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Progress on competitiveness of clean energy technologies

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2025 PROGRESS REPORT ON COMPETITIVENESS OF CLEAN ENERGY TECHNOLOGIES

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EXECUTIVE SUMMARY

The **2025 Competitiveness Progress Report (CPR) on clean energy technologies** provides a snapshot of the trends and challenges of net-zero technologies and their manufacturing in the EU. It encompasses first a **horizontal part on the competitiveness of the EU clean energy sector**, followed by a **sectoral analysis for 15 technologies**. The report builds on the Draghi report and the Competitiveness Compass and supports the implementation of the Net-Zero Industry Act, as the act's monitoring report. Adopted alongside the Clean Industrial Deal and the Action Plan for Affordable Energy, the report underpins both initiatives by providing insights into the technologies required to decarbonise EU industry while strengthening its competitiveness and bringing down energy costs.

Competitiveness of the EU clean energy sector

Clean energy technologies continue to be highly cost competitive in the EU, thanks to low operational costs. In 2024, renewables generated a new all-time high of 48% of electricity in the EU, increasing from 45% in 2023 and 41% in 2022.

While the roll-out rate of clean energy technologies is increasing dynamically, the EU's net-zero industry faces a challenging business environment and fierce competition. As the Draghi report emphasises, as an innovation leader in clean technologies, the EU needs to seize the economic opportunities the global deployment of these technologies represents. At the same time, industrial policies and emerging import restrictions, such as in the US and China, have an increasing impact on the business environment, trade relations and investment decisions.

The EU is home to a diversified net-zero technology manufacturing industry, but struggles to maintain market shares globally, with China having come to dominate production in key sectors. Across net-zero technologies, the EU remains dependent on specific technology components or key raw materials within the supply chain, which poses challenges to its overall economic resilience and strategic autonomy. This is interlinked with challenges the EU faces in energy-intensive industries, which are supplying metals and chemical products to net-zero technology manufacturers.

Clean energy technologies provide high quality jobs, but challenges such as the availability of skilled workers and an ageing workforce persist. Employment continued to grow in 2023 with renewable energy jobs in the EU reaching 1.8 million. In the broader clean energy sector, around a third of the jobs is in the manufacturing of net-zero technologies, confirming the social and economic importance of these value chains.

The EU remains well placed in research in clean energy technologies but, faced with strong global competition, its competitive advantage in innovation has been eroding in recent years. Most recent data indicates that half of the reporting Member States increased their research and innovation (R&I) spending in energy technologies in 2023. If this partial reporting proves to be representative, it would result in a 9% increase of support for the Energy Union R&I priorities. Overall, the EU leads globally in public R&I spending in clean energy technologies. However, private R&I investment, which continues to provide over three quarters of R&I funding for clean energy technologies across major economies, remains significantly higher in major Asian economies. As underlined by the Draghi report and recognised in the Competitiveness Compass, further efforts are needed to ensure the EU remains among the leaders in clean tech R&I and improves its lacklustre performance in bringing this innovation to the market.

Access to risk capital remains a key challenge for starting and scaling up EU firms in the clean energy technologies sector. For 2024, initial data indicates that a difficult macroeconomic environment contributed to a significant decline of the venture capital investments in clean energy technologies in the EU, by -34% compared to 2023. This drop is linked to a decrease in venture capital activity and a lower number of large-scale investments, compared to 2023 which saw large-scale deals in battery and hydrogen-based steel manufacturing facilities. Those deals played a major role in driving EU venture capital investment in the sector to EUR 9.2 billion in 2023 (+20% compared to 2022). At the same time, provisional data indicates that the EU share of global venture capital investment in clean energy technologies remained relatively stable in 2024. The EU ranked second globally in 2023, with a share of 28%, in between the US (30%) and China (24%).

EU competitiveness in net-zero technologies

In 2024, the EU ranked second after China in newly installed solar photovoltaics (PV) capacity. EU manufacturers operate in a highly challenging environment and are struggling to compete globally. The EU is heavily dependent on PV imports from China, where more than 90% of global manufacturing facilities are situated. At the same time, the EU still has a strong role in R&I for specific PV applications.

The EU retains a strong manufacturing capacity for solar thermal technologies. Solar thermal is a mature technology, yet it continued to face challenges in 2023/2024 to keep up with other renewable solutions. While the solar thermal heat market contracted in 2023, the industrial process heat segment showed some promising development, growing three-fold year-on-year globally.

The EU remains highly competitive in wind power technology. However, EU players are under increasing pressure, notably as Chinese companies offer increasingly competitive products at lower prices. In 2024, the EU accounted for close to 13% of global manufacturing capacity in blades and nacelle assembly and about 22% of tower manufacturing. EU companies had a market share of close to 90% of the European market and 23% of the global market in 2023, marking a decline by around 7% in the global market compared to 2022.

There was unprecedented funding and interest in ocean energy technologies in 2024. Around 1230 kW of new ocean energy capacities were installed in Europe in 2024. However, China is leading on high-value inventions in this sector, ahead of the EU. Further actions is needed to increase the economic viability of ocean energy as well as to bring innovative ocean energy technology to the market.

EU battery manufacturers are facing strong headwinds as they aim to increase manufacturing capacity and market shares. China is leading in battery technology and represents more than 85% of the global commissioned manufacturing capacity in 2024, followed by the EU at about 7% and the US at around 5%. EU manufacturers are highly dependent on China for cathodes and anodes. If announced projects are realised, the EU seems on track to meet its production goals for 2030 with a share of 10% (1 510 GWh) of forecasted global operational battery production capacities for 2030. Observers predict an oversupply of battery cells in the coming years, likely to result in fierce global competition.

EU heat pump manufacturers are global leaders in high-end innovative solutions for domestic use as well as industrial heat pumps. Final assembly capacity in the EU is on track to meet the EU's deployment needs for 2030. However, EU industry remains highly dependent on imports for certain components, such as compressors. While the EU trade balance deficit in the supply chain was reduced by one third in 2023, heat pump sales in the EU decreased by

7.2% in 2023, after a decade of growth. This trend worsened in 2024, with sales in Europe falling by 31%. This highlights the need for efforts for the sector to regain momentum.

EU companies play a strong role in the installation and final assembly of geothermal energy technologies deployed in the EU. However, the global market for key components is dominated by non-EU companies. Tackling sectoral challenges, such as the availability of subsurface data, can help EU industry.

European firms continue to play a relevant role in electrolyser manufacturing and are estimated to have provided for around a third to a quarter of the global manufacturing capacity in 2024. While hydrogen electrolysis capacity continues to expand dynamically in the EU, challenges remain in developing a large-scale hydrogen sector, ensuring the availability of large quantities of cost competitive hydrogen. Furthermore, the EU has fallen behind in fuel cell manufacturing.

The EU is home to world leading companies in biogas and biomethane production and component manufacturing. Europe presents a mature biogas and biomethane industry mainly for electricity generation, with growing markets in heat and transport. Almost 50% of production is in Europe, with Germany alone meeting 20% of global demand.

The EU is well positioned on CO2 capture technologies, but lags behind the US and Canada in CO2 transport and storage. The number of CCS projects has been growing rapidly globally and in Europe. EU actions to provide predictability for investors and increase the visibility of demand for and supply of storage are key in this regard.

The EU has some long-standing market and technology leaders for both power lines and transformers. European companies are expected to face increasing pressure from international competitors in the short to mid-term. Manufacturing of grid equipment depends greatly on access to raw materials such as copper, aluminium and grain-oriented electrical steel, where EU manufacturers are exposed to import dependencies.

In nuclear power, the EU retains one active reactor vendor, with a global market share of 5.3% of reactors under construction at the beginning of 2024. As the EU nuclear plant fleet and its workforce are ageing, efforts are needed to rejuvenate the sector. The European Industrial Alliance on Small Modular Reactors (SMRs) was launched in 2024 to facilitate the deployment of SMRs and to support a competitive EU ecosystem in this emerging technology.

While the EU hydropower industry continues to play a leading role globally, it has lost market share in manufactured turbines and in other parts in recent years. From a peak of EUR 466 million in 2015, the EU trade surplus shrank substantially to EUR 213 million in 2023. To maintain a strong manufacturing industry of components in the EU, the home market would need to be supported with new investments. There is also untapped potential in expanding pumped storage hydropower to contribute to grid flexibility.

The EU is among the innovation leaders in the emerging market for sustainable alternative fuels for aviation and maritime transport. Production capacity remains limited and needs to be scaled-up while at the same time reducing prices for such fuels.

Excess energy from industrial processes in the EU could be converted into 150 TWh of electricity annually using organic Rankine cycle (ORC) power plants. EU manufacturers are among the leading players in the global market, but there are barriers, such as long payback periods, to increasing deployment in the EU.

1. INTRODUCTION

Clean energy technologies are key enablers for the EU to become climate neutral by 2050, strengthen its energy supply security, and boost its competitiveness. **Over the last decades, the EU has played a central role in deploying clean technologies**, such as solar and wind energy. In 2024, renewable energy sources reached 48% in the EU electricity mix. This underlines the increasing competitiveness and economic relevance of clean energy technologies compared to fossil energy sources. To reach its greenhouse gas emissions reduction objectives for 2030 and beyond, Europe will need to continue in that direction and step up its efforts.

At the same time, EU industry is facing increasing pressure on its competitiveness in net-zero technologies. Leadership in and manufacturing of technologies that have been developed in the EU is increasingly shifting to other major economies, such as China and the US, which are expanding their production capacities.

Competitiveness has become a focus for EU policy, also in regard to net-zero technologies. The conclusions from the European Council of April 2024 urged the EU to become more competitive[1]. The new Competitiveness Compass sets out a set of measures to strengthen the EU's competitiveness in the coming years, building on the findings of the Annual Single Market and Competitiveness Report and the in-depth analysis in the Draghi report[2]. The Draghi report emphasises the economic opportunities clean technologies represent for the EU, as an innovation leader in clean technologies[3]. It lists the main barriers holding back the EU's competitiveness and calls for an aligned and targeted strategy, taking into account differences between industries. Both the Draghi and Letta report also refer to the importance of strengthening, at the same time the Single Market for energy and related infrastructures, to realise the EU's potential in renewable energy, with the objective of ensuring secure and affordable energy for its industries[4].

To support the EU's strategic autonomy, to secure its industrial base and maintain innovation potential, **manufacturing the net-zero technologies of today and tomorrow in Europe is essential**. **The Clean Industrial Deal is a new blueprint for the EU's prosperity and competitiveness**[5]. With the Clean Industrial Deals, the Commission will improve the access of EU industry to funding, material streams and skilled labour, while creating new lead markets and increasing the resilience of value chains. At the same time, the Commission will take on an unprecedented simplification effort, reducing the burden on businesses. This will pave the way for more competitive industries and quality jobs, with a special focus on clean and strategic technologies.

Access to affordable energy is a key factor for the competitiveness of the EU and the central objective of the new Action Plan for Affordable Energy[6]. The Action Plan complements the Clean Industrial Deal, proposing measures to lower energy costs for industry, businesses and households, while speeding up necessary structural reforms. It is centred around the objective to accelerate the transition to affordable, clean, domestically generated energy, building on the technologies covered in this report. The Action Plan aims to complete the

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1 European Council (2024), Conclusions from the special meeting of the European Council (17 and 18 April 2024); European Council (2024), Budapest Declaration on the New European Competitiveness Deal (7-8 November 2024).

2 COM(2025) 30 final and COM(2025) 26 final.

3 Mario Draghi, *The future of European competitiveness*, 2024.

4 Enrico Letta, *Much more than a market*, 2024.

5 **[PLACEHOLDER FOR REFERENCE TO CLEAN INDUSTRIAL DEAL].**

6 **[PLACEHOLDER FOR REFERENCE TO ACTION PLAN FOR AFFORDABLE ENERGY].**

Energy Union and ensure a fully integrated internal energy market with the required physical interconnections.

This report brings evidence-based monitoring and advice regarding the competitiveness of clean energy technologies and their manufacturers in Europe. Having entered into force in 2024, the Net-Zero Industry Act (NZIA) further strengthens the role of the report, by designating it as the main monitoring tool on the progress of the EU with regard to the production objectives set out in the act. With NZIA, the EU aims to strengthen its domestic manufacturing capacity of key clean technologies and to increase the competitiveness and resilience of its industry. The objective is to reduce dependencies on external actors by reaching a manufacturing capacity of at least 40% of the EU's annual deployment needs for the technologies necessary to achieve its 2030 climate and energy targets, as well as reaching a 15% share of world production by 2040[7].

Part I of the report provides general insights on key issues for the competitiveness of the EU net-zero technology sector as a whole, covering aspects such as energy costs, manufacturing, industrial decarbonisation, skills, trends in investments, research and innovation as well as the global context. Part II of the report maps the state of play on the competitiveness of EU industry in 15 net-zero technologies, highlighting strengths and weaknesses in the respective value chains.

This is the fifth edition of this competitiveness progress report, published since 2020 in accordance with Article 35(1)(m) of the Regulation on the Governance of the Energy Union and Climate Action. This report is underpinned by data from the Clean Energy Technology Observatory (CETO)[8].

2. ASSESSMENT OF THE COMPETITIVENESS OF THE EU CLEAN ENERGY SECTOR

2.1. The global economic context and the competitiveness of the EU net-zero technology sector

2.1.1. Energy prices and costs trends

The energy market situation in the EU improved in 2023 and 2024. Energy prices were significantly lower than in 2022, yet they remained above pre-crisis levels and significantly higher than in competing regions. Increasing import diversification of gas and higher renewable energy generation capacities, combined with lower consumption, helped reduce wholesale gas and electricity prices.

Wholesale gas prices in 2024 were lower than in 2023, and much lower than the prices seen in the first months after the Russian invasion of Ukraine in 2022. However, they remained higher than pre-crisis levels. For 2024, the average price for gas wholesale stabilised at 34 EUR/MWh. While prices decreased to levels closer to 30 EUR/MWh in the first half of the year, they rose steadily to a range of 35-45 EUR/MWh by the end of 2024 and increased again at the beginning of 2025.

For electricity, 2024 was also marked by a continuation of positive market fundamentals that resulted in lower wholesale electricity prices. Lower gas prices, subdued demand, and higher renewable and nuclear generation all helped to depress wholesale electricity prices across all

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7 OJ L, 2024/1735, 28.6.2024, Article 5.
8 For more information and CETO reports: Clean Energy Technology Observatory.

EU markets. The European Power Benchmark averaged 95 EUR/MWh in 2023, 57% lower than in 2022. In the first three quarters of 2024 the average fell to 70 EUR/MWh, but prices rose in the last quarter. Overall, the 2024 average stood at 76 EUR/MWh. Electricity consumption in the EU in 2024 grew slightly (+2%), with industrial demand recovering slightly.

Due to the energy crisis, significant increases in wholesale electricity prices were passed on to final consumers, in some cases with a time delay. As a result, household retail electricity prices increased in 2022 and partially in 2023[9]. In line with EU efforts, Member States put in place temporary measures to mitigate the impact of high prices on consumers. However, high prices remained an issue, in particular for vulnerable consumers. Retail household prices developments in 2024 indicate that prices across the EU have fallen slightly or remain comparable to 2023 prices.

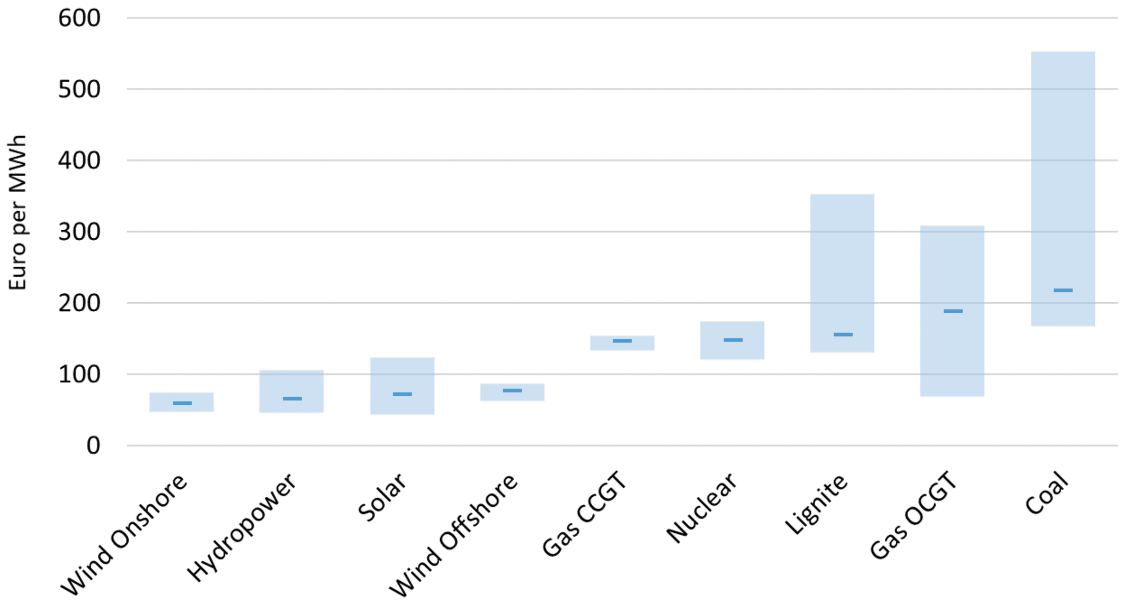
Electricity prices for industrial users decreased significantly in the first half of 2024, compared to the same period in 2023. The decrease ranged from 13% to 27% (excluding taxes) and from 6% to 27% (including non-recoverable taxes)[10] across different consumption bands, intensifying the downward trend that began in 2023. However, EU industry presently faces electricity prices that are about two times higher than in the US or China, at an average of EUR 0.16 per kWh in 2024[11].

The share of renewables in the electricity mix of the EU increased to a new all-time high of 48% in 2024 (compared to 45% in 2023 and 41% in 2022[12]), while the share of fossil fuels fell significantly to 24% (from 28% in 2023). Solar and offshore wind output registered a significant increase in 2024: offshore wind rose by 17% (+9 TWh), while solar generation surged by 19% (+37 TWh). Hydropower improved its output by 7% (+22 TWh), onshore wind generation remained roughly stable (-1 TWh) and nuclear output rose by 5% (+29 TWh) during the same period[13]. At the same time, electrification has not picked up in speed, with electricity as a share of the energy mix remaining stable at around 20% since 2000[14].

Figure 1 presents an overview of **levelised costs of electricity (LCOE) in the EU**[15], estimated based on the specific characteristics of the electricity systems in each Member State for 2023. Investment costs, as well as operation and maintenance costs, increased in 2023 due to inflation, higher material costs, and increased labour costs. The elevated inflation and high interest rates played a major role in impacting or delaying investment decisions in 2023, both for project developers and manufacturers.

9 Eurostat (nrg_pc_204), accessed on 12/02/2025.
10 Eurostat (nrg_pc_205), accessed on 12/02/2025.
11 Eurostat, *Electricity price statistics*. Note: Prices refer to the ID consumption band, with recoverable levies deducted.
12 2022 data based on Eurostat.
13 Data for 2023 and 2024 in this paragraph is based on the ENTSO-E Transparency Platform.
14 COM(2025) 26 final.
15 The levelised costs of electricity (LCOE) is a method for comparing the average cost of generating one unit of electricity (commonly measured in megawatt-hours, MWh) over the entire lifespan of a power-generating asset or project, taking into account all costs associated with building and operating the power plant (capital expenditures, operating and maintenance costs, fuel costs (if applicable), financing costs, and decommissioning costs (if applicable)).

***Figure 1**: Snapshot of technology-fleet specific levelised costs of electricity (LCOE) for 2023. The solid blue lines denote the median and the light blue bars display a ±25% range across the EU, highlighting differences among Member States.*



Source: JRC METIS model simulation[16]

Despite these rising costs, technology fleets with low variable costs (including operational costs, e.g. maintenance and fuel costs), such as renewable energy sources like onshore wind and solar remain more cost-competitive compared to generation technologies with high variable costs, such as fossil energy sources like gas and coal impacted by fuel costs. Overall, renewables continue to be highly cost competitive in the EU.

The LCOE value of a given technology is influenced, amongst others, by the ratio between the annual generation volume of the technology and its installed capacity. The less utilised a technology is, the larger its LCOE value will be. For this reason, conventional technologies, such as lignite, open cycle gas turbines (OCGT), and coal, which have had lower generation in some Member States, are seeing larger upward spreads in their LCOE values. In contrast, the LCOE spread for a technology like combined cycle for natural gas (CCGT) remains very narrow as the usage rate of CCGT power plants is high in most Member States.

Renewable energy sources continue to be the most cost competitive technologies, while CCGT became the most competitive thermal technology on cost. This trend is partly explained by the large drop in natural gas prices compared to the previous year. Additionally, while 2022 saw significant fuel switching between gas and coal due to fluctuating prices, in 2023 the focus shifted more towards the impacts of higher fixed costs across all technologies.

Over the past decade, the LCOE for various generating technologies in Europe has evolved significantly due to several key factors. Technological advancements have led to increased efficiency and capacity, particularly in solar PV and wind energy, driving down costs

[16] According to: Gasparella, A., Koolen, D. and Zucker, A., The Merit Order and Price Setting Dynamics in European Electricity Markets, Publications Office of the European Union, 2023. Computation based on annualised costs for the year 2023. Capex and Opex based on the 2040 climate target PRIMES reference scenario, annualised by technical lifetimes and weighted average cost of capital. Annualised costs are levelised using capacity factors derived from the METIS model. Variable costs are based on 2023 commodity prices, variable Opex and the dispatch in the METIS simulation.

substantially. Economies of scale, especially with larger projects and mass production, have further reduced costs for renewables. Policy support, including subsidies, tax incentives, and carbon pricing, has encouraged the adoption of cleaner energy sources while increasing the costs associated with fossil fuels like coal and natural gas. Improved supply chains and manufacturing processes have increased the overall competitiveness of renewable technologies. These combined influences have shifted the energy landscape, making renewables more cost-effective and reducing reliance on traditional energy sources.

The Draghi report has underlined energy as a key driver for the EU's competitiveness and proposed a mix of measures to address causes of high energy prices in the EU, aiming to enable the benefits of decarbonisation in energy to reach end users[17]. Energy features centrally in the new Clean Industrial Deal and, with the Action Plan for Affordable Energy, the Commission is putting forward concrete measures to reduce energy costs for households and industry.

2.1.2. Support for net-zero technologies on global markets

New geopolitical dynamics and a phase marked by both high interest rates and inflation, have changed the business environment for net-zero technologies over the course of the last years. The global market for key, mass-manufactured, net-zero technologies is set to nearly triple by 2035 and attain an annual worth of around EUR 1.9 trillion [18]. In the race to build up the manufacturing to satisfy the expected demand, it remains crucial to ensure EU industry is competitive and able to play its part in supplying the technologies for the energy transition in Europe and globally. At the same time, uncertainties are a challenge for long-term investment, including in manufacturing or production facilities. To place the EU and its industries in a position to compete for market shares in 2030 and beyond, decisions taken and implemented at this moment will be decisive. Delays in the build-up of net-zero manufacturing capacities risk impacting the EU's competitiveness in the decades to come. While accelerated electrification will bring down import dependencies on fossil fuels, resilient value chains for net-zero technologies, such as wind power or batteries, will be required to avoid new dependencies[19].

In reaction to recent crises and as strategies to support companies in the energy transition, industrial policies to increase the manufacturing of clean energy technologies have been introduced around the world, including in countries such as Canada, China, India, Japan, South Korea and the US. With the adoption of the Inflation Reduction Act (IRA), the US offered grants to support the installation of advanced technologies and offered tax credits for investment in manufacturing facilities for the production of clean energy equipment (with an estimated total of EUR 461 billion[20], of which 60% is targeted at the energy sector). At the same time, China has become a predominant producer of many net-zero technologies and is leading on support for clean technologies through an investment-centred economy[21]. Looking specifically at the solar sector, more than 90% of manufacturing facilities are situated in China[22].

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17 Mario Draghi, *The future of European competitiveness*, 2024.

18 IEA, *Energy Technology Perspectives*, 2024. Global market estimates for solar PV, wind, electric vehicles, batteries, electrolysers and heat pumps. Report refers to USD 2 trillion, converted into EUR at the end of 2024.

19 European Commission, *2025 Annual Single Market and Competitiveness Report*, see KPI 18 on electrification.

20 Using the average exchange rate of EUR 0.9239 for USD 1 over the year 2024, based on ECB.

21 Strategic perspectives, *Competing in the new zero-carbon industrial era*, 2023.

22 For further information, see subsequent section on solar photovoltaics.

Moreover, import restrictions in the US and other countries are increasing the pressure on manufacturers from the EU in their home markets. In addition, a growth in manufacturing capacities globally, which for certain technologies is currently expected to potentially exceed deployment capabilities, brings the danger of overcapacity. Such a development might cause serious damage to segments of EU manufacturing, including net-zero technologies. Forecasts for 2025 indicate that global overcapacities will persist in major clean energy technologies, notably for the entire battery and solar value chains, and nacelles for wind turbines[23].

Estimates suggest that China's overall subsidies range between three to nine times that of other OECD countries such as the US or Germany[24]. The EU has concluded an anti-subsidy investigation on battery electric vehicle (BEV) imports from China, resulting in the imposition of countervailing duties on such imports[25]. To assess the scale and scope of subsidies and the conformity with international trade rules, further channels of government support have to be considered. The EU will also engage with international trading partners as well as seek the assistance of international institutions such as the Organisation for Economic Cooperation and Development (OECD) and the International Energy Agency (IEA) for the monitoring of the situation.

For the global energy transition to succeed, economic opportunities and gains will need to be shared along the value chain. In this regard, global partnerships and a level playing field will be essential for achieving resilience and strategic autonomy for the EU. The current EU initiative Global Gateway is promoting investment in non-EU countries in areas key for the EU and its green and digital transitions. Global Gateway aims to mobilise up to EUR 300 billion in investment[26]. Negotiating, concluding and implementing ambitious trade agreements will help to expand market access and foster economic resilience[27]. In addition, Clean Trade and Investment Partnerships (CTIPs) can complement trade agreements and support decarbonisation efforts in the EU and abroad, tailored to the business interests of the EU and its trade partners in the clean energy sector.

In the EU, accelerating the decarbonisation and clean energy transition has been at the centre of the European Green Deal and subsequent policy measures, including the Fit for 55 package and the Green Deal Industrial Plan. The EU has a solid framework fostering net-zero technologies, combining R&I support, economic incentives such as carbon pricing in the EU Emissions Trading System (ETS) and regulatory instruments such as the Renewables Energy Directive and the Net-Zero Industry Act. The Recovery and Resilience Facility (RRF) provided a budget of EUR 650 billion to support reforms and investment undertaken by Member States, with a share of at least 37% of green measures in the national recovery and resilience plans. Additionally, EU cohesion policy funds from the European Regional Development Fund, Cohesion Fund, the Just Transition Fund and the Interreg provide nearly EUR 120 billion of investment in green measures (with total investment cost reaching more that EUR 166 billion). This represents an average 40% contribution to climate action for these funds, which goes well beyond the minimum regulatory commitments[28]. Furthermore, REPowerEU played a key role in rapidly reducing dependence on Russian fossil fuels and fast forwarding the green transition.

The Strategic Technologies for Europe Platform (STEP) was set up by the EU to support European industry and boost investment in critical technologies in Europe, including clean

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23 BloombergNEF, *Trade & Supply Chains: 10 Things to Watch in 2025*, 2025.
24 Kiel Institute for the World Economy*, Foul Play? On the Scale and Scope of Industrial Subsidies in China*, 2024.
25 OJ L, 2024/2754, 29.10.2024.
26 For more information: https://international-partnerships.ec.europa.eu/policies/global-gateway_en.
27 COM (2025) 30 final.
28 For more information: Exploring investments 2021-2027 – Cohesion policy support to climate action.

energy technologies. Through a mix of financial incentives and measures to facilitate the financing of projects, STEP is leveraging funding in support of critical technologies under existing EU programmes and funds, including cohesion policy funds, InvestEU, Horizon Europe, the European Defence Fund, the EU ETS Innovation Fund and the Recovery and Resilience Facility. Moreover, until 2024 the Horizon Europe programme cluster 5 'Climate, Energy and Mobility' provided more than EUR 3 billion to support clean energy technologies research and innovation.

2.2. Net-zero technology value chains in the EU: opportunities and challenges for a clean industry

2.2.1. Manufacturing supply chains

In recent years, the EU has taken steps to increase its manufacturing capacity for net-zero technologies, aiming to reduce strategic dependencies and to increase the EU's resilience while contributing to EU climate and energy targets.

While the EU is increasing its efforts, it faces strong headwinds from global competitors. In recent years, its position in net-zero technologies manufacturing has been globally deteriorating, despite the EU's strengths in aspects such as research and innovation, skilled labour and regulatory standards. The EU maintains a strong manufacturing basis in certain net-zero technologies, like wind power and electrolysers, while other parts of the world are increasingly dominating certain value chains, like in solar PV and batteries. Challenges consist not only in the dependency on certain net-zero technologies per se, but also on specific technology components in the supply chain. For example, the EU is well positioned in manufacturing and remains the main producer of hydronic heat pumps, but China supplies most 4-way valves and compressors[29]. Furthermore, the EU remains highly dependent on a range of critical raw materials essential to the manufacturing of a range of net-zero technologies.

Global clean technology manufacturing investment surged rapidly until 2023. In 2024 investment remained at a similar level, with EUR 129 billion (EUR 133 billion in 2023)[30]. According to the International Energy Agency (IEA), the EU and the US were able to increase their combined share of global clean technology manufacturing investment to 16% in 2023 (from 11% in 2022)[31]. At the same time, China continues to hold a significant lead in manufacturing investment. For 2024, it is estimated that China accounted for 81% of global clean tech supply chain investment[32].

Manufacturing costs in the EU and the US remain structurally higher than in China. Solar PV module manufacturing costs are 35-65% lower in China compared to the EU and the US[33]. Onshore wind turbine components cost around EUR 355/kW in China, while in the EU and the

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29 See section on heat pump technologies in chapter 3 of this report.

30 BloombergNEF, *Energy Transition Investment Trends 2025*, 2025. Data covers manufacturing for key parts of the batteries (incl. mines and refineries), solar PV, wind and the hydrogen supply chain. Conversion using the average exchange rate of EUR 0.9239 for USD 1 over the year 2024, based on ECB.

31 International Energy Agency (IEA), *Advancing Clean Technology Manufacturing,* 2024.

32 BloombergNEF, *Energy Transition Investment Trends 2025*, 2025. Data covers manufacturing for key parts of the batteries (incl. mines and refineries), solar PV, wind and the hydrogen supply chain.

33 IEA, *Advancing Clean Technology Manufacturing,* 2024.

US, costs range from EUR 448-485/kW[34]. Heat pump final assembly in the EU and the US costs about twice as much as in China[35].

Several factors contribute to these cost disparities, including high energy prices, supply chain disruptions, currency inflation, increased interest rates, intense market competition, various subsidy programmes, and uncertain future demand. Recent analysis by the IEA shows that China remains the most cost-effective location for capital investment in manufacturing facilities, with costs in the EU and the US being 70-195% higher per unit of output capacity[36]. While the challenges to strengthening EU manufacturing are substantial, the EU, as one of the key markets for net zero technologies development and deployment, retains a great potential to harness the economic opportunities presented by the global energy transition.

Net-zero manufacturing is spread across many regions in the EU, each with different specialisations. While the EU share in global solar PV manufacturing has been decreasing in recent years, Germany, Italy, Spain, France and Austria retain production sites. As regards wind energy, while production of components is spread across the EU, main turbine manufacturers are concentrated in Denmark and Germany, complemented by relevant tower manufacturing capacity in Spain. The EU's battery manufacturing is in development, with production in Poland, Germany, Hungary, France, Sweden and further Member States. In hydrogen, more than half of the EU electrolyser manufacturing is concentrated in Germany, with additional capacities in Denmark, Spain, Portugal, Italy, and France. As regards heat pumps, Germany, Sweden, Finland and Denmark are among the countries with relevant manufacturing. In geothermal energy, Italy is leading in manufacturing, with relevant production also in Germany and France. Italy equally plays a leading role in cable production in the EU, followed by Sweden, Germany, France, Poland, and Denmark. The EU is also a leading producer of biogas and biomethane, with relevant manufacturing in particular in Germany and Italy as well as in Czechia, Spain and Poland for relevant components[37].

The EU adopted the Net-Zero Industry Act to reduce its dependence on imported net-zero technologies, strengthen value chain resilience and build a strong domestic manufacturing base. The objective is to establish a regulatory framework to ensure the EU's access to a secure and sustainable supply of net-zero technologies including by scaling up manufacturing capacity for net-zero technologies and their supply chains.

In addition, Member States are increasingly adopting dedicated policies that promote the production of net-zero technologies. These national policy and legal frameworks for net-zero technologies include a mix of incentive schemes, taxation, fiscal policies, and skills and education policies. Many of these national strategies focus on specific technologies rather than net-zero technologies in general. A recent study concludes that a majority of identified policies in Member States focus on electrolysers and fuel cells, followed by batteries and storage technologies, wind energy, and solar PV. For example, Germany and Spain have dedicated strategies for hydrogen technologies in place, while Ireland and Poland have sectoral strategies for wind energy technology[38].

One of the challenges to the widespread production of net-zero technologies is permitting for manufacturing sites, which is addressed extensively in the Net-Zero Industry Act. The rules

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34 Using an average exchange rate of EUR 0.9239 for USD 1 over the year 2024, based on ECB.

35 IEA, *Advancing Clean Technology Manufacturing*, 2024.

36 IEA, *Advancing Clean Technology Manufacturing*, 2024.

37 Ecorys, *The Net-Zero manufacturing industry landscape across Member States - Final Report*, 2025. Non-exhaustive list of examples.

38 Ibid.

vary between countries, potentially affecting the implementation timeline for these technologies. However, Member States are moving towards solutions like digitalisation, establishing one-stop shops and prioritising green projects. Examples include Italy's development of one-stop shops for business activities, Finland's temporary prioritisation of green transition projects, and Hungary's classification of certain projects as priority investments. France's Green Industry Law also aims to reduce permitting times with parallel processing and fast-track procedures for strategic projects[39].

The Draghi report stresses the need to maintain and strengthen clean tech manufacturing in the EU to be able to realise the growth opportunities offered by a growing market in and outside the EU, building on the EU's strong fundamentals in innovation and manufacturing. Furthermore, the report identifies several challenges faced by EU manufacturers in these technologies to scale-up and compete, and it proposes several measures to support EU competitiveness in this area. Among its proposals, the report stresses the crucial role of a full and speedy implementation of the Net-Zero Industry Act to support manufacturing[40].

The Clean Industrial Deal sets out a competitiveness-driven approach to decarbonisation, aimed at securing the EU as an attractive location for manufacturing, including for energy intensive industries and clean technologies. Moreover, the future European Competitiveness Fund will help ensure that strategic technologies, including clean technologies, will be both developed and manufactured in the EU[41].

2.2.2. Decarbonisation of energy-intensive industries

From metals like steel, aluminium to chemical products, the materials produced by energy-intensive industries are strategic for the EU economy, including as the basis for both designing and manufacturing net-zero technologies. Constructing a wind turbine tower requires steel for the tower and its foundation, aluminium for the nacelle and blades, as well as specialised chemical coatings for them. At the same time, net-zero technologies, from renewable energy sources to hydrogen production, energy efficiency and carbon-capture and storage technologies are enabling the decarbonisation of energy-intensive industries. This illustrates how essential energy-intensive industrial products are to net-zero value chains and vice versa.

Therefore, increasing the EU's strategic autonomy requires a value chain approach, considering all essential components and materials of net-zero technologies. The Net-Zero Industry Act recognises the importance of transformative industrial technologies for decarbonising the production of basic materials, such as steel, aluminium, non-ferrous metals, chemicals and cement. It includes support for energy-intensive industry decarbonisation projects, which are part of the supply chain of a net-zero technology[42]. These projects benefit in particular from accelerated permitting. In addition, the EU is supporting the switch from fossil fuel to renewable and low-carbon energy sources, notably via energy efficient electrification, for example using heat pumps to recover heat from exhaust and reuse it.

Energy-intensive industries account for more than half of the energy consumption of EU industry[43], and are the most impacted by structurally higher energy prices in the EU compared to other major economies. Notwithstanding efforts under REPowerEU, production by the EU's

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[39] Ibid.
[40] Mario Draghi, *The future of European competitiveness*, 2024.
[41] Political Guidelines for the next European Commission 2024-2029.
[42] OJ L, 2024/1735, 28.6.2024, Article 2(3).
[43] See: https://single-market-economy.ec.europa.eu/industry/strategy/energy-intensive-industries_en.

energy-intensive industries has fallen 10-15% since 2021[44]. At the same time, energy-intensive industries account for a significant share of EU greenhouse gas emissions. Their decarbonisation is essential to achieving climate neutrality, but requires major investment, putting further pressure on EU companies. Overall, this places a strong pressure on the competitiveness of energy-intensive industries in the EU, compared with countries that enjoy lower energy prices and a less ambitious decarbonisation agenda. Losing production in key industrial products due to this pressure, would weaken EU supply chains in net-zero technologies, increase import dependencies and reduce prosperity.

The Draghi report highlights the importance of energy-intensive industries for the EU economy and the immense challenge they face in needing to invest in decarbonisation while confronted with increasing prices for carbon emission and competing on global markets. In this regard, the report points to the lack of a level-playing field, notably with regard to companies benefiting from high subsidies in countries like China, which is rapidly expanding its production. Building on this analysis, the Draghi report suggests providing coordinated support to EU energy-intensive industries in their transition, from permitting to financial support, including by creating demand for green products to provide a clear business case for investments in clean production. At the same time, the report advises to level the playing field with international competition, building for example on the EU's Carbon Border Adjustment Mechanism (CBAM)[45].

The Clean Industrial Deal puts a strong emphasis on supporting EU industry and its competitiveness on the path to decarbonisation. In particular, the Commission will propose an Industrial Decarbonisation Accelerator Act to support industries that are transitioning, by creating lead markets for clean products, and speeding up planning, tendering and permitting processes for building or transforming manufacturing plants, with a particular focus on energy-intensive industries. The new Competitiveness Compass plans tailor-made action plans for energy intensive sectors, such as steel, metals, and chemicals, sectors which are the backbone of the European manufacturing system. In addition, the Competitiveness Compass proposes actions on horizontal enablers for competitiveness, including on simplifying the regulatory environment and reducing the regulatory burden for EU industry.

2.2.3. Human capital and skills

A skilled workforce is at the base of the EU's capacity to design, manufacture, construct, connect and maintain clean energy technologies and infrastructure. According to the latest IRENA report, employment in the renewable energy sector reached about 1.8 million in the EU in 2023[46]. Data from industry associations show that around 826 000 people were employed in the EU solar sector at the end of 2023 (with 362 000 direct jobs), marking a 27% growth in the number of solar jobs since 2022, with 5% of jobs coming from manufacturing[47]. In the heat pump sector, the number of direct jobs came close to 170 000 in the same year, with 39% in manufacturing[48]. However, negative trends in 2024 and beyond could impact the job market in the sector. In this regard, it is worth noting the role clean energy technologies play in the manufacturing segment, which accounts approximately for a third of the jobs in the broader

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44 Mario Draghi, *The future of European competitiveness*, 2024.
45 Ibid.
46 IRENA and ILO, *Renewable energy and jobs: Annual review 2024*, 2024.
47 Solar Power Europe: *EU Solar Jobs Report 2024 – a solar workforce ready for stronger growth*, 2024.
48 European Heat Pump Association, *European Heat Pump Market and Statistics Report 2024*, 2024.

clean energy sector. This underlines the important role of net-zero technologies and their manufacturing also as regards employment.

While the situation improved slightly in 2024, labour shortages remain a concern. In the third quarter of 2024, the job vacancy rate in the energy supply sector was 1.6%, while the overall rate in the EU economy was 2.3%[49]. The rate of companies reporting labour shortages in the electric equipment manufacturing sector decreased from 20% in the last quarter of 2023 to 15% in the last quarter of 2024[50]. In this regard, a key factor that may exacerbate structural labour shortages in the years to come is the ageing workforce in many Member States[51].

Several policies and initiatives at different levels are already helping to address labour and skills shortages, but efforts need to continue. Member States place high value on reskilling and reallocating workers across occupations, sectors and regions. To the extent possible, objectives and measures on skills are part of the research, innovation and competitiveness policy in the National Energy and Climate Plans[52]. At EU level, following the European Year of Skills in 2023, the skills agenda has remained a priority area. The 2024 Action Plan on labour and skills shortages in EU sets out new actions for the EU, Member States and social partners to support upskilling and reskilling, especially in sectors impacted by the green and digital transition[53]. Three Large Scale Partnerships under the Pact for Skills (on offshore renewables, onshore renewables and digitalisation of energy) and three Net-Zero Skills Academies (a Battery Academy in 2022, a Solar Academy in June 2024 and a Raw Materials Academy in December 2024) have been established to address specific skills shortages in key clean energy technology sectors. In addition, further academies are planned on wind and hydrogen technology.

A competitive clean energy industry and the energy transition therefore require significant, reinforced and targeted public and private coordination efforts to attract, reskill and upskill workers in order to have a sufficient workforce available. Continued effort will be required to increase the share of women working in the development, manufacturing and deployment of clean energy technologies, attract young people to energy professions and develop pools of clean energy talent. In the Competitiveness Compass, the Commission underlines the need for and outlines further measures to tackle skills and labour gaps to support the industries addressed by the Compass. This will include setting up a Union of Skills as well as a renewed focus on skills funding in the EU budget, focusing on sectors involved in the green and digital transition. These measures will be of particular relevance for clean energy technologies and the success of the energy transition.

2.3. The clean energy sector innovation landscape

2.3.1. R&I trends

Historically, the EU has pursued and achieved scientific and technical excellence in clean energy technologies, which also translated into market success through a first-mover advantage. However, this competitive advantage has been slipping in recent years. Whether by advancing in R&I, using captive markets for technology transfer or learning-by-doing, other

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49 Eurostat (jvs_q_nace2), accessed on 13/02/2025.

50 European Commission, DG ECFIN, Business and consumer survey database, subsector data. 'NACE 27: Manufacture of electrical equipment' used as a proxy for renewable energy manufacturing industry as many clean energy technologies fall under this category.

51 IEA, *World Energy Employment, 2024;* Cedefop, *Electroengineering workers: skills opportunities and challenges,* 2023.

52 National Energy and Climate Plan Reports of Member States, where information was provided.

53 COM(2024) 131 final.

economies are catching up or overtaking the EU in the capacity to innovate, with concomitant effects on competitiveness. This is why closing the innovation gap is one of the three strands of the Competitiveness Compass, which sets out measures to strengthen the EU's innovation performance.

At the same time, the EU still has a strong base in clean energy technologies, where in many sectors it remains well placed. However, the EU is falling behind the US and China in digital domains, both overall and when they are related to clean technologies[54]. Considering the horizontal relevance of digitalisation across technologies, this has also repercussions for the EU's competitiveness.

Looking at spending on R&I in clean energy technologies as a share of GDP across major economies, the EU shows a high level of public R&I, but this is contrasted by comparatively lower levels of spending in private R&I. The most recent data available show that half of the Member States that have already reported figures for 2023[55], have increased their public R&I spending. If this partial reporting was representative, it would result - all other things being equal - in an additional EUR 0.7 billion (9% increase) in support for the Energy Union R&I priorities[56].

Public investment in research and innovation in the Energy Union R&I priorities has been steadily increasing, with the figures reported by Member States in 2022 being 23% higher than 2021[57]. About half of the Member States that have provided data[58] increased their public R&I investment in the Energy Union priorities in 2022, compared with 2021. Topped up by EU funds, the public investment declared in 2022 exceeded EUR 9 billion. According to these figures and estimates for China and the US, the EU leads in public R&I spending in clean energy technologies among major economies, both in absolute terms and as a share of GDP (0.057%, followed by Japan 0.055%).

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54 European Commission, Directorate-General for Research and Innovation, *Science, research and innovation performance of the EU 2024*, 2024,

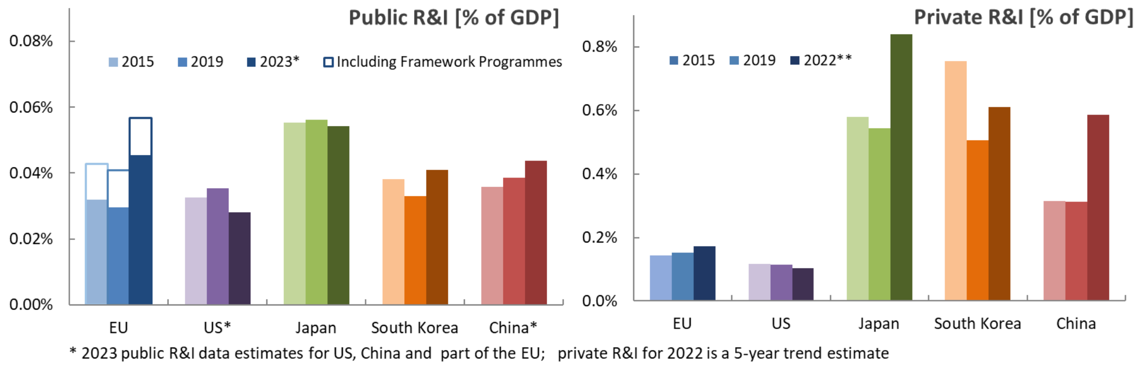
55 Timely, robust and comparable information on R&I trends on clean energy technologies is not readily available. This is, in part, because of the inherent time-lag in certain statistics, but also because there is not always a clear definition of the technology fields concerned, and these are often spread across broader subject areas, such as energy, transport or the built environment. The fragmentation in reporting makes it difficult to have a coherent picture and is one of the areas that need attention, to improve monitoring and coordination in R&I. See also SWD/2023/646 final.

56 COM(2015) 80 final.

57 A significant share of the increase in 2021 and 2022 was due to a change in reporting by Spain, and revisions by France. These two Member States accounted for an additional EUR 1 billion of R&D investment in 2022 France also accounts for much of the 2023 increase. Source: International Energy Agency (IEA), *Energy Technology RD&D Budgets - Database documentation*, 2024.

58 22 Member States are IEA members: AT, BE, CZ, DE, DK, EL, ES, FI, FR, HU, IE, IT, LT, LU, NL, PL, PT, SE, SK (EL and LU do not report, IT still missing). For 2022, BE, DE, EE, ES, FR, LT, IE, PL, PT, FI reported an increase to the IEA for 2022. This far AT, BE, FR, LT, IE, SK have reported an increase for 2023.

***Figure 2**: Public / private R&I investments in Energy Union R&I priorities in major economies as share of GDP*



Source: JRC based on IEA[59], Mission Innovation[60], own analysis[61].

The latest increases mean that Member State investment, from 2021 onwards, has surpassed the peak observed a decade ago – before the effects of the economic downturn – both in nominal terms and when accounting for inflation. Over the same period there has been a notable shift in the share of public R&I investment on the Energy Union R&I priorities. Nuclear safety used to be the most prominent area, attracting nearly a third of public R&I investment; in recent years, sustainable transport has attracted a similar share, with a focus on battery and hydrogen technologies.

Public investments from Member States are complemented by EU funds. The EU Framework Programme for R&I, Horizon Europe, continues to support clean energy technologies and their competitiveness. For instance, the Horizon Europe Cluster 5 'Climate Energy and Mobility' invested around EUR 320 million for R&I in solar PV, EUR 70 million in geothermal energy and more than EUR 230 million on progressing advanced technologies in the field of sustainable alternative fuels for aviation and maritime from 2021 to 2024. Horizon Europe also includes efforts to leverage private investments through European partnerships, like the Clean Hydrogen Partnership, BATT4EU and the Solar PV Partnership.

Private investment continues to provide the majority (over three quarters) of R&I funding for clean energy technologies both in the EU and across all major economies, with investment as a share of GDP remaining significantly higher in major Asian economies than in the EU and the US. Most of the private R&I investment in clean energy technologies in the EU goes to sustainable transport technologies. The automotive sector has the largest share of industrial R&D investment in the EU. It leads in automotive industrial R&D investment globally, investing 8 times more than the energy industry (clean and other technologies)[62]. Nearly a quarter of the sector's innovative activities are directed towards more sustainable technologies, out of which, for example, over a third addressed electromobility (including batteries)[63].

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59 Adapted from: International Energy Agency (IEA) IEA energy technology RD&D budgets database, 2024. Public R&I data estimates for US, based on IEA and Myslikova, Z., Gallagher, K. S., Zhang, F., Narassimhan, E., Oh S., & Chi, K., Global Public Energy RD&D Expenditures Database, 2024.

60 Mission Innovation, *Country Highlights*, 2020. Public R&I estimated for China, based on submissions for previous years and additional sources.

61 European Commission, Joint Research Centre, SET Plan information system Research and Innovation Data; private R&I is a 5-year trend estimate.

62 European Commission, Joint Research Centre, *2024 EU industrial R&D investment scoreboard*, 2024.

63 European Commission, Joint Research Centre, *2023 EU Industrial R&D Investment Scoreboard*, 2023.

The Draghi report emphasised the key role of innovation in increasing productivity, while stressing the need for collective effort to take down barriers to innovation and close the gap with China and the US in key technologies. In this regard, the report stresses that the EU's advantage in green technologies is increasingly under pressure[64]. At the same time, analysis of leading EU R&D investors shows diminishing returns on R&D investment, suggesting that pushing for more investment alone may be an insufficient measure, without addressing other factors such as retaining talent[65]. In 2024, the independent expert group chaired by Manuel Heitor identified a number of measures the EU can take to ensure R&I leadership and support to competitiveness in a fast-changing technological landscape. These range from increasing funding and redefining collaboration, to restructuring R&I policies and instruments[66]. Continuous monitoring of our R&I performance and competitive positioning will help put the changes into practice and assess the effect as needed.

While the EU continues to perform well, China is increasingly leading in research outputs on clean technologies. In terms of scientific publications, the EU is more specialised than the US but stagnating behind China on smart, green and integrated transport and secure, clean and efficient energy. Nonetheless, it is still leading in specialisation, when scientific output is grouped under the headline of the Sustainable Development Goal for affordable and clean energy[67].

The share of patent filings for the protection of climate change mitigation technologies in all inventions peaked in 2011. In parallel to the slow-down in 'green' patenting activity since then, applications for related trademarks have grown, indicating a shift of emphasis to implementation and deployment rather than research and innovation[68]. The EU still maintains a lead in the global output of high-value patent filings[69] in the Energy Union R&I priorities for renewables (29%) and energy efficiency (23%). It is placed second behind Japan in sustainable transport and behind the US in carbon capture, utilisation and storage (CCUS) and nuclear safety, but has not recovered any ground in smart systems. China, after spending a number of years tailoring filings for its domestic market, has increasingly been targeting international protection for clean energy innovations. It is already leading in high-value patent filings for smart systems (33%) and is improving in all other areas. Nonetheless, the EU has consistently maintained specialisation above the global average in renewables, sustainable transport and CCUS. The EU also retains a specialisation advantage in several technologies such as wind energy, hydrogen for transport and bioenergy.

With the Strategic Energy Technology Plan (SET Plan), the main instrument for implementing the research, innovation and competitiveness strand of the Energy Union, the Member States and the Commission are working together and in close partnership with industry and research institutions to establish joint research and innovation agendas in net-zero technologies. Following the revision of the SET Plan in 2023[70], the Net-Zero Industry Act further

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64 Mario Draghi, *The future of European competitiveness*, 2024.
65 European Commission, Joint Research Centre, *2024 EU industrial R&D investment scoreboard*, 2024.
66 European Commission: Directorate-General for Research and Innovation, *Align, act, accelerate – Research, technology and innovation to boost European competitiveness*, 2024.
67 Ibid.
68 Cervantes, M. et al., *Driving low-carbon innovations for climate neutrality, OECD Science, Technology and Industry Policy Papers*, No. 143, 2023.
69 JRC based on all filings included in the EPO Patstat 2024 spring edition. Findings reported for the three most recent years with complete statistics (2018-2020) to avoid distortion of trends due to data lag. For more information: Patent-Based Indicators: Main Concepts and Data Availability.
70 COM(2023) 634 final.

strengthened the role of the SET Plan and its steering group to help support the development of clean, efficient and cost-competitive energy technologies through coordination and collaboration[71].

In 2023 and 2024, work under the SET Plan showed steady progress. Reflecting the strong subject-based links among SET Plan working groups, collaborative work under the SET Plan has intensified, with 2024 seeing the greatest number of collaborations between working groups since the SET Plan's inception. For example, strong collaboration has been established between the group on energy systems and that on sustainable and efficient energy use in industry. SET Plan working groups continue to update and revise their technology-specific implementation plans. For example, in the field of direct current (DC) technologies, a new low-voltage DC (LVDC) implementation plan was released in 2024, aiming to develop and demonstrate LVDC microgrids in buildings and industrial plants. The 2024 SET Plan Progress Report[72] highlights recent developments in greater detail, including for example the vision developed under the plan for the geothermal sector by 2050.

In its new Competitiveness Compass, the Commission has emphasised the need to place research and innovation, as a key driver for competitiveness, at the heart of the EU economy. Among the measures to close the innovation gap, the Commission will present a European Research Area Act to strengthen R&D investment and bring it up to the 3% GDP target. Moreover, the European Research Council and the European Innovation Council will be expanded[73].

2.3.2. *Venture capital investment trends*

The financing of clean energy companies is key to foster the EU's energy resilience and technological sovereignty. Venture capital, which sits at the heart of the ecosystem that finances innovative start-ups and scale-ups, has an essential role to play in ensuring that the EU seizes the industrial opportunities offered by emerging clean energy technologies.

The development of venture capital investment in the EU's clean energy sector attests to the work undertaken by the EU to develop its venture capital industry, mobilise public investors to close large financing gaps and crowd-in other financiers, such as corporate and institutional investors. The EU has the highest relative share of government-provided venture capital (compared to total venture capital)[74], illustrating the strong role of public investments compared with private ones.

A mixed picture emerges for 2023 and 2024, showing both opportunities and challenges for the EU. In 2023, amid a global contraction of venture capital funding, the EU demonstrated its capacity to attract strategic growth deals for large-scale battery and hydrogen-based steel manufacturing facilities. These exceptional deals drove the growth of venture capital

71 OJ L, 2024/1735, 28.6.2024.
72 European Commission, Joint Research Centre, Kuzov, T., Letout, S., Georgakaki, A., Volt, S., Tumara, D., Martinez Castilla, G., Lauritzen, A., Sobczak, A., Paunescu, G., Fromentin, M., Degiorgis, E., Volkanovski, A., Tzimas, E., *SET Plan Progress Report*, 2024.
73 Political Guidelines for the next European Commission 2024-2029; COM(2025) 30 final.
74 European Commission, *Science, research and innovation performance of the EU – A competitive Europe for a sustainable future*, 2024.

investment in clean energy technologies in the EU, which reached EUR 9.2 billion in 2023 (+20% compared to 2022)[75].

In 2024, a persistently adverse macroeconomic environment led to lower deal activity and to the significant decline of the EU's venture capital investment total. This sharp drop (-34% compared to 2023) revealed a substantial reliance on very few large-scale deals (above EUR 1 billion in venture funding). In 2023, three companies raised such amounts, which accounted together for 43% of the venture capital investment total in clean energy technologies in the EU. Among them, the case of the Swedish battery manufacturer Northvolt, which filed for bankruptcy protection in November 2024, highlights the challenge involved in scaling up manufacturing rapidly. This dependence on large deals was even more acute in 2024 with only one deal of this kind, amounting to EUR 2.4 billion and accounting by itself for 39% of the venture capital investment in clean energy technologies in the EU[76].

Due to these major deals, 2023 marked the narrowest investment gap between the EU, where the share of clean energy technologies in the EU's total venture capital investment increased, and the US and China, where venture capital investment dropped. Thus, the EU accounted for 28% - a growing share - of global venture capital investment in clean energy technologies in 2023 and ranked between the US (30%) and China (24%). This share remained relatively stable in 2024.

Overall, access to finance remains a key barrier for most EU firms developing and manufacturing clean energy technologies. Success stories will need to be replicated, including across further technologies where the EU is currently still being outpaced.

In parallel, venture capital investment in solar photovoltaic technologies grew in the EU, capturing 20% of the total worldwide investment between 2021 and 2023. However, this investment mostly benefited solar solution integrators and did not contribute to developing a domestic solar module production. Chinese firms raised 2.7 times more venture capital investment than their EU counterparts, most of which benefited scale-ups developing and manufacturing new types of solar cells and modules.

The EU also accounted for 15% of global venture capital investment in hydrogen technologies between 2021 and 2023. However, its position has been weakened by decreasing venture capital investment in 2023, and by series of larger deals involving Chinese fuel cell manufacturers in 2021 and 2022, and US electrolyser manufacturers in 2023. In 2023, US start-ups developing electrolyser technologies forged ahead, raising 8 times more venture capital funding than their EU competitors, with the aim of scaling up their manufacturing capacities, reducing production costs and addressing overseas markets.

North American start-ups traditionally prevail in all other net-zero technologies and have attracted most of related venture capital investment. This is the case for CCUS, concentrated solar power, geothermal, hydropower, nuclear, renewable fuels from non-biological origin and sustainable alternative fuels technologies, with the EU consistently accounting for low shares of the total venture capital investment realised worldwide in these fields.

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[75] JRC selection based on PitchBook verticals and deep dives carried out for CETO and the European Climate Neutral Industry Competitiveness Scoreboard. For further details, see European Commission: JRC, Georgakaki, A., Taylor, N., Ince, E., Koukoufikis, G., Kuokkanen, A., Kuzov, T., Letout, S., Mountraki, A., Murauskaite-Bull, I., Mancini, L., Miletic, M., Pennington, D., Ozdemir, E. and Terça, G., CETO, *Overall Strategic Analysis of Clean Energy Technology in the European Union*, 2024.

[76] Based on PitchBook, partial 2024 data extracted in 01/2025, based on JRC selection for CETO.

However, the EU has developed a relevant base of ventures in bioenergy, electric vehicle (EV) charging, heat pumps, novel energy storage, ocean, solar thermal, and wind technologies. Together, these account for 18.5% (with EV charging accounting for half of it) of the venture capital investment in net-zero technologies in the EU between 2021 and 2023. In 2023, the EU accounted for the largest share of the total investments worldwide in each of those technologies, on a par with the US. Despite increased investment levels since 2021, EU firms developing such technologies and components still lack the larger deals that enable them to gain a competitive advantage and support the rolling-out of these technologies at scale.

There are several EU funding instruments which foster innovative clean tech investment, such as the Innovation Fund, InvestEU and the venture investment arm of the European Innovation Council (EIC), the EIC Fund. Having entered into force in 2024, the Strategic Technology for Europe Platform (STEP) supports investments in EU start-ups, SMEs and small mid-caps developing and manufacturing critical clean energy technologies[77].

Unlocking the full potential of the EU's clean energy entrepreneurial ecosystem requires removing investment barriers and achieving targeted public intervention[78]. The Draghi report identifies an underdeveloped venture capital market as one of the barriers to clean technologies in the EU and calls for the stimulation of private investments[79]. As the report suggests, scaling up clean energy technology investment entails boosting and streamlining EU level budget and putting in place funding schemes to support private and higher-risk investments in innovative companies, so that EU strategic companies or long-term transition projects can be scaled up.

The Commission's political guidelines recognise the need for further action on public investment and the de-risking of private capital. It is particularly important to facilitate the financing of fast-growing companies by banks, investors, and venture capital. Based on the Letta report[80], the Commission will propose a European Savings and Investments Union, including banking and capital markets[81]. Deepening the EU's banking and capital markets is an essential pre-requisite to unlocking additional sources of funding, fostering cross-border investment and making scale-ups more attractive to investors by improving their exit options.

To ensure that finance flows at the required scale to address the EU's investment gap, clean energy technologies will need to be considered a strategic priority. In this regard, the Commission has announced a European Competitiveness Fund within the next multiannual financial framework, aimed at unlocking investments in clean and strategic technologies. A dedicated EU start-up and scale-up strategy will address obstacles preventing new companies from emerging and scaling up[82].

3. ASSESSMENT OF THE COMPETITIVENESS OF THE EU ON NET-ZERO TECHNOLOGIES

3.1. Solar photovoltaics

Solar photovoltaics (PV) is the fastest-growing electricity production technology from renewable sources. In 2024, the EU was on track to achieve the EU Solar Energy Strategy target of 600 GWac (~720 GWp) installed PV capacity by 2030[83]. Based on preliminary data

77 OJ L, 2024/795, 29.2.2024. For more information: https://strategic-technologies.europa.eu.
78 European Investment Bank, *The scale-up gap*, 2024.
79 Mario Draghi, *The future of European competitiveness*, 2024.
80 Enrico Letta, *Much more than a market*, 2024.
81 For more information: Call for evidence on the European Savings and Investments Union.
82 COM(2025) 30 final.
83 COM/2022/221 final.

for 2024, annual growth has slowed down, but installations have still grown substantially from more than 56 GWp in 2023 to 63 GWp in 2024. In both years, the EU ranked second behind China (374 GWp in 2024) in deployment, followed by the US (45 GWp in 2024)[84]. PV electricity generation costs are now lower than fossil fuel-based alternatives in most countries[85].

The Net-Zero Industry Act refers to the European Solar Photovoltaic Industry Alliance's goal of reaching 30 GWp of annual solar PV manufacturing capacity across the value chain by 2025[86]. This objective has already been surpassed for inverters (82 GWp in 2023[87]) and is close to being achieved for polysilicon (29 GWp in 2024). However, the situation is different for other parts of the value chain. The current EU photovoltaic manufacturing capacity for ingots and wafers is below 1 GWp, while for cells and for modules the figure is below 3 GWp[88], with indications that actual production in 2023 was around 2 GWp for the latter[89]. Overall, the EU is heavily dependent on PV imports from China, where 91% of commissioned manufacturing facilities are situated. In contrast, the EU, US and India each count for a respective share of 1%[90].

The cost of producing a photovoltaic module is estimated to be about 60% higher in the EU than in China[91]. These differences result from higher investment, labour and energy costs, as well as lower scales of production and a lack of vertical integration. Additional challenges for European manufacturers are high inventory levels and oversupply from China driving a sharp decline in spot market module prices, which decreased over 25% year-on-year to EUR 0.105/Wp in January 2025[92]. While this pushes deployment, it puts high pressure on manufacturers. Facilities producing cells and modules are seeing low average utilisation rates of around 50% globally[93].

Overall, EU photovoltaic manufacturers are struggling to compete globally, particularly on price. The concentration of photovoltaic manufacturing capacity in a single country, China, creates risks for the resilience of the value chain and price stability[94]. The EU still has a strong role in research and innovation on solar photovoltaics especially with regard to specific applications such as photovoltaics integrated in buildings, agriculture, infrastructure or vehicles[95].

For the EU to gain competitiveness in photovoltaic manufacturing, it would need to scale-up innovative technologies in large gigawatt-scale factories integrated across the value chain. With the European Solar Charter[96], signed in April 2024, the Commission, 23 Member States and industry representatives committed themselves to a series of voluntary actions in support of the EU PV manufacturing sector.

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84 Jaeger-Waldau, A., *Snapshot of Photovoltaics*, 2025 (forthcoming).
85 IEA, *Advancing Clean Technology Manufacturing*, 2024.
86 OJ L, 2024/1735, 28.6.2024, Recital 16.
87 Solar Power Europe, *Inverter Explained 2.0,* June 2024.
88 European Commission, JRC, Chatzipanagi, A., Jaeger-Waldau, A., Letout, S., Mountraki, A., Gea Bermudez, J., Georgakaki, A., Ince, E. and Schmitz, A., CETO, *Photovoltaics in the European Union*, 2024.
89 ESMC, Letter to the European Commission, January 2024.
90 CETO, *Photovoltaics in the European Union*, 2024.
91 IEA, *Renewables 2023 - Analysis and forecast to 2028*, 2024.
92 PV Exchange, Solar Market Analysis January 2025 - PV module prices at crossroads, 2025.
93 IEA, *Advancing Clean Technology Manufacturing*, 2024.
94 *European Solar Charter*, 2024.
95 CETO, *Photovoltaics in the European Union*, 2024.
96 *European Solar Charter*, 2024.

3.2. Solar thermal

The EU Solar Energy Strategy[97] set a goal of tripling solar heat demand from 2022 to 2030. However, the sector has made limited progress to date and faced several challenges in 2023 and 2024. Investments slowed due to competition from photovoltaics and heat pumps as an alternative renewable solution and effect of cheaper gas and changes in deployment incentives[98]. The EU added 1.3 GWth in solar thermal heat capacity in 2023, down 24% compared to 2022. The resulting net 1.3% increase in capacity (including the decommissioning of older systems) is far below the rate required to triple capacity by 2030[99].

The global market also saw a downturn, with 21 GWth of new installations in 2023, compared to 23 GWth in 2022[100]. More encouragingly, the industrial process heat segment grew globally three-fold year-on-year to reach a total capacity of 0.95 GWth in 2023. This included the EU's new largest concentrated solar heat plant (30 MWth with 68 MWh storage) in Spain. On concentrated solar power (CSP), there has been no increase in EU generation capacity, which remains almost unchanged since 2013 (2.30 GW, almost all in Spain)[101]. In the meantime, China has emerged as the leading CSP developer globally, with 1 GW of new capacity in operation and a further 2 GW in development[102].

The EU has a strong manufacturing sector for solar thermal water heaters and previously was estimated to cover up to 90% of domestic demand, well above the Net-Zero Industry Act's manufacturing benchmark. Despite the sector experiencing consolidation over the last decade, particularly in Germany and Spain, it still features a diverse range of players offering various products. Greek manufacturers of thermosiphon systems have been able to take advantage of strong market growth, also with significant exports[103]. Several EU companies are entering the market for large-scale plants for district heating and for industrial solar thermal heat, which is expected to grow significantly in the coming decade. Trade data for solar and non-electric water heaters show a significant growth in imports, although the EU kept an overall positive trade balance of EUR 27 million in 2023[104].

Solar thermal technology is a mature decarbonisation option, but it remains to be seen whether it can establish a significant market share. Currently solar thermal covers just 0.9% of global heat energy consumption demand[105]. The levelised cost of solar heat can be competitive with conventional sources, particularly in areas with good solar resources. However, solar thermal technology is often installed in a system with another heat source, whereas heat pumps can offer standalone solutions for many applications. Solar thermal would benefit from coordinated efforts and clear roadmaps to put growth on track to reach the 2030 goal.

EU companies are in a good position as technology suppliers, but continued efforts are needed on standardisation and on developing a network of installers with expertise in cost-effective solutions, including hybridisation with other renewable technologies. For concentrated solar power, any renaissance of the EU market will rely heavily on Spain's proposal to add 2.5 GW

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97 COM(2022) 221.
98 EurObserv'ER, Solar thermal and concentrated solar power barometer, 2024.
99 Ibid.
100 Weiss, W., Spörk-Dür, M., *Solar Heat Worldwide*, 2024.
101 Eurostat (nrg_inf_epcrw) , accessed on 12/02/2025 and European Commission, JRC, Carlsson, J., Taylor, N., Georgakaki, A., Letout, S., Mountraki, A., Ince, E., Schmitz, A. and Gea Bermudez, J., CETO, *Solar Thermal Energy in the European Union*, 2024.
102 REN21, *Renewables 2024 Global Status Report Collection: Energy Supply*, 2024.
103 EurObserv'RE Concentrated Solar Power and Solar Thermal Barometer 2023.
104 CETO, *Solar Thermal Energy in the European Union*, 2024.
105 IEA, *Renewables 2023*, 2024.

by 2030[106]. Here also, standardisation in design and manufacturing would be essential to achieving competitive cost levels.

3.3. Onshore and offshore wind energy

The EU is at the forefront of the global wind industry and has so far held a strong position. However, its competitiveness is increasingly under pressure from China. Wind plays a pivotal role in the EU energy transition, with 219 GW of total wind power capacity installed by 2023, 91% onshore and 9% offshore[107]. In 2023, 16.8 GW of new capacity was installed, of which 83% in onshore wind installations and 17% offshore[108]. These developments mark a faster pace of installation (combined installation for 2022 was 15.5 GW) and make 2023 a record year, in terms of annual installation. Preliminary figures for 2024 show that the EU has installed an additional 13.6 GW of wind power capacity, comprising 10.7 GW onshore and 2.9 GW offshore[109].

With the Net-Zero Industry Act, the EU targets a manufacturing capacity for wind of at least 36 GW by 2030[110]. In 2024, the EU accounted for 12.6% of global blade manufacturing (~25 GW), 12.5% of the global nacelle assembly (~35 GW) and 21.8% of the tower manufacturing (~38 GW)[111]. In 2023, EU companies supplied globally more than 27 GW of wind turbines[112]. However, the global market share of EU manufacturers declined in 2023 to 23% from 30% in the previous year, while Chinese manufacturers increased their share from 46% to 55%. In the European market, EU companies continue to dominate with a market share of 89% in 2023. EU manufacturing capacity will need to be increased to match future demand based on the expected increased rate of installations. This is crucial to decrease capital expenditure for new installations, ensure that supply meets demand at competitive prices and to avoid supply bottlenecks or increases in costs.

The main challenges for EU companies relate in particular to intense competition from China. Chinese manufacturers are able to offer much lower prices than their European rivals, with exported turbines from China about 32% cheaper than their competitors[113], in a context where the price of wind turbines and their components increased by around 26% globally compared to pre-pandemic levels[114]. This could create an uneven playing field for EU companies and hinder their future competitiveness in the global market.

As the macroeconomic environment improved, investments in wind power have started to rebound[115], with a record investment of EUR 48 billion in 2023 in the EU (compared to an investment of less than EUR 20 billion in 2022). In 2023, onshore wind remained at an investment level comparable to the one of 2022 at around EUR 18 billion, while offshore increased from EUR 0.4 billion invested in 2022 to EUR 30 billion in 2023.

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106 Government of Spain, Integrated National Energy and Climate Plan, Update 2023-2030, 2024.
107 Eurostat (nrg_inf_epcrw), accessed on 12/02/2025.
108 Eurostat (nrg_inf_epc), accessed on 12/02/2025.
109 JRC based on GWEC and Rystad, 2025.
110 OJ L, 2024/1735, 28.6.2024, Recital 16.
111 JRC based on BloombergNEF and Rystad.
112 European Commission, JRC, Mc Govern, L., Tapoglou, E., Georgakaki, A., Mountraki, A., Letout, S., Ince, E., Gea Bermudez, J., Schmitz, A. and Grabowska, M., CETO, *Wind Energy in the European Union*, 2024.
113 BloombergNEF, *Wind Turbine Price Index 2H 2024*, 27 December 2024.
114 BloombergNEF, *Rising costs dampen the outlook for offshore wind*, 3 July 2024.
115 Rystad and WindEurope, Report*: Rebound in wind energy financing in 2023 shows that the right policies attract investors*, 21 March 2024.

The global wind industry relies heavily on complex supply chains, which can be vulnerable to disruptions, trade tensions, and shortages of critical raw materials. The need for materials like copper and steel is significant, as these are used in various turbine components such as generators, towers, blades, and gearboxes. Of particular concern is the strong dependency on Chinese rare earth elements[116], which are crucial for producing permanent magnets for wind turbines. Vulnerabilities also exist in components and subcomponents, such as generators, increasing the risk of supply chain disruptions. The sourcing of both materials and components can be concentrated in a few countries, which can create supply chain risks due to geopolitical dependencies, underscoring the need for diversified and resilient supply chains to support the wind industry's growth.

With the European Wind Power Action Plan, the Commission has proposed measures to support the competitiveness of the EU wind manufacturing industry[117]. One of the linked initiatives, the European Wind Charter[118], was signed in December 2023. The Charter brings together 26 Member States which have committed to supporting the EU wind sector by, amongst others, scaling up manufacturing capabilities in the EU and improving and simplifying the auction and permitting process. Existing efforts to support deployment, including faster permitting, project pipeline visibility and grid investments will need to be continued to ensure that investments in future wind farms remain attractive and that the EU wind industry is able to profit from the opportunities offered by the global expansion in wind energy.

3.4. Ocean energy

Ocean energy includes several technologies, with the most advanced being tidal stream and wave energy. Although some of these technologies have reached high technology readiness levels, ocean energy technologies are not yet deployed at an industrial scale.

The EU is a leader in the development of ocean energy technologies, particularly in tidal and wave energy. However, it faces growing competition from other major economies, such as the US and China. The US invested EUR 546 million[119] in ocean energy over the last five years. In 2023 and 2024, the market saw unprecedented funding and interest. Provisional data for 2024 shows that at least 1230 kW of new ocean energy capacities were installed in Europe in 2024[120]. In the EU, 878 kW were installed in 2022 and 250KW in 2023[121]. National revenue support (e.g. contracts for difference or feed in tariffs) and EU and national funding were the main drivers over 2023/2024 for attracting private investments and boosting the development of these projects in Europe. Industry representatives expect a pipeline accounting for 165 MW across 15 pilot and pre-commercial farms[122]. Among Member States, France, Denmark and the Netherlands have the majority of cumulative installed capacity in terms of tidal stream energy, while Portugal, and Spain are leading the deployment of wave energy devices.

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116 European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, *Study on the Critical Raw Materials for the EU 2023: Final Report*, 2023.
117 COM/2023/669 final.
118 *European Wind Charter*, 2023.
119 Using the average exchange rate of EUR 0.9239 for USD 1 over the year 2024, based on ECB.
120 Preliminary data by Ocean Energy Europe.
121 Eurostat (nrg_inf_epc), accessed on 12/02/2025.
122 ETIP Ocean, *Strategic Research and Innovation Agenda for Ocean Energy*, 2024.

EU industry is playing a leading role in developing the sector with 41% of tidal stream developers and 52% of wave energy developers based in the EU[123]. Manufacturing of gearboxes, generators, and control systems is predominantly European, with projects estimated to provide at least 415 Full Time Equivalent posts in the EU. Globally, the EU holds 20% of high-value inventions, second only to China (32%)[124].

The main challenge remains the high cost of capital which slows investment and deployment, with a knock-on effect on industrialisation. The Strategic Energy Technology Plan (SET Plan) provides goals in this regard, aiming to bring down production costs to EUR 0.10/kWh by 2030 for tidal stream and to EUR 0.15/kWh by 2030 for wave energy[125]. This is to be achieved in particular through technology-specific auctions for pilot and pre-commercial farms, which are still lacking in some Member States. Delivering the pipeline of projects and achieving this target requires instruments to lower the risk of investments. Such de-risking instruments could include loan guarantees for the first pre-commercial farms to lower the cost of capital, attract investors and accelerate deployments. This will unlock economies of scale and further reduce costs, as has already been experienced with established renewables.

3.5. Battery and energy storage

Europe's ambition to lead the global transition towards clean energy relies on its capacity to develop, produce, and integrate advanced battery technologies fast and at scale. The Net-Zero Industry Act refers to the objective of reaching an EU battery manufacturing capacity of at least 550 GWh by 2030[126].

At the beginning of 2024, the EU seemed on track to meet its goals for 2030. In the meantime, however, Swedish company Northvolt filed for bankruptcy protection in November 2024. Estimates suggest that about 616 GWh of planned manufacturing capacity in Europe is reported as cancelled, delayed or downsized, which could put 2030 targets at risk[127]. As a result, the EU’s share of global operational battery production of 7% in 2024 is lower than previous estimates. At the same time, the overall global production is expected to increase almost five-fold in the coming five years and the projected 10% share of global production in the EU would fully cover the projected EU needs in 2030, if it were to be realised[128].

Cell production in the EU faces critical supply chain risks, particularly due to high dependency on China for cathodes and anodes, and higher production costs - typically 70% to 130% more per unit of output capacity than in China[129]. Increasing global over-production of cells and slumping electric vehicle demand led to European production sites running below capacity or halting/postponing production lines, such as the Volkswagen Salzgitter plant (only 20 GWh instead of 40 GWh)[130]. For 2030, forecasts predict a global oversupply of battery cells. In addition, protective trade measures are on the rise, including for example US tariffs on Chinese electric vehicles. A further escalation of trade tensions could potentially inflate costs and impact

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123 European Commission, JRC, Tapoglou, E., Mc Govern, L., Georgakaki, A., Mountraki, A., Letout, S., Ince, E., Gea Bermudez, J., Schmitz, A. and Grabowska, M., CETO, *Ocean Energy in the European Union*, 2024.

124 CETO, *Ocean Energy in the European Union*, 2024.

125 SET Plan, *Ocean energy implementation plan*, 2021; CETO, *Ocean Energy in the European Union*, 2024.

126 OJ L, 2024/1735, 28.6.2024, Recital 16.

127 BloombergNEF, *Northvolt Collapse Underscores Importance of Supply Chains*, 2024.

128 237 GWh of production capacity in the EU compared to a global production capacity of 3 347 GWh in 2024 and an estimated 1 510 GWh of production capacity in the EU compared to a global production capacity of 14 903 GWh in 2030, based on BloombergNEF, accessed on 20/02/2025.

129 IEA, *Advancing Clean Technology Manufacturing Report*, 2024.

130 Reuters, *Volkswagen's German battery plant to stay at half capacity amid cost pressures*, 2024.

battery supply chain procurement decisions[131]. In the EU, the Commission concluded an anti-subsidy investigation into the imports of battery electric vehicles from China in 2024, resulting in countervailing duties on imported vehicles[132].

Global grid-scale battery energy storage system (BESS) capacity reached 168 GWh in 2024, a substantial increase from 96.1 GWh deployed in 2023[133]. China accounted for 67% of BESS deployments globally, followed by the US and Canada, with Europe currently trailing in BESS deployment. 'Behind the meter' (BTM) energy storage reached 40 GWh globally in 2024. By 2035, stationary applications are expected to account for 16% of batteries deployed globally, up from 6% in 2020[134]. Most leading BESS battery suppliers are headquartered in Asia.

To keep up with its competitors, the EU must deploy production capacity faster and build reliable value chains, invest more in R&D for new battery technologies and address critical gaps in its value chain through alternative solutions.

3.6. Heat pump technologies

Heat pump final assembly manufacturers located in the EU are among the global leaders in high-end hydronic solutions for residential use, while Chinese companies are dominating the market for reversible air-to-air conditioners[135]. EU manufacturers have announced over 30 GWth of final assembly capacity expansions during this decade, compared to an existing capacity of about 24 GWth in 2023. With these planned expansions, EU industry is close to meeting the 2030 EU deployment needs of about 60 GWth identified by the International Energy Agency[136]. While the EU is on track to meet the Net-Zero Industry Act target of at least 31 GWth manufacturing capacity for final heat pump assembly, EU companies are currently not as strongly positioned in the manufacturing of certain components.

The EU trade balance deficit in hydronic heat pumps was reduced by one third in 2023, due to a 13% decrease in imports and a 14% increase in exports[137]. At the same time, heat pump sales in the EU fell by 7.2% in 2023 compared to 2022 after a decade of steady growth[138]. This trend continued in 2024 as sales in Europe dropped 31% compared to 2023[139]. This resulted in short-time work and job cuts in the sector and uncertainties for manufacturing investment decisions. EU manufacturing capacity growth also slowed in 2023[140]. To reverse this trend, the industry

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131 BloombergNEF, *Energy Storage:10 Things to Watch in 2025*, 2025.
132 OJ L, 2024/2754, 29.10.2024.
133 Energy Storage News, *Global BESS deployments soared 53% in 2024*, 2025.
134 Based on BloombergNEF, January 2025.
135 COMEXT/COMTRADE data for HS code 841861 - heat pumps; other than air conditioning machines: EU export to world: EUR 3837m of which EUR 603m ExtraEU; China export to world EUR 971m. And COMEXT/COMTRADE data for HS code 841581 - air conditioning machines: EU export to world: EUR 782m of which EUR 177m ExtraEU; China export to world EUR 549m.
136 IEA, *Advancing Clean Technology Manufacturing*, 2024. Net zero emissions scenario by 2050; scope: heat pumps for space and hot water heating in residential and commercial buildings, reversible air conditioners included where used as primary heating equipment.
137 HS 841861– Heat pumps (excl. air conditioners). More details in: European Commission, JRC, Toleikyte, A., Lecomte, E., Volt, J., Lyons, L., Roca Reina, J.C., Georgakaki, A., Letout, S., Mountraki, A., Wegener, M., Schmitz, A., CETO, *Heat Pumps in the European Union*, 2024.
138 European Heat Pump Association (EHPA), Market Report, 2024, limited to AT, BE, CZ, DE, DK, EE, ES, FI, FR, HU, IE, IT, LT, NL, PL, PT, SE, SK. Including mainly space heating and sanitary hot water heat pumps.
139 BloombergNEF, Europe's Heat Pump Market Collapse Triggers Spending Dip, 2025.
140 IEA, *Advancing Clean Technology Manufacturing*, 2024.

is calling for ambitious EU targets for space heating decarbonisation, stable long-term national policy frameworks and a favourable electricity-to-gas price ratio[141].

The heat pump final assembly step is estimated to cost around EUR 184-230/KW[142] in Europe and the US today, around twice the cost estimated for China. As components represent 75% of the final cost, vertically integrated manufacturers are more competitive[143]. EU industry remains largely dependent on imports for components, such as compressors, heat exchanger, valves, and refrigerant. To strengthen competitiveness and resilience on residential heat pump manufacturing, more diversification of supply and stronger EU value chains would be needed to reduce these dependencies.

As regards **industrial heat pumps (IHPs)**, EU manufacturers have taken a globally leading role and are covering the entire supply chain[144]. According to the International Energy Agency, approximately 30% of the industrial heat demand up to 400°C should be covered by industrial heat pumps until 2050, and already half of it by 2030[145]. Industrial heat pumps also have the potential to cover heat needs below 200°C, which represent 37% of industrial heat needs[146], with existing applications in the food & drink and pulp & paper sectors.

To further develop industrial heat pumps, R&D projects are needed to expand the range of applications and to bring technologies as fast as possible into application and standardisation[147]. In addition, investments in the EU supply chain are needed, to expand production capacities and lower product costs. The industry sees in industrial heat pumps having the potential to become a European success story.

3.7. Geothermal energy

In 2024, geothermal energy gained in public attention and political momentum. This political momentum included the European Parliament Resolution on geothermal energy[148] and the Council Conclusions on geothermal energy[149]. In 2023, installed net geothermal power capacity in the EU was around 0.9 GWe[150] (globally 14.8 GWe[151]). Geothermal direct heat use grew steadily with 298 district heating and cooling systems in place in 2023[152].

EU companies play a strong role in the Single Market from site investigation to decommissioning, as deployment value chains are usually entirely domestic[153]. As regards final products manufacturing, the sector is estimated to be meeting the target in the Net-Zero Industry Act for 40% of deployment needs to be covered by domestic production[154]. By contrast, the global market for components such as turbines, turboexpanders, pumps, valves

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141 EHPA, *EU Heat Pump Accelerator*, 2023.
142 Using the average exchange rate of EUR 0.9239 for USD 1 over the year 2024, based on ECB.
143 IEA, *Advancing Clean Technology Manufacturing*, 2024.
144 IEA HPT TCP, *Annex 58 High-Temperature Heat Pumps*, 2023. 20 in EU and 7 in Norway; 24 in Japan, of which 9 Mechanical Vapour Recompression (MVR) technology; as well as MVR installations in China.
145 IEA, *Net Zero by 2050*, 2021.
146 TNO, *Strengthening Industrial Heat Pump Innovation*, 2020.
147 IEA Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP), *Annex 58 High-Temperature Heat Pumps*, 2023.
148 European Parliament, Resolution of 18 January 2024 on geothermal energy (2023/2111(INI)).
149 Council of the European Union, Conclusions on the promotion of geothermal energy, 16 December 2024.
150 Eurostat (nrg_inf_epcrw), accessed on 12/02/2025.
151 Renewable Energy Policy Network for the 21st Century (REN21), *Renewables Global Status Report*, 2024.
152 European Geothermal Energy Council (EGEC), *Geothermal Market Report 2023*, 2024.
153 EGEC, *Geothermal Market Report 2023*, 2024.
154 European Commission, JRC, Taylor, N., Georgakaki, A., Ince, E., Letout, S. Mountraki, Gea Bermudez, J. and Schmitz, A., CETO, *Geothermal Energy in the European Union*, 2024.

and control systems is dominated by non-EU companies. Japan produces 82% of flash cycle steam turbines and Israel 74% of binary cycle expanders. European manufacturers of these technologies are mainly based in Italy and to a smaller extent in Germany and France[155]. In research and innovation, the EU used to be the global leader for high-value inventions before being overtaken by China in 2019[156].

The co-production of lithium and other raw materials can increase the economic sustainability of geothermal plants. In terms of material dependencies, the technology itself heavily relies on steel, much of which is imported from Asia. To a smaller extent, the geothermal sector also requires critical raw materials such as aluminium[157], copper and titanium[158].The recent own-initiative report from the European Parliament[159] and the Council conclusions[160] recommend, amongst others: (i) increasing political visibility and overall awareness on the potential and challenges of geothermal; (ii) tackling the issue of data availability; (iii) reducing the investment risks by implementing guarantee schemes; (iv) streamlining and accelerating permitting procedures; (v) promoting best practices; (vi) tackling the shortage of skilled workforce; and (vi) improving public acceptance.

3.8. Hydrogen technologies: electrolysers & fuel cells

Water electrolysis is a process whereby hydrogen is produced from water using electricity. If the electricity comes from renewable and low-carbon sources, this technology has the potential to play a key role in decarbonising hard-to-abate industrial sectors, in particular the production of energy-intensive materials (e.g. steel, cement), fertilisers and the maritime and aviation sectors. The manufacturing capacity of electrolysers is on the increase in Europe, supported by regulatory and funding frameworks[161]. The first auction of the European Hydrogen Bank in 2024 provided EUR 720 million for seven projects. While this allows more projects to reach final investment decisions, European companies continue to face financing and operational hurdles.

Installed electrolyser capacity in Europe grew from 228 MWe in 2023 to 663 Mwe in 2024 (projects in operation or with an investment decision in place), with 517 MWe in EU countries[162]. Worldwide installed capacity grew from 1.4-1.7 GWe in 2023 to up to 5 GWe in 2024[163]. Of this, 2.7 GWe is in China and about 300 MWe in the US.

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155 EGEC, *Geothermal Market Report 2023*, 2024.

156 CETO, *Geothermal Energy in the European Union*, 2024.

157 EGEC, *Geothermal Market Report 2023*, 2024.

158 European Commission, Directorate-General for Research and Innovation, Schleker, T., Hicks, M., Cressida Howard, I., Ohrvik-Stott, J. et al., *Study on clean energy R&I opportunities to ensure European energy security by targeting challenges of distinct energy value chains for 2030 and beyond*, 2024.

159 European Parliament, Resolution of 18 January 2024 on geothermal energy (2023/2111(INI)).

160 Council of the European Union, Conclusions on the promotion of geothermal energy, 16 December 2024.

161 Including consumption targets in the Renewable Energy Directive (EU) 2023/2413, the goal of the Electrolyser Partnership to reach 25 GWe per year by 2025, and 4 IPCEIs on hydrogen and fuel cells, see: https://competition-policy.ec.europa.eu/state-aid/ipcei/approved-ipceis_en.

162 Based on the IEA hydrogen projects dataset, accessed in January 2025 for the EU, NO, UK and CH.

163 European Commission, JRC, Bolard, J., Dolci, F., Gryc, K., Eynard, U., Georgakaki, A., Letout, S., Mountraki, A., Ince, E., Shtjefni, D., Rózsai, M. and Wegener, M., CETO, *Water Electrolysis and Hydrogen in the European Union*, 2024; IEA, *Global Hydrogen Review*, 2024. The IEA reports in 2024 significantly lower installed capacity for the US, than in projects database in 2023, which amounted to 717 MWe.

European electrolyser stacks' manufacturing capacity is estimated at 10-15.7 GWe annually in 2024[164], while worldwide capacity projected at 40-54 GWe annually[165]. China has the highest manufacturing capacity, projected at around 20 GWe in 2024[166].

Despite expanded manufacturing capacity and increases in system size, the expected cost reductions have not yet been achieved. This is due to inflation and other costs such as auxiliary components, power connection and indirect costs. Most recent studies indicate capital expenditure related costs for 100 MW alkaline systems of EUR 3 050 per kW and EUR 2 630 per kW for 200 MW systems[167], at least four times more than in Asia. Some European manufacturers indicate that they lack sufficient buyers for their production, which affects their ability to decrease capital costs per kW and the viability for many business cases for renewable and low-carbon hydrogen.

The growth of supply in Europe is slowing down. This is due to upstream supply chain shortages, lack of suitable demand volumes and dependencies on critical raw materials (e.g. platinum group metals)[168] and components[169]. These factors are also contributing to higher manufacturing costs. The competitiveness of European electrolysers companies is therefore moderate. On the one hand, there are commercially available products for the main groups of electrolysers[170], and EU players are well placed as regards high value patents[171]. On the other hand, there are long lead times for stack assembly, upstream weaknesses in the value chain, and more costly systems that impact the competitiveness of European manufacturers. The business case may also be affected by other aspects, such as post-manufacturing guarantees and high operating costs to produce renewable hydrogen.

Electricity costs play an important role in the Levelized Cost of Hydrogen (LCOH). This is because electricity represents a significant share of the total costs, with its relative share varying across locations and specifications of electrolysers[172]. As an example, in the recent projects in the Netherlands the LCOH[173] was 12-14 EUR/kg hydrogen for offshore electricity for electrolyser systems of 100-200 MWe. The LCOH will significantly depend on design, operation and localisation of projects.

Remaining research and innovation challenges are the substitution of 'forever chemicals' used in membranes, decreasing system costs, improving their performance and lifetime, reducing freshwater consumption and the uptake in the end use sectors at competitive prices.

Fuel cells (FC) are systems to produce electricity from clean hydrogen efficiently. They have value added when providing decarbonised solutions for transport, heating or off-grid power. They are used primarily in fuel cell electric vehicles, buses, regional trains and to a lesser extent in heating, machinery and stationary off-grid power. In the EU, emission standards and carbon

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164 IEA, *Global Hydrogen Review,* 2024; CETO, *Water Electrolysis and Hydrogen in the European Union*, 2024. The upper range refers to Rystadt Energy and includes manufacturing capacity under construction (October 2024).

165 IEA, *Global Hydrogen Review*, 2024. Higher range data projected in BloombergNEF, *Electrolysers, too many fish in the Pond*, 2024.

166 IEA, *Global Hydrogen Review*, 2024. The upper range refers to OEM's headquarter locations in China.

167 Based on BloombergNEF, *Electrolyser Price Survey*, 2024; TNO, *Evaluation of the levelised cost of hydrogen based on proposed electrolyser projects in the Netherlands*, 2024.

168 Based on JRC, Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU, 2023. 1-5% of CRM for electrolysers are sourced in Europe.

169 Based on BloombergNEF, Electrolyser Overcapacity, 2024.

170 The four main commercialised technologies are: alkaline, proton exchange membrane, solid oxide, anion exchange membrane. Proton conducting ceramic electrolysis are a further technology in development.

171 European Climate-neutral industry competitiveness scoreboard (CIndECS). 31% of high value inventions in the EU.

172 CETO, *Water Electrolysis and Hydrogen in the European Union*, 2024.

173 TNO, *Evaluation of the levelised cost of hydrogen based on proposed electrolyser projects in the Netherlands*, 2024.

prices create additional incentives for investments. In 2023, the estimated installed capacity was 7.8 GW worldwide, led by Asia (72%), the US and Canada (18%) and Europe with 0.6 GW (8%)[174], with most of the market in mobility[175].

European manufacturers offer fuel cells buses but the fuel cells are, in most cases, purchased from other suppliers, notably from Canada and Japan. Fuel cell prototypes are developed in the EU for heavy-duty vehicles as the interest in clean transport grows and total cost of ownership may come to cost parity with diesel trucks after 2035. It is estimated that fuel cell heavy-duty vehicles will remain more expensive than battery electric ones. Fuel cells in heating will likely only play a niche role in the EU.

The resilience of value chains for both electrolysers and fuel cells need to be strengthened, from the sourcing of raw materials to the manufacturing and supply of components to shorten delivery times of full systems in Europe at competitive costs. Availability of large quantities of cost competitive renewable and low-carbon hydrogen remains a policy priority.

3.9. Sustainable biogas and biomethane technologies

Europe has a mature industry mainly for electricity generation by biogas, with growing markets in heat and transport driven by grid injection with biomethane. Almost 50% of production is in Europe, with Germany alone meeting 20% of global demand[176]. Anaerobic digestion remains the main commercial technology used to produce biogas which is then upgraded to biomethane. The EU is a leading producer of biogas and biomethane, with a combined production of around 22.1 billion cubic metres in 2023[177]. It is also a leader in equipment manufacturing. The EU biomethane production capacity from anaerobic digestion was 3.8 billion m^3 in 2023 with actual annual production estimated at 3.5 billion m^3, but production capacity growth is projected to increase by a factor of 5 by 2030[178]. The current biomethane growth rate in the EU follows closely the 2030 targets in the National Energy and Climate Plans, aligning with the REPowerEU target.

The EU is home to world leading companies in the biogas and biomethane production and manufacturing components (e.g. digesters, biogas cleaning equipment, gasifiers)[179]. Novel pathways are under development, with the EU in the lead[180]. The EU's Horizon programme has invested more than EUR 120 million in 20 innovative projects, progressing technology in the field. Innovative technologies to produce directly biomethane, such as gasification of biomass residues and wastes, is not widely demonstrated yet in the EU (2 000 t/y of installed and operational production capacity in 2023, although biomethane production is expected to grow to 0.7 billion m^3 in 2030[181]). Bio-LNG production plants present a valuable option in the EU, with a capacity of around 7.3 TWh in 2023 expected to rise to 15.4 TWh by 2025[182].

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174 Based on Rystad Energy, Fuel Cell Installed Capacity Dataset, 2024.
175 European Hydrogen Observatory, *Fuel Cell Market Dataset*, 2021.
176 IEA, Renewables 2023, *Special section: Biogas and biomethane*, 2024.
177 Based on European Biogas Association (EBA), Statistical report, 2024.
178 European Commission, Directorate General for Research and Innovation, *Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels*, *(Annex 3)*, 2024.
179 European Commission, Directorate General for Research and Innovation, *Study on energy technology dependence*, 2020.
180 European Commission, JRC, Motola, V., Scarlat, N, Buffi, M., Hurtig, O., Rejtharova, J., Georgakaki, A., Mountraki, A., Letout, S., Salvucci, R., Rózsai, M. and Schade, B., CETO, *Bioenergy in the European Union*, 2024.
181 European Commission, Directorate General for Research and Innovation, *Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels*, *(Annex 3)*, 2024.
182 CETO, *Bioenergy in the European Union*, 2024.

The EU accounts for a significant portion of biogas investments and is the leader in high-value patents[183]. Biogas technologies (anaerobic digestion and gas upgrading) do not show critical dependencies for materials, components or suppliers and there is no reliance on equipment, materials, or suppliers of technologies specific to a gasifier[184]. The EU also has no import dependencies for biological feedstocks[185]. However, dependencies on non-EU suppliers exist for gas engines and turbines for electricity generation as in all gaseous fuels.

High costs currently hinder further biomethane deployment, as the capital cost for an anaerobic digestion biogas plant is about 1500-2000 EUR/KW[186] and the total cost of biogas production and upgrading is estimated at about 100 EUR/MWh[187]. Similarly, for a gasification biomethane plant the capital cost is 2000-3600 EUR/KW and the production cost is around 89-112 EUR/MWh[188].

To maintain the EU's competitiveness in this sector, innovation in technologies for sustainable biomethane production from gasification and from upgrading anaerobic digestion biogas needs to be further supported to increase production capacity and reduce production costs. In addition, grid access for biogas and biomethane plants should be facilitated.

3.10. Carbon capture and storage (CCS) technologies

With its Industrial Carbon Management Strategy[189] adopted in February 2024, the EU sets out a vision for a robust regulatory and investment framework for technologies to capture, transport, use and store carbon and for technologies that remove atmospheric carbon. Supported by the Net-Zero Industry Act, which sets an annual injection capacity target of at least 50 million tonnes in storage sites in the EU by 2030[190], the strategy sets out concrete actions to support CCS technologies.

The EU is well positioned in CO2 capture technologies, with five of the 16 major technology providers of CO2 capture listed being EU companies[191]. However, for CO2 transport, storage and the full value chain, Europe lags behind the US and Canada with very few companies providing these technologies[192]. The EU has caught up in recent years on public R&D spending. In 2022, the EU accounted for around 22% of global spending, slightly ahead of Canada and Japan[193], with the majority of investments going into CO2 storage.

In 2023, the number of CCS projects in various stages of developments doubled compared to the previous year and reached 392 facilities globally (with 119 projects in Europe), amounting

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183 CETO, *Bioenergy in the European Union*, 2024.
184 European Commission, Directorate General for Research and Innovation, *Study on energy technology dependence*, 2020.
185 CETO, *Bioenergy in the European Union*, 2024.
186 European Commission, Directorate General for Research and Innovation, *Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels*, 2023.
187 IEA, *Outlook for Biogas and Biomethane*, 2020; European Commission, Directorate General for Research and Innovation, *Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels*, *(Annex 3)*, 2024.
188 European Commission, Directorate General for Research and Innovation, *Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels*, *(Annex 3)*, 2024.
189 COM/2024/62.
190 OJ L, 2024/1735, 28.6.2024, Recital 36.
191 European Commission, JRC, Martinez Castilla, G., Tumara, D., Mountraki, A., Letout, S., Jaxa-Rozen, M., Schmitz, A., Ince, E. and Georgakaki, A., CETO, *Carbon Capture, Utilisation and Storage in the European Union*, 2024.
192 CETO, *Carbon Capture, Utilisation and Storage in the European Union*, 2024.
193 Ibid.

to 361 Mtpa CO2[194]. In Europe, CCS projects at different stages of development, support industries like hydrogen, ammonia and fertiliser production (20 facilities), power generation and heat (19 facilities), cement (17 facilities), and biomass to power/heat (15 facilities)[195].

In Europe, out of 35 CO2 transport and networks projects under development, several are key Projects of Common Interest (PCI) underpinning an EU cross-border carbon dioxide network[196]. Whilst identified storage capacities continue to be concentrated in the North Sea, new locations for onshore and offshore CCS projects have been mapped in Member States such as Bulgaria, Croatia, Greece and Italy. 2024 saw the granting of the first exploration licenses for land-based storage of CO2 in Denmark, doubling the total amount of exploration licenses for CO2 storage[197]. In January 2025, the Commission awarded funding worth EUR 250 million under the Connecting Europe Facility for Energy to support the construction of three projects and the financing of nine preparatory studies for CO2 infrastructure Projects of Common Interest[198].

The EU is well positioned in key CCS component manufacturing sectors for capture technologies, such as amine solvents used for absorption (the most mature technology). However, it does not operate at scale nor have specialised value chains yet. After a period of stagnation in the past decade, the EU production of amine solvents reached EUR 260 million in 2023, an increased by 8% on the previous year. The EU is well positioned to develop innovative methods, including on membranes (polymeric, ceramic) and adsorbents, while China leads globally in terms of peer-reviewed articles. Projects under the EU's Horizon 2020 programme are expected to strongly improve processes and push these methods to the commercial stage[199].

Despite momentum building up for CCS in the EU in the past year, the pace of deployment of CO2 storage will need to grow exponentially to achieve the significant CO2 capture volumes necessary for meeting the 2030, 2040 and 2050 targets. The EU is putting in place measures to enhance the visibility of demand and supply of storage and lay down the necessary framework for a non-discriminatory, open access and a multi-modal CO_2 infrastructure. These measures will address the main challenges in the deployment of industrial carbon management solutions, increase predictability for investors and de-risk investments. The Commission will propose further measures to incentivise and increase the uptake of carbon capture, utilisation, and storage (CCUS) technologies[200].

3.11. Electricity grid technologies: power lines and transformers

The EU Action Plan for Grids[201] identifies global trends (e.g. growing electricity consumption, digitalisation, and the integration of renewables), which are contributing to increase global

194 Facilities in the deployment pipeline, in construction or operational; not including capacity of CO2 transport and/or storage projects (to avoid double counting) other than those CO2 transport and/or storage facilities that do not have their own CO2 capture source.

195 Global CCS Institute, *Global Status of CCS 2023, Scaling up through 2030.*

196 Such as the PORTHOS and ARAMIS projects in the Netherlands and Antwerp@C in Belgium. The new list of EU energy Projects of Common and Mutual Interest (europa.eu) includes 14 CO2 network projects.

197 Danish Ministry of Climate, Energy and Utilities, *The first exploration licenses for land-based storage of CO2 in Denmark have been granted,* 20 June 2024.

198 See https://ec.europa.eu/commission/presscorner/detail/en/ip_25_377.

199 CETO, *Carbon Capture, Utilisation and Storage in the European Union*, 2024.

200 Mission Letter to Dan Jørgensen, Commissioner for Energy and Housing, 17 September 2024.

201 COM(2023) 757 final.

demand for grid components, including power lines and transformers[202]. Europacable's analysis of the 2024 Ten-year Network Development Plans[203] suggests that almost 100 000 km of new transmission lines and cables will be laid in Europe between 2024 and 2033 (a 10% upward revision of the 2022 figure). Turning to the distribution system, Eurelectric expects that an annual average of 262 000 km of conductors will need to be installed between 2025 and 2050, including new lines and replacements[204]. In addition, the development of the distribution grid in the EU and Norway alone, could require as much as 172 000 units of transformers, added every year between 2025 and 2050, doubling their number from 4.5 million to 9 million by mid-century[205]. Overall, upgrading the European power transmission and distribution infrastructure could require as much as EUR 730 billion of investments until 2040[206].

The EU has some long-standing market and technology leaders for both power lines and transformers. The EU wires and cable market is mostly supplied by European companies, although competitive pressure from international players could increase in the short to medium-term. As for the European transformers market, the picture is somewhat different: while a few big multinational companies dominate the large transmission transformer segment, the medium size transformer segment and distribution transformer manufacturers include both historical national manufacturers and family-run companies from Europe, as well as international competitors.

Copper and aluminium supply chains are critical for manufacturing. While these are expected to keep up with steadily growing demand in the short term, high demand and the concentration of refined copper production constitutes risk for disruptions in the long term[207]. The main high-value component for transformers, the core, is manufactured from grain oriented electrical steel (GOES). The value of the global GOES market is estimated to almost double in size by 2032[208], driven by demand from transformer manufacturing. Although the EU is a major producer, many EU transformer manufacturers rely on imports of core steel[209].

Rising demand for grid components such as power lines and transformers have led to delayed deliveries, long lead times and further price surges. In response, several leading European cable manufacturers have reportedly started implementing investment decisions worth EUR 4 billion, contributing to the doubling of high and extra-high voltage cable production capacities in Europe[210]. A survey of EU and non-EU transformer manufacturers suggests that a 10% production capacity expansion can be expected in the short term (until 2026), with up to 30% until 2030, if the upward demand trend is confirmed[211]. Nevertheless, demand is expected to continue growing faster than supply in the coming years and in the 2030s.

One of the biggest challenges facing the industry is a shortage in skilled labour. Almost half of the surveyed transformer manufactures reported underutilised capacities due to a lack of qualified workers[212]. In its Action Plan for Grids, the Commission has identified measures to

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202 While this edition focuses on power lines and transformers, the last edition focused on high voltage direct current (HVDC) systems and converter stations, see COM(2023) 652 final.
203 Entsog and Entsoe, *Ten-Year Network Development Plans (TYNDP)*, May 2024.
204 This is expected to lead to a net extension of the EU and Norway network from 10 to 16,8 million km from 2025 to 2050.
205 Eurelectric, *Grids for speed*, 2024.
206 European Commission, Directorate-General for Energy, Finesso, A., Kralli, A., Bene, C., Goodall, F. et al., *Investment needs of European energy infrastructure to enable a decarbonised economy*, 2025.
207 IEA, *Critical Minerals Market Review*, 2023.
208 Fortune Business Insights, *Grain Oriented Electrical Steel Market Size, Share & Industry Analysis*, 2024.
209 T&D Europe, *Transformer Commodities Indices*, April 2024.
210 Europacable, *Letter to European Commission Executive Vice-President Maroš Šefčovič*, 5 March 2024.
211 Transformers Magazine's Industry Navigator, *Investments 2024 – Outlook to 2033*, 2024.
212 Ibid.

ensure that EU electricity grids will operate more efficiently and be rolled out faster[213]. Closer cooperation among public authorities, grid operators and technology providers will be key to develop common technology specifications, improve visibility of grid project pipelines, facilitate investments in manufacturing capacity and secure supply chains. During the current term of office, the Commission will consider the legal framework for European grids to support electrification and speed up permitting[214]. The Commission will present an Electrification Action Plan to support electrification across all end-use sectors and propose a European Grid Package to modernise and expand its network of energy transmission and distribution infrastructure.

3.12. Nuclear fission energy technologies

Nuclear power plants (NPPs) are one of the technologies providing dispatchable low-carbon electricity[215]. The unit cost of electricity from NPPs is typically between that of renewables and fossil technologies. NPPs generated 22.8% of electricity in the EU in 2023, slightly up from 21.9% in 2022[216], with three levers to achieve this: lifetime extensions, building new large NPPs, and deploying small modular reactors (SMRs).

Most new reactors under construction are located in Asia. At the beginning of 2024, there was around 61 GW of reactor capacity under construction globally, of which more than half was located in China and India. The EU retains one active reactor vendor[217], who is building 5.3% of the aforementioned capacity[218]. This illustrates the need for EU industry to improve its competitiveness in line with the objectives of the Net-Zero Industry Act.

In 2024, the Commission launched the European Industrial Alliance on SMRs to facilitate their deployment by the early 2030s and to support a competitive European ecosystem[219]. SMRs feature innovative designs and are built around modular components that could potentially be produced in series. They have not been deployed in the EU yet, though the first SMRs are already operating in China and Russia[220].

Delivering the projected capacity in the EU necessitates expanding manufacturing capacities[221]. Furthermore, the ageing workforce in the sector needs to be addressed by bringing in people entering the workforce and reskilling professionals from other industries. Nuclear-specific skills development programmes need to be fostered. The diversification of the supply chain for nuclear fuel, fuel cycle services, and for spare parts needs to continue to address

[213] COM(2023) 757 final.
[214] Mission Letter to Dan Jørgensen, Commissioner for Energy and Housing, 17 September 2024.
[215] Member States have the freedom to choose their energy mix in line with the Treaties.
[216] Commission analysis based on Eurostat, *Net electricity generation by type of fuel - monthly data*, Online data code: nrg_cb_pem, last updated 28/01/2025; ENTSO-E, *Statistical Factsheet 2023*, 2024; European Parliamentary Research Service, *Strategic autonomy and the future of nuclear energy in the EU*, 2024; SWD(2024) 63 final, Part 1/5.
[217] In the 1980s, there were four European reactor manufacturers: ABB (Sweden/Switzerland), Framatome (France), Kraftwerk Union/Siemens (Germany), and National Nuclear Corp. (UK). Only Framatome is active today. Nuclear Energy Agency, *Nuclear New build: Insights into Financing and Project Management*, 2015.
[218] Commission analysis based on IAEA PRIS data (31 December 2023). Framatome completed construction of Olkiluoto 3 (Finland), which started commercial operation in May 2023.
[219] *European Industrial Alliance on SMRs*, 2024.
[220] IAEA PRIS data (31 December 2023).
[221] In addition, according to analyses of the Euratom Supply Agency (ESA), there is a missing enrichment capacity in the global West of up to 2500 tSWU by 2030, with the Western reactors missing, in the stable demand scenario, about 6000 tU of conversion capacity per year. ESA, *Euratom Supply Agency Annual Report*, 2022.

dependencies on any single unreliable partners, particularly on Russia[222]. There must be a continued focus on maintaining nuclear safety, securing diversified supplies, safe waste management, and advancing new technologies[223]. Any future use of nuclear must be conditional on adherence to the strictest nuclear safety standards, as well as safe disposal of all types of nuclear waste and spent fuel.

3.13. Hydropower

Global hydropower capacity was 1 416 GW in 2023[224], with an additional capacity of around 160 GW (of which ca. 15-16 GW in Europe) expected around 2030[225]. Pumped storage hydropower is still the most common energy storage technology with more than 90% of all grid-scale storage globally and 46 GW installed pumping capacity in the EU[226]. While EU companies are active on novel hydropower projects worldwide, a significant focus in the EU is on upgrading and refurbishing of existing installations, representing around 153 GW of installed capacity[227].

The EU manufacturing industry of hydropower components remains strong in 2024, indicating a positive outlook in terms of progress towards the benchmarks of the Net-Zero Industry Act. While the EU supply chain is well developed, there is a risk of future dependency for permanent magnets as a component[228]. The value of EU-manufactured parts and turbines stood at EUR 605 million in 2023, but the trade surplus has shrunk substantially in the last few years to EUR 213 million in 2023, compared to the peak at EUR 466 million in 2015. This is also reflected in the EU share in global exports, which, however, remained high at 44% in 2021-2023[229]. The loss in production value over the last few years highlights that, while EU industry remains competitive, it faces increased global competition, as notably China has been developing its position in hydropower technology[230].

While the EU hydropower industry continues to play a leading role globally, this can be expected to be further challenged in the medium and long term. In this regard a particular issue for EU industry is the lower potential for new hydropower projects in Europe, where identifying new sites for sustainable hydropower remains a major challenge. A further challenge for EU hydropower manufacturing is to maintain skills in the sector.

The EU needs to retain a globally leading position in hydropower by investing more in research and innovation than global competitors and by maintaining its home market with new investments. In particular, there is untapped potential in expanding pumped storage

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222 Five Member States operate VVER-type reactors. Historically, there has been only a single, Russian fuel services supplier for these reactors, which represents a vulnerability in the security of supply. In 2022, the Commission launched consultations with Member States operating VVER reactors to accelerate the process of diversifying fuel supplies in line with REPowerEU objectives.

223 Mission Letter to Dan Jørgensen, Commissioner for Energy and Housing, 17 September 2024.

224 European Commission, JRC, Quaranta, E., Georgakaki, A., Letout, S., Mountraki, A., Ince, E. and Gea Bermudez, J., CETO, *Hydropower and Pumped Storage Hydropower in the European Union*, 2024.

225 IRENA, *The changing role of hydropower: Challenges and opportunities*, 2023; IEA, *Hydropower Special Market Report Analysis and forecast to 2030,* 2021.

226 CETO, *Hydropower and Pumped Storage Hydropower in the European Union*, 2024.

227 Eurostat (nrg_inf_epc), accessed on 12/02/2025.

228 European Commission, Directorate-General for Research and Innovation, Schleker, T., Hicks, M., Cressida Howard, I., Ohrvik-Stott, J. et al., *Study on clean energy R&I opportunities to ensure European energy security by targeting challenges of distinct energy value chains for 2030 and beyond*, 2024.

229 CETO, *Hydropower and Pumped Storage Hydropower in the European Union*, 2024.

230 IEA, *Hydropower Special Market Report Analysis and forecast to 2030,* 2021.

hydropower to help increase grid flexibility, including by retrofitting existing hydropower facilities.

3.14. Sustainable alternative fuels

Sustainable alternative fuels, as defined in the Net-Zero Industry Act, are sustainable and low-carbon fuels that are intended to reduce greenhouse gas emissions in the aviation and maritime sectors[231]. The EU is well positioned in these technologies, but further efforts will be needed to build up competitive mass-scale production in the EU. Overall, the EU currently holds a technological advantage in production: it has most of the world's commercial facilities and plays a strong role in developing novel and innovative technologies.

Hydroprocessed esters and fatty acids (HEFA) fuel is presently the only fully commercial technology for aviation fuels. While there is currently no essential production of sustainable aviation fuels in the EU, existing hydrotreated vegetable oil (HVO) plants could be upgraded to produce about 1.07 Mtoe of advanced HEFA fuels per year. This would be more than twice the total production of sustainable aviation fuels in the world in 2023[232] and less than half the EU policy-driven demand. EU production from eligible biomass feedstocks is projected to expand to 1.5 Mtoe per year by 2030. For maritime use, the EU currently produces 0.1 Mtoe per year from waste-based feedstocks. An expansion to 2.1 Mtoe per year is projected for 2030[233], which is about half the EU policy-generated demand. Announced industry plans estimate that e-kerosene production will reach 1 129 Mtoe per year by 2023, while e-methanol and e-ammonia production will reach 1 464 Mtoe per year[234]. This is about 3% and 4% of the projected EU demand, respectively.

Of the 28 commercial facilities (TRL 9) producing sustainable aviation fuels globally, 15 are in the EU (of which 14 are HEFA facilities) and 6 in the US. There are also 6 pre-commercial plants (TRL 8) for HEFA and advanced technologies in the EU, compared to 4 in the US. For maritime use, only 3 operational innovative biomethane plants (TRL 8) exist (1 in the EU)[235]. This illustrates the EU's current competitiveness in the emerging sector and the need to accelerate the commercialisation of advanced technologies to maintain it.

There are no critical dependencies for technologies as many of the technology developers and equipment manufacturers are in the EU, and the risk of reliance on critical materials is low[236]. For advanced biofuel technologies there is no critical dependency on feedstock imports. By contrast, for renewable fuels of non-biological origins (RFNBOs), there is a critical dependency on non-EU countries producing catalyst materials (cobalt, chromium, vanadium and tungsten), and on the availability of renewable electricity, renewable hydrogen (see section 3.8 on hydrogen technologies), and CO2 feedstock.

Production costs vary by technology and remain a challenge as these technologies still need to be scaled up to commercial levels. The cost for HEFA from advanced feedstock ranges between EUR 15 and EUR 32 per MWh, and for biomethanol via gasification between EUR 89 and

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231 OJ L, 2024/1735, 28.6.2024, Article 3, in line with the definitions in the ReFuelEU Aviation Regulation and the FuelEU Maritime Regulation. This section only covers biofuels and synthetic renewable fuels of non-biological origin.
232 IATA, *Annual Review*, 2024.
233 European Commission, Directorate General for Research and Innovation, *Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels* *(Annex 3)*, 2024.
234 European Commission, Directorate General for Research and Innovation, *Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels* *(Annex 4)*, 2024.
235 See database on Task 39, Biofuels to decarbonize transport.
236 European Commission, Directorate General for Research and Innovation, *Study on energy technology dependence*, 2020.

EUR 112 per MWh[237]. The cost of RFNBOs depends largely on the cost of renewable hydrogen, electricity and CO2 and is between EUR 90 and EUR 180 per MWh for maritime use, but much higher for e-kerosene produced from e-methanol[238].

SAF prices are currently 3 to 10 times more expensive than conventional fuel, although they are expected to reduce substantially as production technologies scale up. Further research and innovation could bring down costs significantly. Combined with the implementation of demonstration and early commercial plants to reduce capital and operating costs, a 5-27% reduction in overall production costs could be achieved[239]. In addition, markets and production facilities for renewable road, aviation, and shipping fuels could be developed alongside each other to create synergies across all transport sectors. For example, the production of aviation fuels through many advanced biofuel pathways creates a by-product market for green diesel (for trucks) and naphtha (for ships). Exploitation of the economic value of by-products can lead to reduction of the cost of the primary fuel. Synergies between advanced biofuels and RFNBOs are also crucial for the use of green hydrogen, biogenic CO2, and related technologies.

3.15. Industrial excess heat recovery technologies

Technologies to recover excess heat from industrial processes are crucial to increasing energy efficiency in industry[240]. Several techniques exist. In general, the heat is first extracted (e.g. from the exhaust gases) by means of heat exchangers. It can then be transferred locally to another process (e.g. raw material preheating), either directly or via a fluid, or exported to a district heating network. The recovered heat can be upgraded (e.g. by heat pumps, see Section 3.6) to be used at a higher temperature or converted for refrigeration. Alternatively, the heat can be converted to mechanical or electrical power.

This section focuses on the recovery of heat and conversion to electrical power via Rankine cycle technology, which uses heat to expand a fluid to drive a turbine and an electrical generator. Both organic (ORC) and steam (SRC) Rankine cycles are commercially available, with research and innovation continuing to improve ORC. Supercritical CO2 (sCO2) cycle technology has the potential to be more efficient and compact but is not yet mature.

In the EU, the theoretical industrial excess heat potential has been estimated at 920 TWh annually, corresponding to a Carnot potential of 279 TWh[241]. It is estimated that excess energy from industrial processes in the EU could be converted by ORC power plants into 150 TWh of electricity annually[242].

The global ORC market was estimated at EUR 750 million in 2023 and is projected to grow[243]. The technology is applied mainly in geothermal energy (77%), industrial excess heat recovery

237 European Commission, Directorate General for Research and Innovation, *Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels*, *(Annex 3)*, 2024.

238 European Commission, Directorate General for Research and Innovation, *Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels* *(Annex 4)*, 2024.

239 IEA Bioenergy Technology Cooperation Programme, *Advanced Biofuels - Potential for Cost Reduction*, 2020.

240 While the literature traditionally referred to industrial 'waste heat' recovery, the term 'excess heat' is now preferred as, when the heat is recovered, it is no longer wasted.

241 Bianchi, G., Panayiotou, G.P., Aresti, L. et al., *Estimating the waste heat recovery in the European Union Industry*. Energy, Ecology and Environment, 2019.

242 KCORC, *Thermal Energy Harvesting*, 2025 .

243 Grand View Research, *Organic Rankine Cycle Market Size & Trends*, 2024. Using the average exchange rate of EUR 0.9239 for USD 1 over the year 2024, based on ECB.

(11%) and biomass (10%)[244]. The main components of ORC and SRC systems are heat exchangers, condensers, feed pumps, and turbines with generators. The materials used are steel, aluminium and (organic) fluids, as well as copper and magnets for the generator, and other components for control electronics.

Europe is home to a large number of ORC system manufacturers and innovation in the field. One US and two EU companies are leading the global ORC market and capture a majority of the market (78% in 2016-2020)[245]. Europe is a leader in related R&D activities in ORC[246], but interest has increased globally and the number of scientific documents on the topic of ORC has more than doubled compared to 2014-2018, reaching 3 329 in 2019-2023. Of these publications, 523 were issued in the EU, behind China (860) and ahead of Iran (368), the UK (176) and the US (165)[247].

There continue to be certain barriers to the deployment of Rankine cycle and other heat recovery technologies, hampering the further development of the industry. The upfront and maintenance costs of heat recovery, as well as the price of the electricity produced, can be very different, resulting in different payback periods[248], while the future availability of heat supply can be uncertain due to potential changes in the respective industrial process (e.g. electrification).

Process-specific and site-specific conditions increase the effort required to plan, design and install heat recovery systems. The deployment and the supply chain of excess heat recovery would benefit from more standardised components, that are designed to meet the needs of most plants in a given industrial subsector. At EU level, further exchanges between technology providers and end user sectors, potentially under the Strategic Energy Technology Plan, could help speed up deployment and strengthen EU competitiveness.

4. CONCLUSIONS

The net-zero technologies sector represents a major economic opportunity for the EU and is essential for the energy transition. The global market for key clean energy technologies could nearly triple and attain around EUR 1.9 trillion by 2035[249]. The EU's industry has the potential to play a key role in providing these technologies, based on a still strong industrial basis and research and innovation (R&I) performance. There may be no other technology field growing at such a high speed in which the EU is as well placed.

The EU remains one of the largest global markets for net-zero technologies. Renewable energy sources are highly cost competitive in the EU and have reached record deployment, providing 48% of electricity in the EU in 2024. At the same time, energy prices in the EU remains substantially higher than in many other major economies, in particular the US and China. This is a structural disadvantage for EU industry, and particularly its energy-intensive industries, but as well for the competitiveness of many manufacturers in the EU's net-zero tech sector. As the EU continues its energy transition, increases electrification and moves away

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244 Wieland, C., Schifflechner, C., Dawo, F., Astolfi, M., *The organic Rankine cycle power systems market: Recent developments and future perspectives*, Applied Thermal Engineering, 2023.
245 Ibid.
246 KCORC, Thermal Energy Harvesting, 2025.
247 Elsevier, Scopus database, using the search string 'Organic AND Rankine AND Cycle AND Power', on 31.01.2025.
248 CE-Delft, ORC Plants for Thermal Energy Harvesting, 2023.
249 IEA, *Energy Technology Perspectives*, 2024. Global market estimates for solar PV, wind, electric vehicles, batteries, electrolysers and heat pumps. Report refers to USD 2 trillion, converted into EUR at the end of 2024.

from its dependency on fossil fuels, net-zero technologies will become even more relevant. The competitiveness of EU manufacturers will decide whether an essential part of this transition will be made in the EU or will be imported. This is a matter not only of security of supply, but also of prosperity and employment.

The EU remains well placed in research in clean energy technologies but continues to lag behind in private R&I investments. Horizon Europe continues to support R&I in clean energy technologies and their competitiveness, including efforts to leverage private investments through European partnerships. At the same time, long-known challenges related to private investments in R&I and the scaling-up of companies continue to hold the EU back. In 2023, the EU performed better in terms of attracting venture capital to the clean energy technology sector, but this was driven by a limited number of large deals. This is a key factor explaining the drop in venture capital in the sector, as preliminary data show for 2024. This also underlines the need to continue EU efforts to mobilise private finance allowing companies to scale up.

Faced with increasingly cost-competitive competition, the EU is at risk of further losing ground in terms of competitiveness and manufacturing. China is already dominating the global manufacturing of solar photovoltaics and batteries and is expected to significantly expand its manufacturing capacities in further clean energy technologies in the years to come. The current issues of the emerging EU battery industry in ramping up production show the immense challenges of building up large-scale manufacturing capacity for technologies of which the centre of gravity and manufacturing know-how is no longer in Europe, notwithstanding substantial public and private investment. The coming years will be crucial to see whether the EU's existing R&I expertise on solar and batteries can help revive these sectors in the EU, for example by exploring solutions requiring less critical raw materials.

The EU still holds a strong position in the manufacturing of several net-zero technologies, including wind energy and heat pumps. Both technologies will continue to increase in global relevance, and estimates indicate potential manufacturing undercapacity compared to the expected global demand. While the EU wind industry is still well positioned, Chinese competitors have started to make inroads into global markets, where EU companies have already lost market shares in the last few years. Heat pump solutions will play a key role in addressing both domestic and industrial heating needs in the future. The EU still holds a strong position, but the sector needs new momentum. Further support to these strategic industries will be required to strengthen EU value chains.

There are further established technologies in which competitive EU industries show growth potential. The EU has a mature biogas and biomethane industry. EU-based companies also have a strong position in the supply of electricity grid components, which are in increasing global demand as electrification increases. However, the sector is likely to experience further competitive pressure in the future. As many other net-zero technologies, grid component manufacturing displays strong dependencies on materials, such as copper and special steel. EU industry has a long tradition in hydropower but has been losing global market share over the last few years. There is untapped potential in hydropower also in the EU. Expanding pumped storage hydropower, including by retrofitting existing facilities, could help increase grid flexibility.

In addition, there are several technologies that are still emerging and need further support to demonstrate their commercial potential. This concerns technologies such as ocean energy technologies, small modular reactors, sustainable alternative fuels, and carbon capture and storage. These technologies require targeted support to increase their commercial viability and deploy them at larger scale.

Innovation has a central role to play in boosting EU competitiveness, both to bring new technologies to the market and to improve existing solutions. R&I is needed to boost efficiency and could limit dependencies on critical raw materials, such as lithium in battery technology. Further efforts are also needed to increase circularity and sustainability, for example, by addressing the use of PFAS chemicals in electrolysers. As global investments in net-zero technologies grow, further efforts will be needed for the EU to keep up in R&I. This is reflected in the focus of the recent Competitiveness Compass on closing the innovation gap. The recently strengthened Strategic Energy Technology Plan has a key role to play to coordinate and align research priorities, bringing together public and private stakeholders, and to increase efficiency of R&I spending among Member States, including through the Clean Energy Transition Partnership[250].

To fully reap the economic benefits of the global energy transition, it is essential for the EU to increase its manufacturing capacity. A value chain approach remains crucial, taking into account the entire chain from raw materials, via energy-intensive industries for materials, to manufacturing and final installation. Skills shortages will remain another significant challenge in the years to come that must be addressed to ensure the sector can thrive.

The implementation of the Net-Zero Industry Act (NZIA) can play a key role in providing coordinated support for EU net-zero technology manufacturing. This will require making use of all tools it provides, from permitting to the use of non-price criteria in public procurement procedures and auctions. The Net-Zero Europe Platform has an important role to play to coordinate policy in the EU and to collaborate with industry. With the entry into force of the NZIA, this Competitiveness Progress Report has been designated as its main monitoring tool. In the years to come, the report will continue to follow closely developments linked to the EU's competitiveness in net-zero technologies and to look into issues regarding the implementation of the NZIA.

With the Competitiveness Compass, the Clean Industrial Deal and the Action Plan for Affordable Energy, the Commission has placed the strengthening of EU competitiveness at the centre of its plans for the years to come. Jointly these three documents outline key actions both building on and strengthening the net-zero technology sector. This includes the joint roadmap for decarbonisation and competitiveness of EU industry provided by the Clean Industrial Deal, and the actions to improve access to affordable energy outlined in the Action Plan for Affordable Energy.

In this context, the Commission will continue to support net-zero technologies, both as an important industrial sector and as enabling technologies for the decarbonisation of the wider economy. This will require continued coordinated efforts at EU and national level.

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[250] For more information: Clean Energy Technology Partnership.