinese and South Korean patenting activity has surged in recent years. Nonetheless, while it contributes less than a 15% of high-value patents globally, the EU remains a strong innovator in the field, its patent portfolio in solar PV being one of the largest among climate neutral solutions. The EU also has a significant portfolio of high-value filings in batteries, fuel cells and EV charging infrastructure. In addition, at least five EU corporates are among the global top in patenting activity related to heat pumps, wind, offshore operations for renewable energy, and decarbonising the cement industry through CCUS[260].

The EU continues to be a global leader for 'green' inventions and high-value patents in climate change mitigation technologies. Nonetheless, there are concerns about the impact of state- or subsidy- backed technology domination, closed markets and different intellectual protection rules, and policies on innovation and competitiveness in the sector[261]. These are addressed through developing and updating Guiding Principles for knowledge valorisation and a Code of Practice for the smart use of intellectual property (IP), providing advice to stakeholders on challenges related to intellectual assets in the current R&I context[262]

In a worldwide comparison, the EU-27 is overall well positioned with a share of 35% of all companies that are active in taking patents or that can be linked to clean energy technologies[263]. It also accounts for 28% of patenting companies and 26% of innovation leaders, well above the shares for other world regions. However, EU companies owned only 10% of patents, well below the shares for Japan (36%), South Korea (21%) and China (20%). In terms of patent trends, the EU had an upward trend in electrolysers, stable trend in heat

[258] COM(2021) 952 final, COM(2022) 643 final ('Progress on competitiveness of clean energy technologies')

[259] High-value patent families (inventions) are those containing applications to more than one office (i.e. they are applying for protection in more than one country or market).

[260] Kuokkanen, A., Georgakaki, A., Mountraki, A. and Letout, S., European climate neutral industry competitiveness scoreboard 2021, European Commission, 2022, JRC129337.

[261] Georgakaki, A., Letout, S., Kuokkanen, K., Mountraki, A., Ince, E., Shtjefni, D., Taylor, N., Schmitz, A., Vazquez Dias, A., Christou, M., Pennington, D., Mathieux, F., Clean Energy Technology Observatory: Overall Strategic Analysis of Clean Energy Technology in the European Union – 2022 Status Report, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/12921, JRC131001.

[262] COM(2020) 628 final

[263] This section is based on data from a report of PPMI and IDEA Consult "Assessment and Monitoring of Industrial R&D&I Technologies in the field of clean/renewable energy industries", February 2023 for DG Research and Innovation, not published; data based on Technote database, together with ORBIS and Patstat for patents

pumps and batteries, and a downward trend in solar photovoltaics, wind energy, advanced biofuels and CCS/CCU. As a result of this trend data and/or EU's comparatively low world patent share, in many technologies the EU's overall positioning was assessed as comparatively weak; or strong but weakening (see Table 14 for summary per each technology).

Looking at "tech market crowdedness"[264] and maturity, several technologies, including batteries, solar photovoltaics, advanced biofuels and wind energy appear to be highly crowded, i.e. between 30-49% of companies within these technologies are innovation leaders.

The technology market appears to be much less crowded in heat pumps and CCS/CCU where the share of innovation leaders was only between 3-9%. Overall, less crowded technologies potentially represent a better investment opportunity compared to already mature tech markets with many already existing incumbents.

Tech market maturity is determined by looking at overall patent output between 2010 and 2020. One can determine technologies where overall patent output was declining, indicating that patent output has already peaked and the market has consolidated. Next, there are technologies with a largely stable output, and technologies with an upward trend. The latter indicate technologies/markets where technologies have not peaked yet and a lot of disruption is still to be expected. Our data show that technologies have potentially consolidated in solar photovoltaics and advanced biofuels. In batteries, wind energy, heat pumps and CCS/CCU, patent output has been large similar throughout 2010-2020, suggesting that the technologies have not consolidated yet. Electrolysers is the only technology with a clear upward trend, suggesting that a lot of disruption is still to be expected in the technology market.

[264] Crowdedness is defined by the share/concentration of innovation leaders present in each technology. "Innovation leaders" Innovation leaders are defined as companies that satisfy one of the following criteria: They own high value (highly cited, large patent family, many claims) or recent CREI patents. They were particularly active in patenting between 2015-2020, i.e. they filed at least 50% of their total patents during this period. These are effectively firms that more than doubled their patent output in recent years. They had a high Future and Emerging Technology (FET) score. The FET score is assigned by Technote. It captures the extent to which companies use terminology related to technologies that are new or fast growing in R&I. The list of FET terminology was created by analysing bibliometric and patent databases.

Table 14: Summary of findings for forecasting the net Zero Sector

Technology	Technology size	EU-27 tech world shares	EU patent trends 2010-2020	Overall tech market crowdedness and maturity	EU-27 overall positioning	Leaders in technology	Ranking Patents Output
Solar photovoltaics	Large (6.8k companies, 43k patents)	24% of companies, 22% of patenting companies, 19% of innovation leaders, 8% of patents	Slight downward trend	Highly crowded market Patent output peaked in early 2010s, tech market appears to have consolidated	EU's overall position: relatively weak; ranked 1st in terms of number of companies and patenting companies, but 5th in patents owned and has a negative patent growth trend in late 2010s, but catching up with highest number of patenting companies	Leader: Japan has most of patents produced in early 2010 South Korea ranked 2nd Challenger: China was ranked 5th in patent output in 2010, became no 3 by 2019	JP 1, SKR 2, CN 3, US 4, EU 5
Wind energy	Medium (4.5k companies, 11.5k patents)	34% of companies, 33% of patenting companies, 30% of innovation leaders, 21% of patents	Downwar d trend	Highly crowded market Patent output has remained largely stable throughout 2010-2020, tech market has not consolidated yet	EU's relative positioning: strong and keeping rank by catching up with highest number of patenting companies EU was ranked 1st in early 2010s, by 2019 it was ranked 2nd-5th with US, Japan and Korea	Leader: China became a clear leader by 2017-2018 thanks to almost tripling patent output compared to early 2010s while other regions reduced their patent output by about 50%. The leader is followed by EU, then by US, Japan and Korea	CN 1, EU 2, US 3, JP 4, SKR 5
Heat pumps	Small/mediu m (7.3k companies, 1k patents)	50% of companies, 38% of patenting companies, 40% of innovation leaders, 29% of patents	Stable	Low market crowdedness Patent output has remained stable throughout 2010-2020, tech market has not consolidated yet	EU 's overall position: strong. Still ranked 1st overall, but China has been catching up	Leader: EU (see comment on the left) Challenger: China was ranked 6th-7th in early 2010s, then overtook the EU in 2019	EU 1, JP 2, CN 3, SKR 4, US 5
Batteries	Very large (7.9k companies,	25% of companies, 23% of patenting companies, 23% of	Stable	Very high market crowdedness Patent output has	EU's overall position: relatively weak; ranked 4th-5th with the US, but rapidly	Leader: Japan, largely thanks to tech output accumulated in early 2010s; Japanese companies filed as many patents in early 2010s as	JP 1, SKR 2, CN 3, EU-US 4

	133k patents)	innovation leaders, 9% of patents		remained stable throughout 2010-2020, tech market has not consolidated yet	catching up with highest number of patenting companies	other countries combined Challengers: China (especially since 2015) and South Korea	
Electrolysers	Small (1k companies, 4k patents)	28% of companies, 25% of patenting companies, 33% of innovation leaders, 17% of patents	Slight upward trend	Medium market crowdedness Patent output has been growing since early 2010s, there is still a lot of disruption/market is not mature	EU 's overall position: ranked 2nd overall, but largely due to performance in early 2010s EU's position is strengthening, with highest number of patenting companies, other regions are moving at a similar pace.	Leader: Japan, leads 2nd ranked country (EU) by about 2x patents Challenger: China, was ranked last in early 2010s, 2nd in 2019 Overall, almost all regions increased their patent output in late 2010s	JP 1, EU 2, US 3, CN 4, SKR 5
Advanced biofuels	Medium (3.3k companies, 7k patents)	28% of companies, 30% of patenting companies, 28% of innovation leaders, 21% of patents	Slight downward trend	Highly crowded market Patent output peaked in early 2010s, tech market appears to have consolidated	EU's overall position: strong and keeping stance by catching up with highest number of patenting companies EU is ranked 2nd behind clear leader (US).	Leader: US, holds most of patents in early 2010s when technology output peaked. EU ranks 2nd, followed by Japan and China Overall, technology appears to have peaked in early 2010s; all regions have a downward trend in terms of patent output in recent years No clear challenger, i.e. advanced fuels one of few CREI technologies where China has not significantly grown its output	US 1, EU 2, JP 3, CN 4, SKR 5
CCS/CCU	Small (0.9k companies, 0.3k patents)	18% of companies, 26% of patenting companies, 22% of innovation leaders, 17% of patents	Downward trend	Low market crowdedness Patent output has remained stable throughout 2010-2020, tech market has not consolidated yet	EU's overall position: strong (ranked 2nd/3rd) and improving relative to other regions	Leader: US, followed closely by Japan; but there is no clear edge over other regions/the trend is not clear yet who's leading. Overall, 5 regions are competing in the technology (US, Japan, EU, China)	US 1, JP 2, EU 3, CN 4

Source: Assessment and monitoring of industrial R&D&I technologies in the field of clean/renewable energy industries (CREI) – input for the net-zero industry report.

Annex 8: Sources and Literature for Part 1

Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis - Publications Office of the EU (europa.eu)

EU's global leadership in renewables - Publications Office of the EU (europa.eu)

BNEF (2022): Localising clean energy supply chains comes at a cost (Figure 6), cell manufacturing

BNEF (2021): Wind Trade and Manufacturing A Deep Dive

Bortolotti, P., D. Berry, R. Murray, E. Gaertner, D. Jenne, R. Damiani, G. Barter, K. Dykes. 2019. A Detailed Wind Turbine Blade Cost Model. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-73585

Mann K Margaret, 2016, Heat Pump Supply Chains and Manufacturing CompetitivenessConsiderations, NREL/CEMAC, US DOE

McKinsey (2022): Building a competitive solar-PV supply chain in Europe

Brodd J. Ralph , Carlos Helou, 2013, Cost comparison of producing high-performance Li-ion batteries in the U.S. and in China, Journal of Power Sources, 231, pages 293-300

Chung Donald, Emma Elgqvist, and Shriram Santhanagopalan, 2016, Automotive Lithium-ion Cell Manufacturing: Regional Cost Structures and Supply Chain Considerations, Clean Energy Manufacturing Analysis Center, NREL/TP-6A20-66086

Orangi Sina, Anders Hammer Strømman, 2022, A Techno-Economic Model for Benchmarking the Production Cost of Lithium-Ion Battery Cells, Norwegian University of Science and Technology, Working paper

Elia A., M. Taylor, B. O' Gallachoir, F. Rogan, 2020, Wind turbine cost reduction: A detailed bottom-up analysis of innovation drivers, Energy Policy, 147

IEA (2023): Energy Technology Perspectives 2023, Energy Technology Perspectives 2023 – Analysis – IEA (accessed 01 March 2023)

Mandal Amrit, How to set up 5MWp/10MWp solar PV module production unit, 2015, ΩhmSolar Manufacturing, India

Brittany, Smith, Michael Woodhouse, David Feldman, and Robert Margolis. 2021. Solar Photovoltaic (PV) Manufacturing Expansions in the United States, 2017–2019: Motives, Challenges, Opportunities, and Policy Context. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-74807

Ahmad, Mayyas, Mark Ruth, Bryan Pivovar, Guido Bender, and Keith Wipke. 2018. Manufacturing Cost Analysis for Proton Exchange Membrane Water Electrolyzers. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-72740

VESTAS, https://www.tradeandindustrydev.com/industry/manufacturing/vestas-wind-systems-windsor-brighton-pueblo-2363

VESTAS, https://www.itv.com/news/tyne-tees/2022-06-17/worlds-largest-wind-turbine-factory-to-be-built-on-teesside

Wood MacKenzie & WindEurope (2020): Wind Energy and economic recovery in Europe", WindEurope-Flagship-report-2020.pdf (accessed 01 March 2023)

Tyler, Stehly, Philipp Beiter and Patrick Duffy. 2020. 2019 Cost of Wind Energy Review. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-78471.

BATTERY: Eurostat "Employment by sex, age and detailed economic activity - year: **2021** - age group: 15-64". The figure refers to the share of female employment in "Manufacture of electrical equipment [C27]".

HYDROGEN: Eurostat "Employment by sex, age and detailed economic activity - year: **2021** - age group: 15-64". The figure refers to the share of female employment in "Manufacture of chemicals and chemical products".

WIND: International Renewable Energy Agency (IRENA) **2020** Report Wind Energy: A Gender Perspective. The figure refers to the share of women in the solar PV workforce in Europe and North America (no figures available for the EU alone).

SOLAR: International Renewable Energy Agency (IRENA) **2022** Report, Solar PV: A Gender Perspective. The figure refers to the share of women in the solar PV workforce in Europe and North America (no representative figures available for the EU alone).

HEAT PUMP: Eurostat "Employment by sex, age and detailed economic activity - year: **2021** - age group: 15-64". The figure refers to the share of female employment in "Manufacture of machinery and equipment [C28]" and "Repair and installation of machinery and equipment [C33]".

CARBON CAPTURE, USE AND STORAGE: Eurostat "Employment by sex, age and detailed economic activity - year: **2021** - age group: 15-64". The figure refers to the share of female employment in "Remediation activities and other waste management services", which includes "specialised pollution-control activities".

EDUCATION: Eurostat. Female students as a percentage of total students enrolled in tertiary education in the fields Information and Communication Technologies and Engineering, Manufacturing and Construction in **2020** in EU-27

INNOVATION: The first figure refers to the **2019** Women Inventor Rate for individual patent activity in "Engines, pumps, turbines" according to the European Patent Office Report "Women's participation in inventive activity - November 2022". The second figure refers to 2021 applications where women are listed for combustion apparatus, engines, pumps and power in a study of the International Energy Agency https://www.iea.org/commentaries/gender-diversity-in-energy-what-we-know-and-what-we-dont-know.

WOMEN ON BOARDS: EIGE. 2022 data for mining & quarrying, electricity, gas, water, construction

WOMEN IN START-UPS: 2022 Competitiveness Progress Report on Clean Energy Technologies, COM(2022) 643 final

INVESTMENTS: Georgakaki, A., Letout, S., Kuokkanen, K., Mountraki, A., Ince, E., Shtjefni, D., Taylor, N., Schmitz, A., Vazquez Dias, A., Christou, M., Pennington, D., Mathieux, F., Clean Energy Technology Observatory: Overall Strategic Analysis of Clean Energy Technology in the European Union – 2022 Status Report, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/12921, JRC131001.