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REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL

Progress on competitiveness of clean energy technologies

2023 PROGRESS REPORT ON COMPETITIVENESS OF CLEAN ENERGY TECHNOLOGIES

EXECUTIVE SUMMARY

In response to the unprecedented disruption of the world's energy system - caused by the COVID-19 pandemic and exacerbated by Russia's unprovoked and unjustified military aggression against Ukraine - **the EU has decided to accelerate its clean energy transition**.

Despite rising prices due to the peak in energy and material costs in 2022, **clean energy technologies remain highly cost competitive. The roll-out rate of clean energy technologies is increasing in the EU**. In 2022, the roll-out rate of wind and solar increased around 50% compared to 2021. However, this trend should not obscure the challenges that the EU's clean energy manufacturing industry faces. Even in sectors such as wind energy or heat pumps, where the EU has a strong manufacturing base, EU market shares are falling.

Overall**, from raw materials to key intermediate components and final clean energy technologies, the EU is increasingly dependent on imports from third countries**. Over 60% of the global manufacturing capacity for key value chain segments of batteries and solar is located in China. Over 90% of capacity for the wafers and ingots required for solar PV is in China.

The Green Deal Industrial Plan, the Net-Zero Industry Act and the Critical Raw Materials Act are amongst the EU's key actions to lower the dependence on the imports of net-zero technologies, strengthen value chain resilience, and build a strong domestic manufacturing base. They seek to tackle the most pressing challenges. One such challenge is to **improve skills, ensure quality jobs** and to turn **innovation into industrial production**. Despite the positive trend in employment, the latest data show that the **skills gaps** and **shortages** seen since 2021 may curb growth in the clean energy sector. In 2023, nearly 4 in 5 small and medium-sized companies report it is generally difficult for them to find workers with the right skills.

Designing a **successful R&I pathway is also key for a competitive clean energy industry**. The EU remains at the forefront of clean energy research, maintains a strong position in internationally protected patents, and is leading on renewables and energy efficiency. Still, stepping up efforts in the synergistic use of the EU and national programmes, and defining clear national R&I 2030 and 2050 targets are crucial elements to design this successful R&I pathway.

The EU also needs to remain an attractive place to invest in, manufacture and deploy clean energy technologies. In 2022, venture capital (VC) investments in clean energy in the EU rose by 42% compared to 2021 and accounted for a growing share of global VC investment in clean energy technology firms, ranking third behind the US and China. However, when looking at strategic net-zero technologies as defined in the Net-Zero Industry Act, except for batteries, the EU has still not fully unlocked its capacity to attract higher growth deals as the US and China have done. To boost the EU's competitiveness, resilience and leadership, the EU's regulatory and financial frameworks are evolving to ensure investments and that capital keeps flowing to EU companies at the required scale.

In addition to these cross-cutting issues, net-zero technologies also face specific challenges and present different opportunities.

2022 was a record year for solar PV installed capacity in the EU. From a value chain perspective, however, the EU is strongly dependent on Chinese imports. For the EU to bridge the cost gap compared to its competitors, building on planned measures, it needs to scale up its manufacturing plants and focus on innovative products and advanced and more sustainable manufacturing processes.

The EU holds technology leadership on solar thermal but faces growing competition from Asian players. Innovative solutions and continuous technological advances are key to boost competitiveness. High EU demand for industrial process heat in the range of 150 – 400 °C is also a good opportunity to roll out solar thermal.

The EU **wind sector** remains one of the strongest players in the world, with EU manufacturers accounting for 30 % of the global market share in 2022, but down from 42% in 2019. The sector is facing specific challenges, including uncertain demand, auction design issues and slow permitting procedures. To tackle these issues, the Commission adopted the **Wind Power Action Plan** which will help accelerate permitting even more, improve auction systems across the EU, facilitate access to finance and strengthen supply chains.

The EU's ocean energy technology industry is a strong innovator. To boost the competitiveness of this sector, investors need reassurance. Running technology-specific auctions or developing multiple uses (e.g. with other renewable installations or for multiple activities) would also support the industry.

The EU is on track to meet the forecasted demand for batteries for 2025 and 2030. The number of announced lithium-ion gigafactories increased in 2022 from 26 to 30 and continues to rise. While Europe's share in global investment announcements in lithium-ion production capacity fell from 41% in 2021 to 2% in 2022, battery factories are being built with increasing speed across Europe and are projected to meet most of EU demand by 2030. The biggest relative increase needed to meet the 2030 target is in recycling.

The EU market for individual heat pumps is growing. Estimates indicate that sales of individual heat pumps increased by 41% in 2022. However, this growth has been partially captured by imports, with the trade balance deficit doubling in 2022 since 2021. EU production capacity was estimated to have covered 75% of EU demand for individual hydronic heat pumps in 2021 but EU manufactures are dependent on imports for components such as compressors and synthetic refrigerants. The Commission is preparing an EU action plan to accelerate the deployment of heat pumps.

Although the EU geothermal sector has limited installed capacity, it has the potential to contribute to REPowerEU targets and to the secure supply of raw materials. The sector needs more available underground data to increase the success rate and predictability of new geothermal projects as well as technology improvements. The sector would also benefit from action to simplify the licensing process, de-risking schemes, higher public awareness and a more skilled work force.

Investments in the EU in generating renewable hydrogen through water electrolysis have opened up the possibility for several manufacturers to build new electrolyser factories in Europe. At the same time, the EU faces the challenges to increase renewable and cost-efficient energy to power these electrolysers and avoid any negative impacts on freshwater availability to deploy this technology. Further action is needed to increase recycling capability in Europe including of the critical raw materials needed for electrolyser manufacturing.

In 2022, the EU was the largest producer of biogas, accounting for over 67% of global production. The EU is also an R&I leader in sustainable biogas. Decreasing production costs, notably through innovation, replication and a stable regulatory framework, could help boost the EU's competitiveness in the sector.

On carbon capture and storage (CCS), this range of technologies is mature in the EU, proven and readily available. However, CCS needs to be deployed at scale if the EU is to reach climate neutrality by 2050. The EU is relatively well positioned on CO2 capture technologies and in terms of R&I, but has not yet developed full industrial carbon management value chains and facilities are still not operational on a commercial basis. Public funding – both at EU and national level – will be needed to attract private capital. Furthermore, proposing business models for this emerging market will also be essential. The EU has several policy tools in place supporting CCS development. The Commission is now working on an Industrial Carbon Management Strategy which is planned for the first quarter of 2024.

The emergence of sizeable offshore wind farms and regional interconnectors have made the European market very attractive for **High Voltage Direct Current** (HVDC) system developers and technology providers. However, the sector will need to overcome challenges such as higher global demand for components and the risk of supply chain disruptions. Closer cooperation between stakeholders is key, as is support for harmonisation and standardisation, in particular to stimulate investment in production capacity by EU suppliers. Bringing in streamlined procurement procedures and voluntary demand pooling for EU buyers could help tackle the main supply chain issues.

The competitiveness of the clean energy sector has been a topic of increased attention over the past year. The EU has reacted swiftly to support its industry in meeting the current challenges and will pursue coordinated action to this end. This 2023 edition of the Competitiveness Progress Report is particularly topical as it provides insights into the main drivers, opportunities and barriers to competitiveness in the EU's clean energy sector.

1. INTRODUCTION

The COVID-19 pandemic and Russia's unprovoked and unjustified military aggression against Ukraine have massively disrupted the world's energy system. The all-time high energy prices and the disruption of global supply chains have challenged the EU's energy system as never before and required actions to give people both secure and affordable energy. In response, **the EU has taken decisive actions to diversify its energy supply and fast-track the transition to clean energy**.

Since 2020, the EU's economic recovery policies adopted in response to the pandemic, such as the **Recovery and Resilience Facility**, have substantially increased investments in clean energy solutions. The reforms and investments proposed by Member States in their Recovery and Resilience Plans alone represent some EUR 203 billion in climate-related expenditure[1]. In addition, cohesion policy funds provide further EUR 46 billion of clean energy related investments.

In 2022, the EU adopted the **REPowerEU plan**,[2] setting out the course of action to phase out the EU's dependency on Russian energy imports as soon as possible. The plan sets out measures to save energy, diversify energy supplies and to accelerate the roll-out of renewable energy.

These actions have produced substantial results. The share of Russian pipeline gas out of total EU gas imports has fallen from around 45-50% pre-pandemic to around 10% between January and June 2023. The roll-out rate of wind and solar in the EU increased by around 50% compared to 2021. Wind and solar energy accounted for 22% of the EU's electricity production, overtaking natural gas for the first time. In addition, the EU adopted more ambitious energy efficiency and renewable energy targets for 2030.

This large-scale, accelerated energy transition must be underpinned by **measures to secure the resilient supply of clean energy technologies**. These measures include scaling up domestic manufacturing capacity, diversifying supply chains, and applying circular economy measures. **This is crucial to reinforce the EU's open strategic autonomy**. Not only are such measures important to increase energy supply security: they can also create jobs and growth. The global market for key mass-manufactured net-zero technologies is set to triple by 2030 from today's level, with an annual value of around EUR 600 billion[3].

Today, the **clean energy manufacturing industry in the EU faces headwinds**. Even in sectors such as wind energy or heat pumps, where the EU has a strong manufacturing base, market shares are falling. Other regions in the world have taken large-scale initiatives to boost their net-zero industry and competition is growing fierce and fast.

This is why, in February 2023 the European Commission presented the **European Green Deal Industrial Plan**[4]. The plan aims to boost the competitiveness of the EU's net-zero industry by improving the regulatory framework, accelerating access to funding, investing in skills, and supporting trade. The plan was followed in March 2023 by the proposals for a **Net-Zero**

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1 As of 1 June 2023. Following the climate tracking methodology, using Annex VI of the RRF Regulation.
2 COM(2022) 230 final.
3 International Energy Agency (IEA), *Energy Technology Perspectives*, 2023.
4 COM(2023) 62 final.

Industry Act[5] and a **Critical Raw Materials Act**[6]. The aim of these initiatives is to simplify the regulatory framework, consolidate the EU's industrial leadership in net-zero technology manufacturing, ensure sustainability of supply for critical raw materials, reduce the EU's reliance on highly concentrated imports, and increase the recycling rate of strategic raw materials. These actions build on other existing initiatives such as the Circular Economy Action Plan and the new Rules on Batteries.

Other initiatives, including the communications entitled **The Single Market at 30**[7] and **the Long-term view on competitiveness of the EU**[8] complement the Green Deal Industrial Plan by setting out a long-term sustainable and comprehensive approach to boosting the EU's competitiveness. The **European Economic Security Strategy**[9] aims to minimise risks arising from certain economic flows, while maintaining maximum levels of economic openness and dynamism. Finally, the Strategic Technologies for Europe Platform (STEP) boosts the investment capacity for critical technologies, including clean energy technologies.

To track progress on these initiatives, these measures must be underpinned by data, requiring continuous **monitoring of the competitiveness of the EU's clean energy sector.** This **Competitiveness Progress Report on clean energy technologies**[10] is part of this monitoring process in several ways. First, it provides insights into the main drivers, opportunities and barriers of the competitiveness of the EU clean energy sector as whole. It looks at both technological and non-technological challenges related to the high prices of energy and materials, the risk of value chain disruptions, skills and labour shortages, and the innovation landscape. Second, it assesses the competitiveness of the strategic energy technologies identified in the Net Zero Industry Act proposal, highlighting segments of the value chains that require attention.

The Commission has published this report every year since 2020, in accordance with Article 35(1)(m) of the Regulation on the Governance of the Energy Union and Climate Action. This report accompanies the State of the Energy Union reports and is underpinned by data from the Clean Energy Technology Observatory (CETO) [11].

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5 COM(2023) 161 final, SWD(2023) 68 final.
6 COM(2023) 160 final.
7 COM(2023) 162.
8 COM(2023) 168 final.
9 JOIN/2023/20 final.
10 For more information: Clean Energy Competitiveness (europa.eu), and 2022 edition of the Progress Report on Competitiveness of Clean Energy Technologies (CPR): COM(2022) 643 final.
11 For more information: Clean Energy Technology Observatory.

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

2.1 The impact of high energy and raw materials prices on the EU's clean energy sector

In 2022, Russia's unprovoked and unjustified military aggression against Ukraine and attempts to manipulate the energy market led to all-time high energy prices in the EU and the rest of the world. Wholesale gas prices in the EU hit a historic high in August 2022 (EUR 294 /MWh[12]) and remained very high until the end of 2022. Despite most electricity being produced from lower-cost sources (41% renewable and 23% nuclear), electricity prices still largely reflect the price of natural gas[13]. As a result, electricity prices reached record highs on the wholesale markets in 2022 (EUR 474/MWh[14]), thus challenging the EU's competitiveness.

The EU has been taking decisive action starting already in 2021[15]. Thanks to a strategy based on supply diversification, mandatory storage levels, a concerted effort to improve energy efficiency, energy demand reduction and a faster roll-out of renewables, natural gas prices fell significantly from the record highs seen last year. Assisted by a mild winter, European gas and electricity markets stabilised by the end of 2022 and prices started a sustained downward trend. From their historic peak, the wholesale **gas prices** dropped to EUR 130-140/MWh by the end of 2022 and steadily decreased in the first half of 2023, reaching EUR 30-40/MWh by August 2023. Mirroring the fall in gas prices, **electricity prices** also gradually fell from record highs, thanks to reduced demand, higher renewable generation, and recovering hydro stocks. Electricity prices on the wholesale market fell to EUR 74/MWh in the first week of August 2023.

Despite the improvement in market fundamentals - as EU policy action and market forces brought supply and demand for energy into balance - and having secured new gas supply sources[16], industrial electricity and gas prices remain higher than the pre-crisis average[17]. The spread with other global economies has also increased[18]. This is both an opportunity and a challenge for the competitiveness of the clean energy sector.

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[12] Weekly average price on the Title Transfer Facility (TTF).

[13] Gasparella, A., Koolen, D. and Zucker, A., *The Merit Order and Price-Setting Dynamics in European Electricity Markets*, European Commission, Petten, 2023, JRC134300.

[14] Wholesale (EU5): weighted average of prices of main EU electricity markets (DE, ES, FR, NL) and Nordpool market (NO, DK, FI, SE, EE, LT, LV).

[15] Measures include the Toolbox for action and support Communication (COM(2021) 660 final), the Security of supply and affordable energy prices communication (COM(2022) 473 final), the Gas Storage Regulation (COM(2022) 135 final - Regulation (EU) 2017/1938), the Gas Demand Reduction Regulation (COM(2022) 361 final - Council Regulation (EU) 2022/1369), the Regulation to address high energy prices (COM(2022) 473 final - Council Regulation (EU) 2022/1854), the Solidarity Regulation (COM(2022) 549 final - Council Regulation (EU) 2022/2576), the Market Correction Mechanism (COM(2022) 668 final - Council Regulation (EU) 2022/2578), the Permitting Regulation (COM(2022) 591 final - Council Regulation (EU) 2022/2577).

[16] In particular, the EU increased LNG imports from the United States and pipeline supply from Norway, Azerbaijan and the United Kingdom.

[17] Wholesale gas prices are still double the average of the 15 years preceding the aggression of Russia against Ukraine. Pre-crisis electricity prices were at EUR 40-60/MWh. See also: EU fossil generation hits record low as demand falls | Ember (ember-climate.org).

[18] Since the energy crisis and the war in Ukraine, the EU's gas prices have been among the highest in the world. Although the market stabilised, EU gas prices have been four to five times higher than prices in the US in the period from January 2023 to July 2023, although comparable to prices in the UK and other gas-importing countries such as China and Japan.

On the one hand, **high energy prices make clean energy solutions even more competitive than fossil fuel options and stimulate higher rates of adoption**. High energy prices and Russia's unprovoked and unjustified military aggression against Ukraine have led to a significant increase in EU public and private investments in energy efficiency and renewable energy sources. This includes an increase in public funding for energy infrastructure, notably through the contribution of the Recovery and Resilience Facility (RRF) to the REPowerEU Plan[19].

High fuel and carbon prices have led to a fall in the share of fossil fuel generation in the EU electricity mix (from 34% in 2021 to 32% in 2023), while the share of renewables has risen from 37% in 2021 to 42% in 2023. The EU policy measures have played a major role in accelerating the roll-out of clean energy technologies: in 2022, the installation of solar and wind capacities increased respectively by 60% and 45% and for the first time, the share of electricity generated by wind and solar exceeded the share of gas and coal-generated power.

On the other hand, **high energy prices combined with high interest rates also have a negative impact on the EU clean energy technology value chains, both directly and indirectly**. Since 2020, the economic and geopolitical turmoil has put a significant strain on clean energy supply chains and temporarily stalled the downward trend in the roll-out costs. This combination of factors drove up manufacturing and installation costs for wind and, to a lesser extent, solar projects. According to industry estimates[20], the cost of building offshore wind farms has increased by 40% in 2023 in the EU.

Rising interest rates have also had a negative effect on the financing of renewable energy projects, as upfront capital costs represent most of project costs. This is particularly acute for offshore wind power due to the high upfront investment needed. A 3.2% increase in interest rates is estimated to raise the cost of offshore projects by 25%[21]. As a result, no new final investment decisions were made in offshore wind farms. Orders of new wind turbines fell by 47% in 2022 compared to 2021 in Europe[22]. However, this trend reversed in 2023. In the first six months of 2023, almost EUR 9.3 billion were raised for the construction of four wind farms in the EU with the generation capacity of 2.7 GW.

Raw materials supplies and their price evolution are another challenge to the competitiveness of the EU's clean energy sector, as they affect the costs of clean energy technologies. Between 2021 and early 2022, the price of several critical materials (lithium and nickel in particular) rose, and volatility increased sharply[23]. Although prices began to moderate in the second half of 2022 and the beginning of 2023, they remained well above the historic average.

Prices for **lithium carbonate** continued to rise throughout 2022 too, nearly doubling between January 2022 and January 2023. At the beginning of 2023, lithium prices were six times above their average over the 2015-2020 period. Between January and March 2023, lithium prices dropped 20%, returning to their late 2022 level. **Cobalt prices**, after peaking at USD 80 000

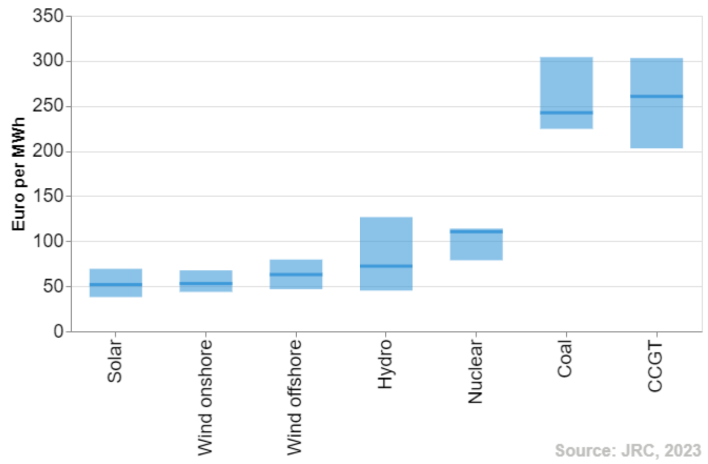
[19] Regulation (EU) 2023/435.
[20] WindEurope, press release*: Investments in wind energy are down – Europe must get market design and green industrial policy right*, 31 January 2023.
[21] M. Đukan, A. Gumber, F. Egli, B. Steffen, *The role of policies in reducing the cost of capital for offshore wind*, 2023.
[22] Based on Enerdata, Daily Energy and Climate News, 01 March 2023.
[23] International Energy Agency (IEA), *Critical Minerals Market Review*, 2023.

(EUR 72 600[24]) per tonne in March 2022, then fell consistently and remained around USD 50 000 (EUR 47 485[25]) per tonne throughout the rest of the year. In 2023, cobalt prices are expected to remain low due to oversupply. Lithium and cobalt are both key components of batteries and essential for the clean energy transition.

High energy and raw material prices had an impact on the decade-long trend of falling costs of clean energy technology due to innovation and economies of scale[26]. For example, the price of wind turbines and solar PV modules rose between 2020 and 2022. However, prices are falling again in 2023. Despite these price dynamics, the prices of all clean energy technologies are still significantly lower today than they were a decade ago. Although high energy and raw materials prices have impacted the clean energy sector, the energy produced by clean energy technologies remains highly cost competitive in the EU[27].

Figure 1 provides a snapshot of levelised costs of electricity (LCOE) calculations for 2022 for a range of representative conditions[28] across the EU. The results indicate that in 2022 technology fleets with low variable costs (including variable operational costs and fuel costs) such as renewable energy generation, had lower levelised costs than generation technologies with high variable costs, such as fossil fuel-fired generation.

Figure 1: Snapshot of technology-fleet specific levelised costs of electricity (LCOE) for 2022. (The light blue bars display a range across the EU and the solid blue lines denote the median)[29].



Source: JRC METIS model simulation, 2023[30]

[24] Using the average exchange rate of EUR 0.9075 for USD 1 over March 2022. See: https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html

[25] Using the average exchange rate of EUR 0.9497 for USD 1 over the year 2022. See: https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html

[26] International Energy Agency (IEA), *Clean energy equipment price index, 2014-2022*, 2023.

[27] This section focuses on cost analysis. More information on market value: The development of renewable energy in the electricity Market, June 2023.

[28] Data points shown for the first to third inter-quartile range to filter for outliers.

[29] In the Figure, CCGT means combined cycle for natural gas.

[30] 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, JRC134300.
Computation based on annualised costs for the year 2022. Capex and Opex based on the 2022 PRIMES scenario, annualised by technical lifetimes and the weighted average cost of capital. Annualised costs are levelised using capacity factors

2.2 From resources to assembly: strengthening the EU as an industrial powerhouse

The current geopolitical context has also had an impact on the global clean energy competitive landscape as it has triggered new policy dynamics and market trends.

Globally, **the sector of net-zero technologies is growing fast.** The global market for key mass-manufactured net-zero technologies is set to triple by 2030 with an annual worth of around EUR 600 billion[31]. Higher demand goes hand in hand with a higher demand for resources and materials. Estimates indicate that global demand for some raw materials that are key in the clean energy technology value chains will increase substantially over the coming decades. In 2050, global demand for terbium, gallium or lithium[32] is projected to be around 100% of current supply, even in a low demand scenario[33]. These projections emphasise the risks that could arise for economies that are highly dependent on the supply of these critical raw materials.

From raw materials to key intermediate components and final clean energy technologies, **the EU is increasingly dependent on imports from third countries.** The situation varies depending on the technology, but for most technologies the EU depends on China for at least one stage of the value chain. China plays a key role in the supply of **critical raw materials**, a sector where the EU is heavily dependent on imports from a few countries. For example, the EU gets 98% of its rare earth supply and 97% of its magnesium from China[34], about 80% of its lithium from Chile, and more than 60% of its cobalt from the Democratic Republic of Congo[35]. For the **manufacturing** of clean energy technologies, China is also in a dominant position across different technologies. Over 60% of global manufacturing capacity for key value chain segments of batteries and solar PV is located in China. Over 90% of global manufacturing for the wafer and ingots required for solar PV is in China[36].

For wind turbine manufacturing, China's share in global production increased from 23% in 2017 to 50% in 2022[37]. Over the same timeframe, the EU's share fell from 58% in 2017 to 30%[38,39]. For chips, a key component in the manufacturing of clean energy technologies, in the

derived from the METIS model. Variable costs are based on 2022 commodity prices, variable OPEX and the dispatch in the METIS simulation.

31 International Energy Agency (IEA), *Energy Technology Perspectives*, 2023.

32 Terbium is part of the rare-earth elements which are fundamental materials for the magnets in wind turbines. Gallium is used in some PV panels as well as electronics, data networks, robotics and satellites. Lithium is crucial for the production of batteries.

33 Carrara, S., et al., *Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study*, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/386650, JRC132889.

34 RMIS - Raw Materials Information System (europa.eu), 2023

35 European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, Grohol, M., Veeh, C., *Study on the critical raw materials for the EU 2023 – Final report,* Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2873/725585.

36 BloombergNEF, *Localizing clean energy supply chains comes at a cost*, 2022.

37 Carrara, S., et al., *Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study*, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/386650, JRC132889.

38 Estimates indicate that in 2022 onshore installations outside the EU and China were 51% by EU companies, 34% by US and 9% by China. For offshore the split was 94% EU companies and 6% Chinese. Source: JRC based on Wood Mackenzie and 4C Offshore.

39 Tapoglou, E., Tattini, J., Schmitz, A., Georgakaki, A., Długosz, M., Letout, S., Kuokkanen, A., Mountraki, A., Ince, E., Shtjefni, D., Joanny Ordonez, G., Eulaerts, O.D. and Grabowska, M., Clean Energy Technology Observatory: Wind energy in the European Union - 2023 Status Report on Technology Development Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/618644 (online), JRC135020.

2021 update of the EU Industrial Strategy[40], the Commission confirmed that the EU is strongly dependent on the US for general design tools and on Asia for advanced chip fabrication.

For semiconductors, Taiwan Semiconductor Manufacturing Co (TSMC) accounted in 2022 for 92% of the most advanced semiconductor fabrication across the world, making Taiwan responsible for about half of the world's semiconductor fabrication[41]. The EU has a significant share of in the global production of digital components, but it produces only 9% of semiconductors and microprocessors[42].

The global supply chain disruptions triggered by the COVID-19 pandemic and exacerbated by Russia's unprovoked and unjustified military aggression against Ukraine have shown that it is crucial to boost the EU' capacity and competitiveness to produce the technologies and components needed to make the transition to climate neutrality. Designing new materials with properties optimising the performance of net zero technologies should also unlock new possibilities for industries[43].

Looking at the major economies, the 2022 **US Inflation Reduction Act** (IRA)[44] aims to catalyse investments in domestic manufacturing capacity by providing an estimated USD 400 billion (EUR 380 billion[45]) in federal funding for clean energy, mostly via subsidies and tax incentives. In 2021, the US also adopted the Bipartisan Infrastructure Deal (Infrastructure Investment and Jobs Act) including USD 1.5 billion (EUR 1.27 billion[46]) to support hydrogen electrolysis and USD 8 billion (EUR 6.7 billion) to fund a broad Regional Clean Hydrogen Hubs program. These hubs will create networks of co-located ecosystems for clean hydrogen production, distribution, storage, and end-use. The US also issued a *U.S. National Clean Hydrogen Strategy and Roadmap*. More recently, in July 2023, the US issued an executive order *Invent it here, make it here*, stating that federal agencies will have to prioritise domestic manufacturing when US-funded innovative technologies are brought to market.

The 10-year technology policy initiative **Made in China 2025**[47], published in 2015, aims to modernise China's industrial capacity, including replacing its dependence on imports of foreign technology with domestic innovations. In July 2023, China announced restrictions on the export of raw materials used in the manufacturing of a wide range of technical applications, including semiconductors and other advanced technologies (gallium and germanium).

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40 COM/2021/350 final.

41 Netherlands Enterprise Agency, *Research on the Next Generation Semiconductor Industry in Taiwan,* 2022.

42 European Commission, Directorate-General for Energy, Guevara Opinska, L., Gérard, F., Hoogland, O. et al., *Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis – Final report, Publications Office of the European Union*, 2021, https://data.europa.eu/doi/10.2833/946002.

43 For more information: announced initiative "Advanced materials for industry leadership" during the 2023 State of the Union address.

44 The White House, *Inflation Reduction Act Guidebook | Clean Energy*, 2022.

45 Using the average exchange rate of EUR 0.9497 for USD 1 over the year 2022. See: https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html

46 Using the average exchange rate of EUR 0.8455 for USD 1 over the year 2021. See: https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html

47 Institute for Security & Development Policy, *Made in China 2025*, June 2018.

In early 2023, Japan presented the **Japanese Basic Plan for the Gx: Green Transformation Policy**[48]. This is a JPY 150 trillion (EUR 0.95 trillion[49]), 10-year decarbonisation strategy to promote the development of innovative technologies and achieve "beyond-zero" CO_2 reduction by 2050.

Around the same period India earmarked INR 350 billion[50] (EUR 4 billion[51]) to invest in the nation's energy security and green transition (with a focus on solar power and green hydrogen production), with the aim of reaching net zero emissions by 2070.

In addition to increasing the circular use of materials and diversifying supplies, the EU aims to massively scale-up the manufacturing and accelerate the roll-out of clean energy technologies. This will support the EU in securing its industrial leadership in fast-growing sectors and to move from a net importer of net-zero technologies to have a strong domestic manufacturing base.

The Commission outlined its plans for this purpose in the **Green Deal Industrial Plan**. The plan aims to boost the EU's clean energy competitiveness by simplifying the regulatory framework, accelerating access to funding, boosting skills, and supporting trade. It followed up by issuing the **Net-Zero Industry Act (NZIA)** and the **Critical Raw Materials Act (CRMA)**. The proposed NZIA aims to overcome barriers to scaling-up the manufacturing of net-zero technologies. It would provide a regulatory framework that simplifies and speeds up permitting, improves net-zero technology access to markets and promotes a range of tools. The proposed CRMA would enable the EU to boost the energy sector by securing access to the critical raw materials needed for renewables and clean energy technologies, along with other strategic sectors. It also focuses on diversifying supply chains to build resilience and preparedness in times of crisis and to boost the circular economy.

In February 2022, the Commission also presented a proposal for a **European Chips Act**[52] to tackle semiconductor shortages and boost Europe's technological leadership. The Act, which entered into force on 21 September 2023, will mobilise over EUR 43 billion in public and private investments and contains measures to prepare, anticipate and swiftly respond to any future supply chain disruptions, together with Member States and the EU's international partners. The aim is to double the EU's share of global chip production to 20% by 2030.

Following the REPowerEU plan and the Green Deal Industrial Plan, the Commission has simplified its state aid rules allowing the Member States to grant state aid to facilitate the rapid deployment of renewable energy generation projects and implement industrial decarbonisation measures to achieve a net zero economy. The **Temporary Crisis and Transition Framework (TCTF)**[53], adopted in March 2023, permits aid to all renewable technologies and to renewable hydrogen and biofuel storage and eliminates the need for open tendering procedures for less

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48 The Japanese Cabinet confirms the Basic Plan for the GX: Green Transformation Policy, March 2023.

49 Using the average exchange rate of EUR 0.006341 for JPY 1 for 2 January 2023. See: https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-jpy.en.html

50 Bloomberg, *India plans $4.3 billion spending for energy transition*, 1 February 2023.

51 Using the average exchange rate of EUR 0.011351 for INR 1 for 2 January 2023. See: https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-inr.en.html.

52 COM(2022) 46 final.

53 OJ C 101, 17.3.2023, p. 3.

mature technologies. It also expands the possibilities of aid for the decarbonisation of industrial production processes through electrification and/or the use of renewable and electricity-based hydrogen. The TCTF also permits investment support schemes for production of strategic net-zero technologies, including the possibility for granting higher aid to match the aid received for similar projects by competitors located outside of the EU. This action was further complemented by the adoption, in June 2023, of a revision of the General Block Exemption Regulation (GBER)[54].

Through these proposals, the EU is stepping up action to attract more capital into the EU to invest in and manufacture clean energy technologies. To underpin these initiatives, it provides support from several funds and instruments. For example, in May 2023, the Commission presented the **2024 Flagship for Support to the Green Deal Industrial Plan under the Technical Support Instrument**[55] to help Member States implement the Green Deal Industrial Plan.

As additional support for and boost to investment in critical and clean energy technologies, in June 2023, the Commission put forward the **Strategic Technologies for Europe Platform (STEP)**[56]. It provides funding under the **EU Innovation Fund,** a key investment instrument to support the manufacturing of clean energy technologies. The results of the third call for large-scale projects[57] already show that projects pre-selected for grant funding under this call of the ETS Innovation Fund, together with the previously awarded projects, will cover 17% of the NZIA 2030 solar manufacturing objectives, 11% of the electrolysers manufacturing objectives and 7% of the battery manufacturing objectives, if all projects are realised. Furthermore, along with other investments, the Recovery and Resilience Facility will also support the construction of manufacturing plants of electrolysers, solar PV panels and batteries.

The EU is not starting from scratch, as a number of projects are already underway across multiple technologies. In recent months, the EU has witnessed major developments on the market in terms of **new project and investment announcements for key net-zero technology manufacturing in the EU.** These include solar PV, wind, batteries, heat pumps, electrolysers and fuel cells. Project pipelines have continued to evolve too. For these key net-zero technology value chains, as of August 2023, there are over 100 projects planned for building or expanding existing production capacity[58]. The consistently strong results of the ETS Innovation Fund, including in the latest heavily oversubscribed large-scale call, shows there is a strong pipeline of innovative and competitive European projects.

In the **batteries** value chain, the number of announced lithium-ion gigafactories rose in 2022 from 26 to 30. In the **solar PV** value chain, despite major challenges that the manufacturing sector faces, several existing production facilities consider expanding to become giga-scale factories and have secured Innovation Fund funding in the last call, and some new giga-scale manufacturing projects have been announced. In the **wind** industry, several projects are considered, encompassing new facilities, expanding existing facilities and creating new port

54 OJ L 167, 30.6.2023, p. 1.
55 For more information: Technical Support Project (europa.eu), 2023.
56 For more information: Strategic Technologies for Europe Platform (europa.eu), 2023.
57 For more information: Third call for large-scale projects (europa.eu), 2023.
58 Based on feedback from industrial alliances and relevant stakeholder organisations.

infrastructure. It should be noted that it is possible not all announced investments will be realised in the end.

In 2022 alone, nearly 800 MW of power purchase agreements were signed with heavy industry in the EU (4.5 GW when considering all sectors) without public support. For **heat pumps**, the total investment to build new production capacity across the value chain announced over the last 5 months and due to be made over the next 3 years adds up to nearly EUR 5 billion.

For **electrolysers**, no company yet manufactures at GW-scale in the EU and the technology is still in development. Several manufacturing plants have emerged in Europe, including thanks to the state aid support of the Important Projects of Common European Interest and several companies have announced plans for major expansions to their manufacturing capabilities in Europe.

Higher demand for clean energy technologies together with fast-evolving geopolitical events have highlighted the strategic dimension of the clean energy technology value chains. **The EU's dependency on third countries makes it crucial to strengthen the competitiveness of its clean energy sector by increasing its domestic manufacturing capacity, diversifying supply chains and reinforcing circularity measures.** Building on projects already underway, the EU has put forward a comprehensive suite of initiatives and instruments to develop and strengthen EU clean energy technology value chains. Achieving this will be instrumental to strengthen the EU's strategic autonomy while supporting the transition to a carbon neutral continent. It will require coordinated action from different angles. For example, it is essential to ensure the sector has access to a sufficient supply of skilled workers.

2.3 Human capital and skills: bridging skill gaps and shortages to avoid bottlenecks

The latest data on employment and skills worldwide show that, despite the positive trend in the employment rate, **the skill gaps and shortages seen since 2021 may curb the growth of the clean energy sector.**

In the EU, employment in the renewable energy sector reached 1.5 million in 2021, up 12% compared to 2020[59], outpacing employment growth in the overall economy by a considerable margin (0.6%) and representing a notable increase after employment stalled between 2015 and 2020.

The growth registered in employment in the EU's renewable energy sector in 2021 was mainly driven by heat pumps and solid biofuels. Since 2020, the heat pump industry has been the largest employer (26% of jobs in 2021), followed by solid biofuels[60]. In 2021, jobs in solar PV grew 35% on 2020 values and became the third biggest sector, ahead of the wind industry.

This positive trend is expected to continue, supported by EU policy priorities on clean energy deployment and manufacturing. To meet the REPowerEU targets for 2030, **additional workers will be needed to roll out clean energy technologies**, with wind and solar alone potentially leading to 100 000 additional jobs in the EU[61]. Accounting for all renewable energy sectors, achieving the REPowerEU targets will require the creation of over 3.5 million jobs by

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[59] EurObserv'ER, *The state of the renewable energies in Europe – Edition 2022 21st annual overview barometer EurObserv'ER Report*, 2023.

[60] COM(2022) 643 final.

[61] For more information: *Employment and Social Developments in Europe (ESDE) Report 2023* (europa.eu). Estimate to deliver on policy goals (EGD-fit for 55, REPowerEU).

2030[62]. On the manufacturing side, the NZIA scenarios estimate between 198 000 and 468 000 in new jobs and from EUR 1.7 billion to EUR 4.1 billion in investment needs for retraining, re-skilling and upskilling[63]. Finally, it is estimated that 3 to 4 million construction workers in the EU would need to develop their energy efficiency related skills in the building sector[64].

However, the EU industry as a whole and clean energy manufacturing in particular, have seen a rise in **labour shortages** since 2021. This is mainly due to demand increasing faster than the supply of skilled workers, evidenced by the job vacancy rate doubling in 2019-2023.

In the third quarter of 2023, labour shortages in the manufacturing segments of the renewable energy sector remained high as reported in the 2022 edition of the Competitiveness Progress Report, with 25% of EU businesses involved in electrical equipment manufacturing[65] facing shortages. The energy sector is one of the sectors with persistent 10-year long labour shortages in some occupations, such as electrical equipment installers and repairers, and it is also one of the sectors most affected by an ageing workforce[66], exacerbating structural labour shortages.

Both **skill and labour needs** can be a bottleneck to growth, particularly in sectors where there is a high degree of specialisation[67]. Energy and manufacturing are among the sectors with the highest re-skilling and upskilling needs in terms of technical and job-specific skills, with over half of the workforce in need of upskilling[68]. Three quarters of businesses in EU industry already struggled to find workers with the skills they needed in 2019[69]. In 2023, nearly 4 in 5 small and medium-sized companies report it is generally difficult for them to find workers with the right skills[70].

Skills policies, working conditions and mobility and migration policies, together with actions to help people join the job market[71], are key to tackling these shortages. 2023 was the European year of skills. The EU budget[72] plays a pivotal role in fostering the development of skills, including up-skilling and re-skilling. In addition to cross-sectoral policy initiatives[73], the EU has put forward a number of specific measures to accelerate skills development in the green transition, and in the clean energy sector in particular. These initiatives include support to the *Large-Scale Skills Partnership* for the renewable energy industrial ecosystem[74], launched in March 2023, and the Net-Zero Industry Act, which proposes boosting skills for net-zero

62 For more information: Pact for Skills, Launch of large-scale renewable energy skills partnership (europa.eu).
63 Under the NZIA+ scenario (100% demand met by EU manufacturing), SWD(2023) 68 final.
64 European Construction Sector Observatory, *Improving the human capital basis*, March 2020.
65 'NACE 27: Manufacture of electrical equipment' used as a proxy for renewable energy manufacturing industry as many renewable energy technologies fall under this category. It is also used as a proxy for renewables industrial ecosystem in the EU Industrial Strategy [COM(2020) 108 final and its recent update COM(2021) 350 final].
66 For more information: Employment and Social Developments in Europe 2023 (europa.eu).
67 SWD(2023) 68 final.
68 Georgakaki, A.,Kuokkanen, A.,Letout, S., Koolen, D., Koukoufikis, G., Murauskaite-Bull, I., Mountraki, A., Kuzov, T., Dlugosz, M., Ince, E., Shtjefni, D., Taylor, N., Christou, M., Pennington, D., Clean Energy Technology Observatory: Overall Strategic Analysis of Clean Energy Technology in the European Union: 2023 Status Report, European Commission, 2023, JRC135404
69 Eurofond, *European Company Survey 2019* (europa.eu), 2019.
70 For more information: 2023 Flash Eurobarometer on skills shortages, recruitment and retention strategies in small and medium-sized enterprises.
71 Active support to quality employment, including of under-represented groups, such as women, is among the comprehensive policy packages under the Council Recommendation on ensuring a fair transition towards climate neutrality.
72 Cohesion policy, through the European Social Fund + (ESF+), is the main EU instrument to fund investment in skills, making EUR 5.8 billion available for green skills and green jobs. The European Regional Development Fund (ERDF) complements this Fund by investing in skills, education and training, including infrastructure. The Just Transition Mechanism (JTM) provides EUR 3 billion in support for training and skills development of workers to adapt to the green transition. Other measures are set out in the 2022 Competitiveness Progress Report.
73 E.g. Council Recommendations on individual learning accounts, micro-credentials, and vocational education and training.
74 For more information: Pact for Skills: Launch of large-scale renewable energy skills partnership (europa.eu).

technologies by setting up dedicated training programmes for the green transition (e.g. on raw materials, hydrogen, heat pumps and solar technologies). The Commission is also looking into advancing skills under the upcoming Heat Pump Action Plan.

As mentioned above, **activation policies can also help address skills and labour shortages in the sector, including the under-representation of women**. The **gender imbalance** in the EU energy sector's workforce is considerable. Only 26.6% of women are employed in the electricity, gas, steam, and air conditioning supply sector in 2022, though it varies across Member States (34% in Portugal, 14.5% in Croatia). Solar PV manufacturing has the highest share of women employees in the renewable sector with a 47% share, while only 21% of the workforce in the global wind industry are women. Policies, including skills policies, aimed at encouraging the participation of women in these jobs can help increase the pool of talent that is essential to its future growth and competitiveness.

2.4 From research and innovation to market uptake: charting a successful path for the EU

Research and innovation (R&I) is key to developing clean energy solutions that perform even better and are cheaper.

In 2021, public-sector **R&I spending** in the Energy Union priorities[75] was – in current prices - higher than it was a decade ago. However, as a share of GDP, public-sector R&I spending on the Energy Union priorities, both at national and EU level, remained below the levels spent before 2016. The other major economies also saw the same trend (Figure 2).

Over half of the EU Member States that provide data[76] increased their public R&I investment in the Energy Union priorities in 2021 in comparison to 2020, with EUR 5.4 billion reported so far[77].

Since 2020, Horizon 2020 and its successor, Horizon Europe, have added over EUR 2 billion a year to the Member States' national programme funding, providing a vital boost to R&I investment. Although the level of national funding is low compared with major economies, when factoring in EU funds, the EU topped the ranking of major economies in 2021 on public-sector R&I investment in the Energy Union priorities in absolute spending (EUR 8.2 billion[78], ahead of the US with EUR 7.7 billion), an improvement up compared to 2020[79]. The EU also ranked second as a share of GDP (0.056%, with Japan leading with 0.057%[80]).

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75 COM(2015) 80 final.

76 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).11 of the above Member States reported an increase to the IEA: AT, CZ, DK, DE, ES, FR, HU, IE, NL, PT, SE

77 A significant share of the increase was due to a change in reporting by Spain, coupled with a significant increase in a number of Member States. In Spain, coverage has been expanded, including data from state and regional governments, increasing the EU Member States total by over EUR 0.5 million. The changes have not been applied to previous years resulting in a break in the time series between 2020 and 2021. IEA, 2023. Energy Technology RD&D Budgets, May 2023 Edition, Database documentation. 11 out of 17 Member States reported an increase to the IEA: AT, CZ, DK, DE, ES, FR, HU, IE, NL, PT, SE. International Energy Agency (IEA), *Energy Technology RD&D Budgets - Database documentation*, 2023.

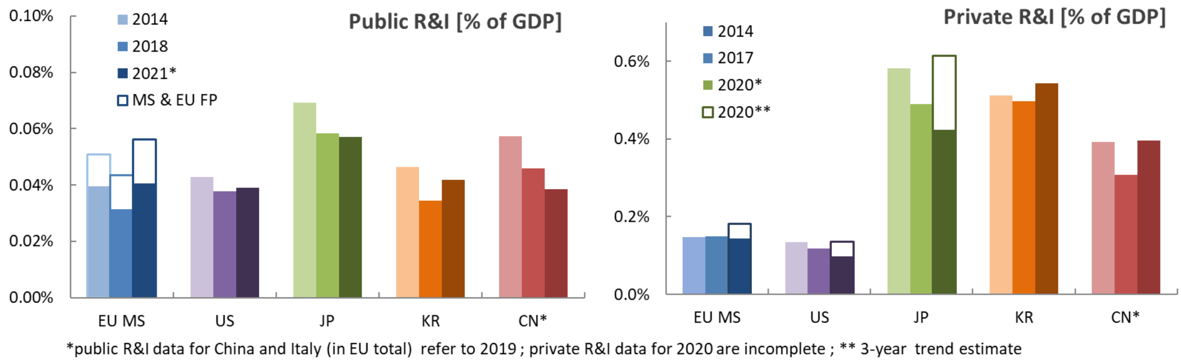
78 This figure includes an estimate for Italy, which has yet to report for 2020 and 2021.

79 COM(2022) 643 final.

80 These figures include national and EU-level Framework Programme funds. National funds alone remain below other major economies as a share of GDP.

Regarding **private-sector R&I investment**, it is estimated that 2020 spending in technologies related to the Energy Union R&I priorities also increased across all major economies. Consistent with the findings of the 2022 CPR[81], in 2020 the private sector in the EU continued to invest comparable amounts – in absolute terms – with the US and Japan, accounting for around 80% of all R&I funding. In terms of private R&I investment per GDP, this still positions the EU ahead of the US but behind the major Asian economies (Figure 2).

Figure 2: Public and private-sector R&I investments in major economies as a share of GDP[82].



Source 1: JRC based on IEA[83], MI[84], own work[85].

Since 2014, EU **patent filings** in the Energy Union R&I priorities increased by an average of 5% per year[86]. While there are notable differences in patenting trends both between Member States and for specific technologies, overall, the EU maintains a strong position in internationally protected patents. Overall, between 2014 and 2020, the EU ranked second to Japan on international patent fillings and led on renewables (29%) and energy efficiency (24%), losing some ground on smart systems (17% and ranking fourth among major economies).

As highlighted in the 2022 CPR and in the *Guidance to Member States for the update of the 2021-2030 national energy and climate plans*[87], plotting a successful R&I path requires sufficient experts and entrepreneurs, supported by the coordinated use of EU, national and regional programmes. It also requires clear national R&I targets and objectives to 2030 and to 2050, increased cooperation between Member States, and a continuous monitoring of national R&I activities. The joint and coordinated efforts across the Member States, notably through the revised Strategic Energy Technology Plan (SET Plan), and the National Energy and Climate Plans[88] are also a unique opportunity to deepen the dialogue on clean energy R&I and competitiveness between the EU and its Member States.

Lastly, it is **crucial to keep accelerating the transfer of EU clean energy innovations into the market.** This aim is set out in the New European Innovation Agenda, with support from

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[81] See Section 2.2 page 12, COM(2022) 643 final.
[82] EU FP refers to the EU Framework Programmes (Horizon 2020 and Horizon Europe).
[83] Adapted from the 2023 spring edition of the International Energy Agency (IEA) energy technology R&D budgets database.
[84] Mission Innovation, Report: *Country Highlights, 6th MI Ministerial*, June 2021.
[85] For more information: JRC SETIS (europa.eu).
[86] For more information: JRC SETIS (europa.eu).
[87] OJ C 495, 29.12.2022.
[88] For more information: National energy and climate plans (europa.eu), 2023.

EU funding sources such as InvestEU, the European Innovation Council, the LIFE programme and the Innovation Fund. Member States are also invited to foster experimentation, following the recent guidance[89] on regulatory sandboxes, test beds and living labs. Further action is also needed to attract private capital.

2.5 The venture capital landscape: attracting capital to the EU[90]

Over the years, **the EU's innovation policy has expanded, and the institutional landscape has evolved in parallel**. The aim is to narrow the equity gap in EU and reduce fragmentation in venture capital (VC) markets and innovation ecosystems. This includes complementary initiatives to foster equity investment and boost the funding of innovative start-ups and scale-up companies. To name a few, the European Innovation Council (EIC) Fund is the EU's own venture capital arm that aims to fund breakthrough innovation under the Horizon Europe's pillar III on 'Innovative Europe'. The New European Innovation Agenda[91] includes additional initiatives to accelerate the growth of deep-tech start-ups in the EU. The InvestEU Fund, using guarantees from the EU budget, mobilises public and private-sector investments, including funds that provide equity financing.

As **VC investment** is at the forefront of innovation, it is key to boosting the EU's competitiveness and to strengthening the EU's open strategic autonomy in the clean energy sector. In 2022, macroeconomic factors - such as rising inflation and interest rates - led to a fall in global VC funding. Total VC investment[92] in EU firms fell by 18% in 2022 compared to 2021. A similar trend is observed in the US (-20%), China (-36%) and worldwide in the first half of 2023.

Global VC investment in **clean energy technologies** performed better than other segments[93] such as biotechnology or digital. In 2022, the global clean energy sector attracted an increasing share of VC investment[94] up 4.4% in 2022 as compared to 2021, to EUR 39.5 billion, accounting for 6.2% of all VC investment. Despite this continuing positive trend observed since 2015, it has slowed since the growth seen between 2019 and 2020 (+37%), and the record in 2021 (+109%).

In the EU, VC investment in the clean energy sector reached EUR 7.4 billion in 2022, a 42% increase compared to 2021. The EU accounted for 19% - a growing share - of global VC investment in clean energy technology firms, ranking third behind the US (38%) and China (28%)[95]. VC investment in the clean energy sector also proved to be more resilient in the EU – where both early and later stage investments increased in 2022 – than in the rest of the world. Nonetheless, it remains largely concentrated in a few technologies (mainly battery manufacturing, recycling and electric vehicles).

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89 SWD 2023 277/2 final.

90 The analysis presented in this section focuses on clean energy technologies. It differs from Section 2.4 of the 2022 Competitiveness Progress Report by excluding activities previously considered in PitchBook's climate tech vertical and related to food systems, land use, micro-mobility, shared mobility and autonomous vehicles.

91 COM(2022) 332 final.

92 Based on PitchBook data, 01 June 2023

93 International Energy Agency (IEA), *World Energy Investment 2023*, 2023.

94 Georgakaki, A.,Kuokkanen, A.,Letout, S., Koolen, D., Koukoufikis, G., Murauskaite-Bull, I., Mountraki, A., Kuzov, T., Dlugosz, M., Ince, E., Shtjefni, D., Taylor, N., Christou, M., Pennington, D., Clean Energy Technology Observatory: Overall Strategic Analysis of Clean Energy Technology in the European Union: 2023 Status Report, European Commission, 2023, JRC135404.

95 Ibid.

Global VC investment in **strategic net-zero technologies,** as defined as in the NZIA proposal, accounted for EUR 20.8 billion in 2022 (compared to EUR 19.5 billion in 2021). In 2022, however, VC investment in strategic net-zero technologies in the EU increased at a slower rate (+2.3% from 2021 to 2022) compared to the overall rate of growth in the clean energy sector. The US outpaced the EU, recording a 41% increase in 2022 compared to 2021, as VC investments in renewable hydrogen and fuel cells, sustainable biogas/ biomethane, heat pumps and geothermal rose sharply. In the EU, foreign later-stage investments in those technology areas grew much faster in 2022 than intra-EU investments, accounting for over half of all funding of EU firms in 2022 (against 15% overall in 2021). In general, except for battery technologies, the EU has still not fully unlocked its potential to attract higher growth deals as the US and China have done in strategic net-zero technologies.

To boost the EU's competitiveness, resilience and leadership, **it is crucial to ensure that capital keeps flowing to EU companies at the scale needed** to accelerate the roll-out of strategic net-zero technologies. Deep and integrated capital markets and an effective sustainable finance framework are essential pre-requisites to mobilising private investments at scale towards clean energy technologies. Following up on the 2020 Capital Markets Union Action Plan, the Commission has tabled all the planned legislative proposals. The swift adoption by the co-legislators of the pending proposals would help improve access to finance, diversify sources of funding for companies and tackle structural obstacles in cross-border financial services. While developing the sustainable finance framework, the Commission has remained responsive to the needs of the users and adopted a series of measures and initiatives to reduce complexity, enhance the usability of the rules and support stakeholders in their implementation. It also took steps to streamline reporting obligations in view of reducing the administrative burden for companies.

In June 2023, the Commission proposed to set up the European Strategic Technologies for Europe Platform (STEP) to bolster and leverage the EU's current instruments (in particular, the EIC Fund, InvestEU, and the Innovation Fund) to allocate (e.g., by earmarking public funding) and disburse financial support to clean tech investments. This can help **de-risk innovation investments**, bridge the gap between project developers and corporate and institutional investors, and ultimately to channel further private-sector investment.

3. ASSESSING THE COMPETITIVENESS OF STRATEGIC NET-ZERO TECHNOLOGIES

This section assesses the **competitiveness of the strategic net-zero technologies** specified in the Net-Zero Industry Act (NZIA). It provides insights into how the technology and the market are evolving to meet the European Green Deal and REPowerEU objectives. The proposed NZIA specifies eight strategic net-zero technologies to achieve the 2030 Fit-for-55 target of reducing net greenhouse gas emissions by at least 55% relative to 1990 levels. They are solar (PV and solar thermal), onshore wind and offshore renewable technologies, electrolysers and fuel cells, batteries and storage, sustainable biogas and biomethane, carbon capture technologies and storage, heat pumps and geothermal, and grid technologies. In the proposed NZIA, the EU sets an overall headline benchmark for each of these strategic net-zero technologies to ensure that by 2030, the EU's manufacturing capacity of the strategic net-zero technologies approaches or reaches at least 40% of the EU's annual deployment needs.

The evidence-based analysis on which this section is built was carried out in the framework of the Commission's in-house Clean Energy Technology Observatory (CETO)[96].

3.1 Solar photovoltaics

Solar photovoltaics (PV) is the fastest growing power generation technology. It provides cheaper electricity than fossil-fuel power plants in most countries. It **plays a pivotal role in all scenarios to reach a climate neutral energy system**[97]. In the EU, solar PV already generated 7% of electricity production in 2022 from a cumulative installed capacity of 212 GWp[98.] The EU Solar Energy Strategy[99] aims to reach 600 GWac (720 GWp) installed by 2030, a four-fold increase on 2021 levels. The PV value chain is dominated by Asian countries, in particular China. Nonetheless, the European Solar Photovoltaic Industry Alliance launched on 9 December 2022 aims to expand the EU's manufacturing capacity to reach at least 30 GWp across the full supply chain by 2025. However, there is stiff international competition to attract manufacturing investments.

PV installations rely to a very large extent on crystalline silicon wafer technology, which continues to improve energy conversion efficiency and reduce material usage. In 2022, commercial modules offered an average efficiency of 21.1%, and a maximum of 24.7%[100]. Innovative materials, such as perovskites, offer scope for further gains in energy conversion efficiency: a perovskite/ silicon tandem device set a new record efficiency of 33.7% in May

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96 Chatzipanagi, A., Jaeger-Waldau, A., Cleret De Langavant, C., Gea Bermudez, J., Letout, S., Mountraki, A., Schmitz, A., Georgakaki, A., Ince, E., Kuokkanen, A. and Shtjefni, D., Clean Energy Technology Observatory: Photovoltaics in the European Union - 2023 Status Report on Technology Development Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, JRC135034.

97 Most notably, the scenarios projected by non-governmental organisations such as Greenpeace, the Energy Watch Group, Bloomberg New Energy Finance, the International Energy Agency, the International Renewable Energy Agency, as well as by PV industry associations.

98 Chatzipanagi, A., Jaeger-Waldau, A., Cleret De Langavant, C., Gea Bermudez, J., Letout, S., Mountraki, A., Schmitz, A., Georgakaki, A., Ince, E., Kuokkanen, A. and Shtjefni, D., Clean Energy Technology Observatory: Photovoltaics in the European Union - 2023 Status Report on Technology Development Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, JRC135034.

99 COM(2022) 221 final EU Solar Energy Strategy.

100 Chatzipanagi, A., Jaeger-Waldau, A., Cleret De Langavant, C., Gea Bermudez, J., Letout, S., Mountraki, A., Schmitz, A., Georgakaki, A., Ince, E., Kuokkanen, A. and Shtjefni, D., Clean Energy Technology Observatory: Photovoltaics in the European Union - 2023 Status Report on Technology Development Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, JRC135034.

2023[101]. Pilot lines for these tandems are in development, also in the EU, but commercial products are not yet available.

In 2022, EU companies were active in silicon, ingot/wafer, cell, module and inverter manufacturing and offering commercial products. Inverter production remains by far the largest EU solar manufacturing segment, with a production capacity reaching almost 70 GW, about 5 GW more than in 2021. The EU also has a major producer of polysilicon, which primarily exports to China. In the EU, at the start of 2023, nominal module production capacity reached 8.28 GWp/a, cells 0.86 GWp/a, and ingots and wafers 1.4 GWp/a[102]. EU Manufacturers are estimated to have assembled approximately 4 GW of modules in 2022, mostly from imported cells. This represents a 10% share of the EU market[103].

In 2022, Chinese companies provided at least three quarters of global capacity in all steps in the PV supply chain [104] and were the predominant exporters of wafers, cells and modules[105]. In addition, Chinese companies produce more than 80% of global polysilicon, material used in wafer production. China's Uyghur region alone supplies approximately 35% of the world's polysilicon (albeit down from 45% in 2020), but has been linked to strong concerns over forced labour use[106].

Solar PV prices were broadly stable in 2022 with mainstream modules at EUR 0.35 /W, but started falling again during the first half of 2023 due to intense competition and oversupply of components across the whole value chain. The price reached a record low in September 2023 at almost EUR 0.22/Wp[107] making it more difficult for EU manufacturers to produce profitably.

The PV market continued to grow significantly in 2022, with global installed capacity reaching 1 185 GWp (230 GWp year-on-year growth). China was the single largest market with approximately 90 GWp. It was a record year for the EU with 41 GWp installed (18% share). This growth was led by Spain (8.1 GWp), Germany (7.5 GWp), Poland (4.9 GWp) and the Netherlands (3.9 GWp)[108]. The residential segment was particularly strong, accounting for over 50%. High electricity prices have boosted the competitiveness of solar PV electricity (which at utility scale has the lowest levelised cost of any technology in almost all markets[109]).

With solar PV set to continue expanding rapidly worldwide, the last 12 months have seen policy initiatives from different geographical areas (e.g. USA, India and the EU) to develop more local manufacturing of solar photovoltaic systems and components. On this front**, the EU should capitalise on its position as one of the largest markets for PV systems, its world-**

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101 Green et al, Solar cell efficiency tables (62), Progress in Photovoltaics, 31, 7 (2023), https://doi.org/10.1002/pip.3726

102 Chatzipanagi, A., Jaeger-Waldau, A., Cleret De Langavant, C., Gea Bermudez, J., Letout, S., Mountraki, A., Schmitz, A., Georgakaki, A., Ince, E., Kuokkanen, A. and Shtjefni, D., Clean Energy Technology Observatory: Photovoltaics in the European Union - 2023 Status Report on Technology Development Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, JRC135034.

103 JRC own calculation based on available data.

104 IEA Special Report on Solar PV Global Supply Chains, 2022

105 Wood Mackenzie, press release: China's solar export booming, 23 May 2023. Modules represented the lion's share of these exports, followed by wafers and cells. In 2022, China exported 86GWp of modules to Europe (representing 56% of its modules exports).

106 Sheffield forced labour report Crawford, A. and Murphy, L. T, "Over-Exposed: Uyghur Region Exposure Assessment for Solar Industry Sourcing," Sheffield, UK: Sheffield Hallam University Helena Kennedy Centre for International Justice (2023)

107 PVXchange, reading the PV price index, accessed 7 October 2023

108 EA, 2023 Snapshot of Global PV Markets, 2023

109 IEA WEO 2022

leading research and development and a society that places a high value on minimising environmental impact, protecting biodiversity and ethical supply chains.

Nonetheless, **EU producers still face higher costs compared to their competitors**[110]. This can be mitigated with measures such as those proposed in the NZIA, REPowerEU or the reform of the Electricity Market Design to reduce energy and financing costs and to accelerate permitting procedures for production facilities. It will also require an increase in the scale of manufacturing plants and a focus on innovative, high-efficiency, low-carbon products and advanced and more sustainable manufacturing processes. On the importance of minimising environmental impact for the sector, the proposed Ecodesign and Energy Labelling legislation for PV panels and inverters can be an important driver. An immediate concern is the current global production over-capacity[111]. Although it is keeping prices on local markets low (at least in the EU), it is a disincentive to making full use of current capacity.

To develop the EU market, it is essential to continue action to **improve permitting procedures and to build public acceptance**. The PV residential market has considerable scope for further growth, but this will depend on the cost of battery systems continuing to fall. Specialty applications such as various forms of integrated PV and other innovative deployment options also have scope for significant market growth, especially for EU manufacturers.

3.2 Solar thermal

Solar thermal energy[112] has the potential to contribute significantly to the decarbonisation of the energy system, as recognised in the EU Solar Energy Strategy. Solar thermal technologies make little or no use of critical raw materials and can offer high rates of recycling[113].

A new generation of highly concentrated solar power plants in operation, typically using molten salts for heat transfer and with eight-plus hours of thermal storage, is building confidence in these types of systems that help improve power grid reliability with cost-competitive electricity. The EU has traditionally led the field in this technology, but is facing strong competition from China, which, for instance, took top place for high-value patents in 2020. EU companies remain involved in international projects in the UAE and South Africa, and in several on-going tenders. Here also Chinese companies are taking a leading role based on expertise developed in the construction of over 1 GW of systems in their home market. Worldwide there are 6.4 GW of concentrated solar power (CSP) plants operational. Of the 2.4 GW in the EU, almost all is in Spain. New plants are under construction in the United Arab Emirates, China and South Africa that can add 1.8 GW by 2025. In the EU, no new plants have started operating since 2014, but Spain has plans to build at least another 2 GW by 2030[114].

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[110] The actual cost gap is very dependent on project specifics; "McKinsey (2022): Building a competitive solar-PV supply chain in Europe" estimates 20-25% compared to low-cost competitors.

[111] IEA Special Report on Solar PV Global Supply Chains, 2022 "At the end of 2021, global capacity for manufacturing wafers and cells and for assembling modules exceeded demand by at least 100%".

[112] Data reported in this section are from Taylor, N., Georgakaki, A., Mountraki, A., Letout, S., Ince, E., Shtjefni, D., Kuokkanen, A., Tattini, J. and Diaz Rincon, A., Clean Energy Technology Observatory: Concentrated Solar Power and Solar Heating and Cooling in the European Union - 2023 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, JRC135004.

[113] Energy Transition Expertise Centre (EnTEC), Report: *Supply chain risks in the EU's clean energy technologies*, 2023, doi 10.2833/413910.

[114] Spain's 2019 NECP foresees reaching 7.4 GW by 2030. However, the draft of the first update revises this 4.8 GW by 2030. For more information: https://commission.europa.eu/publications/spain-draft-updated-necp-2021-2030_en.

Solar heating and cooling technology offers a range of options for buildings, for district heat networks and for industrial processes. The current levelised cost of heating/cooling (EUR 20 to 110 /MWh in Europe[115]) can be competitive with gas heating, particularly in areas with good solar resources. The overall EU market share is still small at 0.678 TWh (0.1%), compared to a total derived heat demand of 651 TWh in 2021[116]. The EU's glazed collector sector is reported to have grown by 10% in 2022, an encouraging rate, albeit below the rate needed to triple capacity from 2021 to 2030, as proposed in the Solar Energy Strategy. Solar thermal systems supply district heating systems in 264 cities and towns in Europe (corresponding to less than 5% of the 6 000[117] in operation). High EU demand for industrial process heat in the range 150 – 400 °C is also a good opportunity for solar thermal. For instance, the DECARBOMALT project in Croatia (supported by the EU's Innovation Fund) will use solar heat for malting. EU companies supply a large share of the EU solar water heater market as well as exporting. They faced significant supply chain disruptions in 2022[118].

Continued action is needed to boost the competitiveness of the EU solar thermal sector (both concentrated and non-concentrated solar), both at component level with standardisation and scale-up, and at system level with cost-effective integrated solutions, in **particular for industrial needs**. For CSP solar power generation, getting the right auction design and market access conditions can improve the technology's capacity to meet demand peaks outside day-light hours.

3.3 Onshore and offshore wind energy

Wind energy plays a significant role in the EU's transition to carbon neutrality. The REPowerEU plan calls for faster installation of wind energy capacity, with the aim to reach 510 GW of wind capacity by 2030[119].Wind energy is projected to have a 31% share of installed electricity capacity in 2030 in the EU. At the same time, the EU wind sector is facing several challenges. To address them and to enhance the EU competitiveness in the wind sector the Commission adopted the Wind Power Action Plan.

In 2022, the EU had a total cumulative installed capacity of 204 GW (189 GW onshore; 16 GW offshore). 16.2 GW were installed in 2022 (15 GW onshore; 1.2 GW offshore)[120] , which is nearly a 50% increase compared to 2021. In 2022, new capacity was installed onshore mainly in Germany, Sweden and Finland, and offshore capacity mainly in France and the Netherlands. The industry[121] expects to instal 20 GW of wind energy capacity a year in the EU over the next 5 years, below the 30 GW/year needed to achieve 2030 targets[122]. Overall, China remains in the lead in terms of wind capacity with a cumulative capacity of 334 GW (31GW offshore), and 37.6 GW added in 2022, including 5 GW in offshore. The EU ranks second, and the US

[115] Solar Heat Europe, *Solar Heat Markets in Europe, Trends and Market Statistics 2021, Summary*, December 2022.
[116] Solar Heat Europe, *Preliminary Report 2022*, Solar Heat Markets in EU27, Switzerland and UK, 7 July 2023.
[117] Cited in the IEA SHC Task 68 presentation to the Webinar '*The Rise of Solar district Heating*', 28 March 2023, Euroheat and Power and Solar Heat Europe.
[118] Energy Transition Expertise Centre (EnTEC), Report: *Supply chain risks in the EU's clean energy technologies*, 2023, doi 10.2833/413910.
[119] SWD (2022) 230 final.
[120] Tapoglou, E., Tattini, J., Schmitz, A., Georgakaki, A., Długosz, M., Letout, S., Kuokkanen, A., Mountraki, A., Ince, E., Shtjefni, D., Joanny Ordonez, G., Eulaerts, O.D. and Grabowska, M., Clean Energy Technology Observatory: Wind energy in the European Union - 2023 Status Report on Technology Development Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/618644 (online), JRC135020.
[121] WindEurope, Report: *Wind energy in Europe: 2022 Statistics and the outlook for 2023-2027*, 28 February 2023.
[122] The figure reported by Wind Europe of 30 GW/year is lower than the one that would result from REPowerEU: 38.25 GW/year. The difference is explained by using different capacity factors in the calculations.

third with 144 GW of total capacity. The global total of new wind energy capacity installed in 2022 was 68 GW onshore and 9 GW offshore [123]. The EU Member States have concluded in January 2023 non-binding agreements on offshore renewable goals per sea basin, giving a cumulative result for the EU of 109-112 GW by 2030, 215-248 GW by 2040 and 281-354 GW by 2050[124].

The EU wind sector remains one of the strongest players on the world market. EU manufacturers accounted for 85% of the EU wind energy market and for 30% of the global market share in 2022, down from 42% in 2019[125]. Specifically for the offshore sector, the market share of EU companies for installations in the EU in 2022 reached 94%. To meet the REPowerEU objectives, it will be crucial to massively speed-up the roll-out of wind energy. **However, increasing costs along the value chain undermine the economic viability of several projects. EU wind manufacturers face other challenges** due to low installation volumes, high inflation and commodity prices, high interest rates, limited access to capital and slow, complex permitting that does not reflect specific market conditions: **all factors that have negatively affected the sector.**

According to the industry, inflation in commodity prices and other input costs have led to a 40% increase in the price of wind turbines over the last two years[126]. More importantly, there are persistent bottlenecks in the permitting process - which have been already addressed at EU level, but issues like insufficient staffing levels compared to the large number of permit applications in public administrations persist- and a lack of visibility of the upcoming project pipeline. These factors have led the EU wind turbine industry to report losses and issue repeated profit warnings.

Given the strategic importance of wind energy for the EU, action must be taken to boost the competitiveness of the wind industry. To stimulate the growth of the wind energy supply chain in the EU, it is necessary to diversify imports of raw materials, further implement circular economy approaches and increase manufacturing capacity. The proposed Net Zero Industry Act and the Critical Raw Materials Act were designed to ensure the resilience of the EU supply chain across all segments. Support is also needed to make substantial investments in grids, ports and installation and maintenance vessels. Installation volumes must increase to generate economies of scale, stability and the predictability needed to support investment and to make the business case for profitable wind manufacturing. Faster permitting and simplified procedures should be further enhanced along with higher transparency and planning visibility of future auctions and project pipelines by Member States. **Continued support from governments, especially providing sufficient and skilled staff to deal with permitting files, and a favourable business environment will be crucial to maintaining the EU's competitive position in the wind energy sector.** EU and national-level funding should be used to promote innovation scale up, in accordance with EU state aid rules. **To tackle the challenges that the EU wind industry is currently facing, the Commission adopted a Wind**

[123] Tapoglou, E., Tattini, J., Schmitz, A., Georgakaki, A., Długosz, M., Letout, S., Kuokkanen, A., Mountraki, A., Ince, E., Shtjefni, D., Joanny Ordonez, G., Eulaerts, O.D. and Grabowska, M., Clean Energy Technology Observatory: Wind energy in the European Union - 2023 Status Report on Technology Development Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/618644 (online), JRC135020.

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

[125] JRC analysis based on Orbis, Pitchbook, 2023

[126] Wind Europe, Press release*: Investments in wind energy are down – Europe must get market design and green industrial policy right*, 2023.

Power Action Plan which will help accelerate permitting even more, improve auction systems across the EU, facilitate access to finance and strengthen supply chains.

3.4 Ocean energy

The 2020 EU strategy on offshore renewable energy[127] calls for action to install 1 GW of ocean energy commercial capacity by 2030 and 40 GW by 2050.

Ocean energy includes five distinct technologies: tidal stream energy, tidal range energy, wave energy, ocean energy thermal conversion and salinity gradient power generation. Tidal and wave technologies are the most advanced. Globally, over 98% of all[128] combined capacity currently operational is tidal range technology (521.5 MW), including the 240 MW tidal power station of La Rance (France), built in 1963[129]. In 2022, there were limited new installations of ocean energy devices both globally and in the EU[130]. Currently, only a few devices have reached a commercial stage, but several devices are at higher technology readiness levels, with tidal having converged on specific types of devices. **The barriers to developing this sector stem mainly from its lack of maturity**. Devices and procedures are not yet optimised, and this leads to high costs (with average LCOE for wave energy devices EUR 0.27/kWh and for tidal energy devices EUR 0.2/kWh), long permitting processes, scarcity of financing, non-proven concepts and the absence of dominant designs. Still, multiple pilot projects are expected to be operational by 2025[131].

According to industry[132], over the past 10 years the EU has invested over EUR 375 million in ocean energy research, development and innovation via multiple funding programmes. The 2023-2024 Horizon Europe work programme provides an additional indicative amount of EUR 94 million in support. Since 2018, the European Innovation Council has funded 10 ocean energy-related projects with a total budget (for ocean energy) of approximately EUR 25 million. According to the European Technology and Innovation Platform (ETIP) on ocean energy, the EU leadership in wave and tidal energy could generate economic activity worth EUR 140 billion and 500000 jobs with a 293 GW global market by 2050[133] .

Specialist manufacturing products such as gearboxes, generators, control systems and drivetrains are most likely to be sourced in Europe. Particularly rare earth elements used in the permanent magnets of the turbine generators are identified as critical raw materials in the ocean energy sector. Dysprosium, neodymium, praseodymium, terbium and borate are subject to a high supply risk.

The EU industry is leading the development of the ocean energy sector with 41% of tidal stream developers with technology readiness level higher than 5 in the EU[134] leading with the

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127 COM/2020/741 final.

128 Tapoglou, E., Tattini, J., Schmitz, A., Georgakaki, A., Długosz, M., Letout, S., Kuokkanen, A., Mountraki, A., Ince, E., Shtjefni, D., Joanny Ordonez, G., Eulaerts, O. and Grabowska, M., Clean Energy Technology Observatory: Ocean Energy in the European Union - 2023 Status Report on Technology Development Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/82978 (online), JRC135021.

129 This plant, very innovative when it was built, had a significant environmental impact that nowadays would be hardly acceptable. SONNIC Ewan, « La Rance, 50 ans de turbinage. Et après ? Le statu quo est-il la seule option pertinente ? », L'Information géographique, 2017/4 (Vol. 81), p. 103-128. DOI : 10.3917/lig.814.0103

130 In EU waters 62 kW of new tidal energy capacity and 33.5 kW of wave energy capacity was installed in 2022.

131 International Renewable Energy Agency (IRENA), *World Energy Transitions Outlook 2023: 1.5°C Pathway, Volume 1, Abu Dhabi*, 2023.

132 Ocean Energy Europe (OEE), Policy Topics: *Research and Innovation*.

133 ETIP Ocean, *Industrial Roadmap for Ocean Energy*, 1 July 2022.

134 Tapoglou, E., Tattini, J., Schmitz, A., Georgakaki, A., Długosz, M., Letout, S., Kuokkanen, A., Mountraki, A., Ince, E., Shtjefni, D., Joanny Ordonez, G., Eulaerts, O. and Grabowska, M., Clean Energy Technology Observatory: Ocean Energy

Netherlands, France and Ireland. Non-EU players are predominantly based in the UK, Canada, US and China. Similarly, 52% of companies developing wave energy devices are located in the EU[135]. Denmark has the highest number of developers, followed by Italy and Sweden. Outside the EU, the UK, US, Australia and Norway have a large number of wave energy developers.

In 2022, China overtook the EU in the number of scientific publications and now leads in both the wave and the tidal sector. The EU ranks second in both ocean energy categories[136]. **A combination of technological innovation, flanking policies, lower costs and the systematic integration of more long-term reliable technologies, processes or devices are needed to provide the necessary reassurance and confidence to investors to boost the EU's competitiveness in the ocean energy sector.** Creating technology-specific auctions can enable the roll-out of commercial devices that will, in turn, help reduce the LCOE and highlight the advantages of ocean energy to the system. Sharing infrastructure with other renewable installations (e.g. offshore wind) and developing common platforms for multiple activities (e.g. aquaculture) can also be helpful to boost ocean energy development.

3.5 Batteries

Batteries play a crucial role in the clean energy transition, both for transport and stationary applications. As the EU transitions to exclusively zero-emission new light-duty vehicles by 2035[137], it is substantially increasing its domestic battery production to be competitive on a global scale, meet its political goals and prevent new fossil fuel dependencies from arising.

Battery production in the EU is set to reach 458 GWh by 2025 and 1083 GWh by 2030[138], **on track to meet the forecast EU demand**[139,140]. The European Battery Alliance is playing a key role in this context, and in 2022, Europe's battery industrial network under the Alliance grew from 750 to 800 members spread along the entire value chain. Europe's battery ecosystem accounts for around EUR 180 billion, mostly private, investment commitments so far[141].

Despite the overall decline of the EU car market in 2022, sales of the EU's fully battery electric vehicles (BEV) increased by 28% compared to 2021, accounting for 12.1%[142] (1.12 million) of the 9.1 million vehicles sold on EU markets. Altogether, BEV, plug-in EV and hybrid EV, accounted for 44.1% of EU car sales in 2022 [143]. The rising trend continues and in October 2023 81 9000 for BEV only, or 1.288 million for total plug-in EV [144] were sold in the EU27. Worldwide, the trend indicates 14 million by the end of 2023 (+35% over 2022), resulting in a possible 18% of total car sales in 2023[145].

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in the European Union - 2023 Status Report on Technology Development Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/82978 (online), JRC135021.

135 Ibid.

136 Ibid.

137 Member States' final approval 28 March 2023 to regulation banning the sale of carbon-emitting cars and vans after 2035.

138 The European Battery Alliance (June 2023); but e.g. Fraunhofer institute data indicates wide range for 2030 EC battery production capacity from min 677 GWh to mean 1770 GWh to max 2050 GWh.

139 European Court of Auditors, Special Report: *The EU's industrial policy on batteries*, 2023. Range: 700GWh to 1200GWh/a.

140 For more information: Transport & Environment, as of 6 March 2023. Range: up to 50 Gigafactories with 1800GWh.

141 For more information: the European Battery Alliance (Europa.eu).

142 As compared to 9.1% in 2021 and of just 1.9% as recently as 2019.

143 European Automobile Manufacturers' Association (ACEA), Press Release: *Fuel types of new cars: battery electric 12.1%, hybrid 22.6% and petrol 36.4% market share full-year 2022*, 1 February 2023.

144 See: European Alternative Fuels Observatory (europa.eu).

145 International Energy Agency (IEA), *Global EV Outlook 2023 Executive Summary*, 2023.

While **most batteries will go into the automotive sector**, **stationary storage is also increasing exponentially.** Battery storage of 154 GWh Battery Energy Storage Systems is forecast to be installed globally by the end of 2023, 102% more than in 2022[146], of which roughly 10% is to be installed in the EU[147].

Despite global production increasing by 180% compared to 2017, once again very high global demand for lithium in 2022 exceeded supply. In 2022, about 60% of lithium, 30% of cobalt and 10% of nickel demand was for EV batteries (15%, 10% and 2%, respectively in 2017)[148]. After a decade in which prices mainly fell, and despite increasing shares of lower cost chemistries such as lithium iron phosphate (LFP)[149,150], average prices for lithium-ion battery (LIB) packs reached EUR 136/kWh[151] in 2022, up 7% increase compared to 2021. In Europe, due to higher production costs, average prices were EUR 152/kWh in 2022, 24% higher than in the US, and 33% higher than in China[152]. The Inflation Reduction Act (IRA) pledges of USD 134 billion[153] (EUR 113 billion[154]) to support the US battery industry. According to BloombergNEF[155], Europe's share in global investment announcements in LIB production capacity fell from 41% in 2021 to 2% in 2022. It should be borne in mind that such announcements of major investments are typically 'lumpy' and do not follow a linear pattern. Since mid-2023 forecasts see the US overtaking the 2031 EU battery capacity pipeline. While the US added 436 GWh (57.9% increase) to their project pipeline since the start of IRA, the EU only added 25 GWh (3%)[156]. When factoring in IRA support and lower US energy prices, the effective price for EU batteries would be 40% higher than the US, up to EUR 4 000 higher battery cost for a European BEV[157], a price gap that risk at having negative impact on production capacity roll out in the EU[158].

The stationary EU battery market is also growing steadily. In the first quarter of 2023, the installed base for energy grid storage (except pumped hydro storage) in the EU was about 11GW/ 14.7GWh of storage assets, of which ~5.3 GW/ 5.6 GWh were front-of-meter (FoM) installations. At least ~19GW/ 42.3 GWh FoM are currently under development[159]. Behind-the-meter home battery storage is also rapidly increasing. In Germany, for example, it increased from 2.0 GW in mid-2022 to 4.1 GW (+105%) in mid-2023[160]. However, to achieve the EU's

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146 For more information: the European Battery Alliance - EBA250

147 EMMES 7.0, LCP-Delta, 20232023 status quo first quarter: 11GW / 14.7GWh; Fraunhofer extrapolation go even up to 20 GWh.
Industry data. EMMES 7.0 - March 2023 | EASE: Why Energy Storage? | EASE (ease-storage.eu) 2023 status quo first quarter: 11GW / 14.7GWh; Fraunhofer institute extrapolated estimates go even up to 20 GWh.

148 International Energy Agency (IEA), *Global EV Outlook 2023,* 2023.

149 BloombergNEF, press release: *Lithium-ion Battery Pack Prices Rise for First Time to an Average of $151/kWh*, 6 December 2022.

150 Which were 20% cheaper than lithium nickel manganese cobalt oxide (NMC) cells in 2022.

151 Exchange rate €0.9 = $1 used in whole document for currency conversion when sources gave $ values.

152 InsideEVs, Press Release: *Europe: Plug-In Car Sales Accelerated In March 2023*, 10 May 2023.

153 The White House, Investing in America, 2023.

154 Using the average exchange rate of EUR 0.8455 for USD 1 over the year 2021. See: https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html.

155 Bloomberg NEF, 2023 Q1 -Energy Transition Investment Trends report.

156 BenchmarkSource, article: IRA supercharges USA's gigafactory capacity pipeline as it overtakes Europe for first time, 2 June 2023.

157 EBA, Discussion Paper for the 7th High-Level Meeting of the European Battery Alliance

158 Transport & Environment, Report: *How not to lose it all*, March 2023.

159 Industry data. EMMES 7.0 - March 2023 | EASE: Why Energy Storage? | EASE (ease-storage.eu) 2023 status quo first quarter: 11GW / 14.7GWh; Fraunhofer institute extrapolated estimates go even up to 20 GWh.

160 RWTH Aachen University, *Battery Charts,* 2023

Fit-for-55 and REPowerEU objectives, the roll-out of stationary energy storage must accelerate rapidly to achieve the forecast demand of 200 GW by 2030[161].

The EU's projected lithium battery demand is currently estimated to be around 1 TWh by 2030[162]. Although China still covers most of the EU's excess demand, EU private investments in local battery production will prompt companies to build plants near EV production lines to cut transport costs. Despite the potentially negative effects of the IRA on the expansion of EU battery value chains, **battery factories are being built with increasing speed across Europe and are projected to meet most of EU demand by 2030**. For example, Stellantis[163] continued as planned, and in 2023 inaugurated in France the first (final capacity 40 GWh/a) of three large ACC[164] EU-based battery gigafactories. Altogether the three factories are expected to account for 25% of the total projected EU 2030 demand[165], corresponding to a total of 250 GWh capacity by 2030.

The biggest relative increase needed to meet 2030 targets is in the area of recycling[166]. In 2023 only some 50 kilotons of waste were recycled in Europe, against the forecast demand for 200-800 kilotons by 2030[167]. **Strongly ramping up recycling would allow the EU to increase its presence in the early stages of the value chain und thus security of supply.** The Horizon Europe partnership on batteries, with a budget almost EUR 1 billion, supports research and innovation in this area. Subsidies should be allocated wisely to avoid distorting the single market, which is vital for both competitiveness and innovation.

3.6 Heat pumps

The revised Renewable Energy Directive[168] includes new targets for renewables in heating and cooling, in industry and in buildings and calls for better integration of heating with the power grid. Further support to replace fossil fuel boilers is provided by the Ecodesign[169] and Energy Labelling legislation[170]. The Commission is also preparing an EU action plan to accelerate the deployment of heat pumps[171].

In the eighteen EU Member States covered by European Heat Pump Association (EHPA), 17.4 million individual heat pumps mainly intended for heating were in operation at the end of 2022. Their sales grew by 41% in 2022 to 2.75 million units[172]. In the first half of 2023, heat pump sales continued to increase in the EU, while in some countries, like Italy, sales decreased compared to the first half of 2022, due to changing national support schemes, and unfavourable electricity-gas price ratios[173]. **Model-based decarbonisation scenarios have identified a high**

161 Energy Storage Coalition, Press Release: *Energy Storage Coalition calls for more targeted support for energy storage in key EU legislation*, March 2023.
162 McKinsey & Company, Article: *Battery 2030: Resilient, sustainable and circular*, 16 January 2023.
163 Stellantis is a constellation of 14 automotive brands.
164 Cells Company's (ACC) battery gigafactory in Billy-Berclau Douvrin, France
165 Green Car Congress, Press Release: *First ACC gigafactory inaugurated in France; initial 13 GWh capacity*, 31 May 2023.
166 For more information: the European Battery Alliance: Short brief European Battery production - June 2023
167 Based on calculations by Fraunhofer ISI.
168 OJ L 328, 21.12.2018.
169 OJ L 239, 6.9.2013.
170 OJ L 198, 28.7.2017.
171 For more information: Heat pumps – action plan to accelerate roll-out across the EU (europa.eu)
172 European Heat Pump Association (EHPA), *Market Report 2023*, limited to AT, BE, CZ, DE, DK, EE, ES, FI, FR, HU, IE, IT, LT, NL, PL, PT, SE, SK, 29 June 2023. Including mainly space heating and sanitary hot water heat pumps.
173 Lyons, L., Clean Energy Technology Observatory: Heat pumps in the European Union - 2023 Status Report on Technology Development Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, JRC134991.

growth potential. According to the JRC's POTENCIA model, for example, the number of individual heat pumps used mainly for heating in the EU (13 million in 2020) is projected to grow 2.5-fold by 2030 and almost 10-fold by 2050. Unit capacity is expected to fall by half by 2050, thanks to better building insulation; this fits the ambition of REPowerEU plan to install 30 million or more heat pumps by 2030.

District heating may be the preferred heating option in densely populated urban areas, where large heat pumps can harvest energy from solar, geothermal or excess heat from industrial or urban processes. The Heat Roadmap Europe project[174] estimates a potential 50% market share for district heating by 2050 in Europe, with approximately 25-30% capacity based on large electric heat pumps. This could coverup to 38% of all district heating production[175].

The technical potential for industrial heat pumps[176] varies by sector from around 65% of process heat in the paper industry, 40% in the food industry to 25% in the chemical industry. In Europe alone, heat pumps with a combined capacity of 15 GW could be implemented in almost 3 000 installations[177].

EU production capacity was estimated to have covered 75% of EU demand for individual hydronic heat pumps in 2021.[178] However, the **EU manufacturers are dependent on imports for components** (such as expansion valves and 4-way valves coming mainly from China), **and for compressors, inverters and synthetic refrigerants**, largely imported from China and South-East Asian countries[179] and the US. Their production does not require critical raw materials but is affected by the current long lead times for chips, heat exchangers, pumps, wires and tanks[180].

Focusing on individual heat pumps, growth on the domestic market has been partially captured by imports. The trade balance deficit more than doubled to EUR 856 million in 2022 compared to 2021, against a surplus of EUR 186 million five years before. Imports from China doubled in 2021 to reach EUR 533 million and nearly doubled again to EUR 898 million in 2022[181].

The manufacturing base in Europe is relatively fragmented with 175 manufacturing facilities, including multinationals and SMEs[182]. By comparison, the large Asian and US companies can benefit from economies of scale. Manufacturers of hydronic heat pumps are investing at unprecedented scale and speed in European-based manufacturing capacity, with investment reaching nearly EUR 5 billion[183] over the period 2023-2026, and a new the Heat Pump Accelerator platform set up to speed up the roll-out. For large heat pumps for commercial and network applications, the European industry has a dominant market position. For industrial heat pumps too, there are 17 EU manufacturers, 8 in Norway, and only 3 non-European

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174 For more information: Heat Roadmap Europe, https://heatroadmap.eu/.
175 Euroheat & Power, *Large heat pumps in district heating & cooling systems*, 2022.
176 Industrial heat pumps are commonly used for processes below 100 °C, commercial products exist up to 160 °C still to be demonstrated in more industrial sectors. Ongoing developments for temperatures up to 280 °C.
177 International Energy Agency (IEA), *Future of heat pumps*, 2023.
178 Eunomia, *EU Hydronic Heat Pump Manufacturing Market Assessment*, 2023.
179 Japan, Thailand.
180 Eunomia, 2023, ibid.
181 COMEXT, Goods Trade EU, 841861.
182 Eunomia, *EU Hydronic Heat Pump Manufacturing Market Assessment*, 2023.
183 European Heat Pump Association (EHPA), press release: *Manufacturer investments*, June 2023.

manufacturers (all based in Japan). Their major components (e.g., compressors) are locally manufactured[184].

R&I into individual heat pumps would give a further boost to EU competitiveness by designing more efficient, compact, silent and aesthetic EU products, as well as more digitised and flexible to minimize power grid reinforcements. The competitiveness of heat pumps using natural refrigerants will benefit from the inclusion of relevant international standards[185] in installers' certification schemes to ensure the safe use of flammable refrigerants inside buildings. Tools are needed to assess the heat pump readiness of individual or multi-family buildings and propose solutions. **Together with R&I to improve automation in manufacturing, modularisation and rationalisation of heat pump installation, consolidating the manufacturing base in the EU would help drive down the upfront costs of heat pumps and boost EU global competitiveness**[186].

For industrial heat pumps, **cooperation between end-user sectors and the heat pump sector to optimise and standardise products would also lower the costs and risks linked to their roll-out**. Energy service companies can lower the risk for end users by proposing a leasing model.

3.7 Geothermal energy

The revised Renewable Energy Directive sets binding targets for renewable heating and cooling and promotes the roll-out of direct geothermal heat use. The Critical Raw Materials Act is expected to increase the scope for exploiting the geothermal resources needed to co-produce critical raw materials, especially lithium.

Deep geothermal energy has the highest capacity factor of all renewable energy sources (which can exceed 80%[187]), **low operating costs and an extensive manufacturing base**. In 2022, deep geothermal power capacity reached 16.1 GWe globally[188], with 877 MWe in the EU[189]. No new plant was commissioned in 2022 in Europe, and the global increase of 286.4 MWe, mainly in Kenya, Indonesia and the US, was below the pre-pandemic annual trend of 3%[190]. More promisingly, geothermal direct heat use has had a steady growth rate of 9% since 2010 in the EU[191], especially for district heating and cooling. There are now 261 systems that use geothermal direct heat, with 12 new systems added in 2022 (5 in France alone).

The EU has a strong position on R&I investments, patents and scientific publications. R&I funding from the European Commission and the Member States puts the EU in the lead

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[184] International Energy Agency (IEA) Technology Collaboration Programme, *Heat Pumping Technologies, Annex 58 Final report*, August 2023.

[185] For more information: IEC 60335-2-40:2022: Household and similar electrical appliances – Safety – Part 2-40: Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers, 2022.

[186] Eunomia, *EU Hydronic Heat Pump Manufacturing Market Assessment*, 2023.

[187] IRENA and IGA Global geothermal market and technology assessment, International Renewable Energy Agency, International Geothermal Association, 2023.

[188] European Geothermal Energy Council (EGEC), Report: Geothermal Market Report 2022 – Key Findings, July 2023.

[189] Taylor, N., Ince, E., Mountraki, A., Georgakaki, A., Shtjefni, D., Tattini, J. and Diaz Rincon, A., Clean Energy Technology Observatory: Deep Geothermal Energy in the European Union - 2023 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, JRC135206.

[190] European Geothermal Energy Council (EGEC), Report: Geothermal Market Report 2022 – Key Findings, July 2023.

[191] Taylor, N., Ince, E., Mountraki, A., Georgakaki, A., Shtjefni, D., Tattini, J. and Diaz Rincon, A., Clean Energy Technology Observatory: Deep Geothermal Energy in the European Union - 2023 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, JRC135206.

worldwide in terms of public support for the sector between 2010 and 2020, followed by the US. Over the same period the EU also led on the number of new high value patents, before China overtook the EU in 2019[192].

Although enhanced geothermal system (EGS) technology has not yet reached maturity, R&I has brought new developments in subsurface heat and cold storage, resource assessment and exploration, Closed-Loop Geothermal Systems and stored CO_2 use for power production.

Turbines for geothermal power production are mainly manufactured by a few large industrial corporations, such as Toshiba (JP), Fuji Electric (JP), Mitsubishi Heavy Industries (JP), Ormat Technologies (US/IL) and Ansaldo Energia (IT), mostly non-European with some notable exceptions in Italy. The market for building geothermal facilities is spread across multiple public and private-sector companies[193]. In district heating, the suppliers of geothermal equipment for the underground part of the installations are mostly in the oil and gas industry. Pumps, valves and control systems are usually imported from the US and Canada. Exploration and drilling operations, which account for the major costs of deep geothermal projects, are dominated by a few specialised non-European companies[194].

In 2022, **the sector faced the shortages in their workforce, equipment and materials**, such as drilling rigs or steel for casing. Geothermal energy makes a very limited use of critical raw materials, but the extraction of lithium from lithium-rich geothermal brines, as in the current commercial development in southern Germany[195], can help mitigate the EU dependency on imports.

The sector needs more available subsurface data to reduce resource development risks, cheaper, more reliable exploration techniques and innovative production processes to increase the range of exploitable geological settings, such as EGS or Closed Loop Geothermal Systems. **Simplifying the licensing process, de-risking schemes, raising public awareness and developing the skills of the workforce would also be beneficial for the sector.**

3.8 Water electrolysis to produce renewable hydrogen

Water electrolysis is currently the only key technology able to produce renewable hydrogen at scale. It can contribute to the decarbonisation of hard-to abate sectors in industry, heavy duty, maritime and aviation transport, or to other uses such as energy storage (especially seasonal).

In the EU, the revised Renewable Energy Directive sets specific sub-targets for the use of renewable fuels of non-biological origin (RFNBO) for renewable hydrogen in industry (42%) and transport (1% RFNBO and 5.5% combined with advanced biofuels) by 2030. The new delegated regulation on the definition of RFNBOs[196] outlines requirements to produce RFNBOs, including renewable hydrogen, such as temporal and geographical correlation and

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[192] Taylor, N., Ince, E., Mountraki, A., Georgakaki, A., Shtjefni, D., Tattini, J. and Diaz Rincon, A., Clean Energy Technology Observatory: Deep Geothermal Energy in the European Union - 2023 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, JRC135206.

[193] Ibid.

[194] Ibid.

[195] Ibid.

[196] OJ L 157, 20.6.2023.

the additionally principle. The European Hydrogen Bank[197] is expected to launch its pilot auction in November 2023, which aims to secure long-term 'offtake agreements' between producers and buyers and the contracting authority will award up to EUR 800 million.

Global electrolyser deployed capacity is expected to reach about 2 GW by the end of 2023[198] up from the 600-700 MW range at the end of 2022[199], and 500 MW at the end of 2021[200]. The majority of this capacity estimated in the range of 50%-75% is alkaline[201], with the rest almost completely made up of proton exchange membrane (PEM) electrolysers[202]. In terms of installed capacity, China leads with about 1 GW of expected installed capacity by the end of 2023 with world's largest project of 260 MW operationalised in 2023, up from 204 MW already installed in 2022. It is followed by Europe (EU 27, EFTA, UK) with an expected capacity of 500 MW by the end of 2023 (a quarter of the global one), up from 162 MW in operation (August 2022[203]). For the US there is not enough detailed data and installed capacity in 2022 was estimated at 19 MW. This growth is largely driven by support schemes. However, the market studies highlight that the US support schemes are expected to trigger rapid market uptake. Deployment is growing globally and is expected to reach gigawatt scale by the end of 2023, in part driven by such support schemes.

By the end of 2022, the global manufacturing capacity of electrolysers was estimated at some 13-14 GW/year, with around 3.3 GW/year in Europe[204].

Industry-led initiatives such as the European Clean Hydrogen Alliance[205] under policy umbrella of the European Commission to promote the industrial leadership in the field of renewable and low carbon hydrogen, and the Electrolyser Partnership[206] aim to reach 25 GW of annual electrolysers manufacturing capacity by 2025. China has the highest manufacturing capacity, covering at least half of global volumes and focussing almost exclusively on alkaline. North America's manufacturing capacity is similar to the European one, focusing currently more on PEM electrolysis. In terms of cost competitiveness, the price of electricity is one of the main factors contributing to the final cost of hydrogen produced via water electrolysis and its weight grows together with electrolyser full load hours. US sources estimate that electricity prices of around USD 30/MWh (EUR 28.4/MWh) would give a hydrogen price in the order of USD 2/kgH_2 or around EUR 1.9/kgH_2[207].

In Europe, the Clean Hydrogen Joint Undertaking invests EUR 2.4 billion in the entire hydrogen value chain[208]. Investments spurred on by hydrogen Important Projects of Common European Interest have opened up the possibility for several manufacturers to build new electrolyser factories in Europe, increasing EU technology autonomy, industrial know-how and

197 COM(2023) 156 final.
198 IEA, Global Hydrogen Review, 2023, an update of the database is expected in October 2023,
199 International Energy Agency (IEA), *Global Hydrogen Review*, 2022.
200 International Energy Agency (IEA), 2022, ibid.
201 International Energy Agency (IEA), *Global Hydrogen Review,* 2023, the range is large due to the o "unknown" type reported by IEA.
202 Bloomberg NEF, *1H 2023 Hydrogen Market Outlook*, March 2022.
203 Hydrogen Europe, *Clean Hydrogen Monitor*, 2022.
204 International Energy Agency (IEA), *The State of Clean Technologies*, May 2023 and *Clean Hydrogen Monitor,* 2022.
205 For more information: European Clean Hydrogen Alliance (europa.eu).
206 Hydrogen Europe, Press Release: *New Electrolyser Partnership*, 16 June 2022.
207 U.S. Department of Energy, *the U.S. National Clean Hydrogen Strategy and Roadmap*, June 2023. Estimates are based on the available data.
208 Funding comes from the EU budget amounting at 1.2 BN EUR (including the additional appropriations from REPower EU of 200 M EUR) and an equivalent amount from the private stakeholders in the period 2021-27.

creating jobs[209]. Examples are the factories of Accelera-Cummins (BE, ES), Topsoe (DK), by John Cockerill (BE, FR), by Hydrogen Pro (DE), and announcements of ventures between Siemens and AirLiquide, Enapter (IT) to produce for the first time a megawatt anion electrolyser.

Renewable hydrogen production faces some challenges. There is the issue of energy efficiency loss, which means production must be coupled with a significant generation of renewable electricity. In addition, access to freshwater resources - which could exacerbate local water stress in the EU and in third countries – should be taken into consideration when starting new water electrolysis projects to avoid the scarcity of another vital element for human life.

Renewable hydrogen and its derivatives are not yet traded globally, despite the increase in the number of projects that aim to ship hydrogen across the world, from regions rich in renewables but relatively low demand to regions with high demand, such as Europe and Japan. There is not yet a specific trade code available for renewable hydrogen. Some voluntary certification schemes have been notified to the Commission.

Development of safety standards including for the handling of hydrogen derivatives, some of which are toxic, is also an important aspect. Manufacturing full electrolyser systems is possibly to take place in proximity to deployment due to the difficulties in shipping such large systems. However, raw materials, processed materials and components can be traded globally[210].

Deployment projects are experiencing delays due to the nascent nature of the market, unprecedented electrolysers' volumes and projects' economic and technical complexity, as well as the fact that key industrial off-takers delay investments due to current economic situation. **The deployment of large-scale projects that benefit from EU or state aid support due to high risks involved, should be monitored closely by the implementing parties to identify bottlenecks and address these with proportionate policy responses**. These projects should benefit from enhanced dissemination efforts, which will also guarantee efficient sharing of valuable knowledge and best industrial practices, leading to steeper learning curves in this still emerging industry. In this context, the IPCEI Forum is expected to be launched soon.

European manufacturing capacity building needs to be matched with proper recycling infrastructure. Additional research and investments will be needed in recycling including of the critical raw materials necessary for electrolysers manufacturing. **A new challenge will be to develop of substitute materials for membranes** that have comparable levels of durability and performance to the current state of art, usually based on per fluoroalkyl and polyfluoroalkyl substances. Research is needed to find satisfactory substitution solutions.

3.9 Sustainable biogas and biomethane technologies

Sustainable biogas and biomethane are important contributors for the EU to achieve energy autonomy and climate neutrality quickly and cost-effectively. The Commission proposed a biomethane action plan[211], under REPowerEU supported by the Bio-methane Industrial Partnership, with the aim to replace about 10% of natural gas a year with the

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209 European Hydrogen Alliance, *2nd European Electrolyser Summit State of play on the Joint Declaration*, 22 June 2023.

210 Carrara, S., et al, *Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study*, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/386650, JRC132889., document of the Joint Research Center, 132889.

211 SWD(2022) 230 final.

sustainable production of biomethane by 2030. The renewable and natural gases markets and EU's Hydrogen Regulation[212] will facilitate action to integrate biomethane into the EU's gas network.

The commercial technology to produce biogas or biomethane is anaerobic digestion, but efficiency to biomethane is low. Innovative technologies to produce biomethane as gasification of biomass residues and wastes, and biological methanation of biogas, are close to market readiness. Novel pathways based on both thermochemical and biological processes are currently under development too. The current trend to increase biomethane production is to build new plants and to convert the existing biogas plants producing combined heat and power to biomethane production plants.

The EU public R&I funding to biomethane production technologies in 2014-2021 totalled EUR 77 million[213], putting **the EU in the lead on high value inventions globally**. In 2010-2022, the EU led by far on scientific publications, with China ranking third in 2022.

In 2022, the **EU was the largest producer of biogas**[214], accounting for over 67% of global biogas production. Of this, 53% was produced in Germany, followed by North America with about 15%, while China is providing biogas incentives to increase its biogas production[215]. Many European companies are major market players in the manufacturing of biogas plant equipment and overall plant design and construction. The turnover of the EU biogas sector was EUR 5 530 million in 2021 with 60% in Germany and 12% in Italy, and 47 100 direct and indirect jobs[216].

Biogas feedstock is varied and locally sourced in Europe with no risk of imports dependency[217]. Recent policies shifted feedstock supply from an unsustainable mono-cropping system (e.g., maize) to biowastes and sustainable biomass sources. For instance, organic municipal solid waste will need to be collected separately by 2024,[218] which unlocks a huge potential. **The EU is leading in the technological development of the sector but will face challenges to upscale due to high capital and operational costs, cost-competitiveness with natural gas, and access to the gas grid**. Today, biomethane production costs[219] are EUR 40-120 per MWh; however, technology innovation, replication of first-of-a-kind innovative biomethane technologies and market incentives with EU support by stable regulation and investment framework, could help drive down production costs by 25-50%. This could boost the EU's competitiveness in the sector. Moving to residue and waste feedstock limits

[212] COM(2021) 804 final.

[213] H2020 Energy Societal Challenge and Horizon Europe Cluster 5 Energy. https://cordis.europa.eu/projects/en (europa.eu). Based on H2020 Energy Societal Challenge and Horizon Europe Cluster 5 Energy EC CORDIS data. Projects & results | CORDIS | European Commission (europa.eu).

[214] European Biogas Association, *Statistical Report*, 2022.

[215] Motola, V., Scarlat, N., Hurtig, O., Buffi, M., Georgakaki, A., Letout, S., Mountraki, A., Salvucci, R. and Schmitz, A., Clean Energy Technology Observatory: Bioenergy in the European Union - 2023 Status Report on Technology Development Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, JRC135079.

[216] Based on EurObserv-ER, Employment & Turnover, April 2023.

[217] Based on Eurostat data. Bioenergy Europe, *Statistical report*, 2022, *Bioenergy Landscape*. Only 4% of solid biomass is imported in the EU for bioenergy.

[218] OJ L 150, 14.6.2018.

[219] European Commission, Directorate-General for Mobility and Transport, Maniatis, K., Landälv, I., Heuvel, E. et al., *Building up the future, cost of biofuel*, 2018, https://data.europa.eu/doi/10.2832/163774.

availability but also reduces input costs. Current facilities are small to medium scale due to feedstock availability, logistics and cost. Biomethane upgrading of existing biogas installations requires a high investment cost of EUR 1-2 million[220] for small operators (farmers or SMEs), which means that business incentives are needed. Grid injection is not always possible as plants are built where feedstock is available and the gas grid is not well developed in all regions of the EU, necessitating supporting access to gas grid. Today, about half of all biomethane plants are connected to the natural gas grid[221].

The volume of combined biogas and biomethane production from anaerobic digestion in the EU in 2021 made up 4.4% of natural gas consumed i.e. 18.4 billion cubic metres (bcm)[222]. Of this volume, 3.5 bcm biomethane was produced in 1067 industrial plants from upgraded biogas and 14.9 bcm biogas was produced in 18843 anaerobic digestion industrial plants[223]. The EU is the largest producer of biomethane worldwide. At the end of 2020, there were 1 161 biogas upgrading facilities operating worldwide, with a production capacity of 6.7 billion cubic metres per year[224]. Reaching the 35 bcm REPowerEU target in 2030 would require both building new installations and upgrading electricity producing biogas plants to biomethane or around 5 000 smaller additional biomethane plants[225]. Potential production by 2050 could reach 165 bcm[226]. The production of bio-LNG for transport is growing rapidly in the EU with 15 plants in 2021 and 1.24 TWh/year capacity (0.12 bcm/year). The potential capacity by 2025 could reach 12.4 TWh/year in 104 plants[227].

Innovation in sustainable biomethane production and biogas upgrading technologies and components can increase production capacity, cost competitiveness and gas grid access. Assembling resilient biomethane value chains entails adapting an EU strategy of deploying decentralised and centralised production to local conditions of feedstock availability, resources, technology, costs, and social acceptance. **Strategic planning, uptake of the measures set out in EU policies** (such as infrastructures for separate collection and organic waste management) **and price signals resulting from potential binding biomethane production targets can facilitate deployment.** Continuous research and innovation support will also be important to secure domestic supply and increase domestic production over the longer term.

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220 Based on International Energy Agency (IEA) data. European Energy Innovation, [A new policy context for assessing biogas and biomethane (europeanenergyinnovation.eu)](), Autumn 2022

221 European Biogas Association, [Biomethane Map](), 2021.

222 Motola, V., Scarlat, N., Hurtig, O., Buffi, M., Georgakaki, A., Letout, S., Mountraki, A., Salvucci, R. and Schmitz, A., Clean Energy Technology Observatory: Bioenergy in the European Union - 2023 Status Report on Technology Development Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, JRC135079.

223 European Biogas Association, *Statistical report*, 2022.

224 Motola, V., Scarlat, N., Hurtig, O., Buffi, M., Georgakaki, A., Letout, S., Mountraki, A., Salvucci, R. and Schmitz, A., Clean Energy Technology Observatory: Bioenergy in the European Union - 2023 Status Report on Technology Development Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, JRC135079.

225 European Biogas Association, *Breaking Free of the Energy Dependency Trap–Delivering 35 bcm of biomethane by 2030*, 2022.

226 European Biogas Association, *Statistical report*, 2022.

227 European Biogas Association, *Statistical report*, 2022.

3.10 Carbon capture and storage (CCS)

The Commission scenarios towards climate neutrality by 2050 indicate that the EU will require capturing up to 477 million tonnes of CO_2[228]. Cement production, solid biomass and waste incineration plants will deliver the highest capacities for CO_2 capture.

The Commission already supports and regulates the deployment of CCS through an enabling legislative framework including the CCS Directive[229] and the ETS Directive[230]. The Commission also provides direct funding for projects, mainly through the Innovation Fund and Connecting Europe Facility. The Commission's proposal for a Net Zero Industry Act defines an EU objective of at least 50 million tonnes of CO_2 injection capacity per year by 2030 and would impose an obligation on EU oil and gas producers to contribute to achieving this objective. To support the emerging CO_2 value chain with a comprehensive long-term policy framework, the Commission published in 2021 a Communication on Sustainable Carbon Cycles[231], and in 2022 a proposal for a Regulation for a Union Certification Framework for carbon removals[232]. The Commission will also publish, in the first quarter of 2024, a Communication on an Industrial Carbon Management (ICM) Strategy, covering CCS, Carbon Capture and Use (CCU), and industrial carbon removals, which will be launched.

The CCS Directive implementation reports[233] submitted in 2023 show an increasing interest for CCS from market players across the EU. However, at this time, there is no homogeneous application of the Directive across all EU Member States, nor harmonized regulations for CO_2 transport and storage infrastructure. One of the goals of the ICM Strategy is to address this. The EU is relatively well positioned on CO_2 capture technologies, with a number of companies supplying different capture technologies (pre- and post-combustion and oxy-fuel) on commercial terms. However, there is currently no deployment at scale. The cost of CCS varies significantly depending on site-specific factors, technology developments, access to finance, economies of scale through shared infrastructure, and varies by the sector and technology. Overall, the **costs of the technology are still considerable**. Indicative unit costs in EUR/ton CO_2 range between 28-55 for capture, 4-11 for transport, and 8-30 for storage[234].

From a research perspective, the EU is well positioned on the global market. In 2021, public R&I investments in CCS and CCU reached around EUR 170 million, once again an increase on the previous year.

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[228] Itul, A., Diaz Rincon, A., Eulaerts, O.D., Georgakaki, A., Grabowska, M., Kapetaki, Z., Ince, E., Letout, S., Kuokkanen, A., Mountraki, A., Shtjefni, D. and Jaxa-Rozen, M., Clean Energy Technology Observatory: Carbon capture storage and utilisation in the European Union - 2023 Status Report on Technology Development Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, JRC134999.

[229] OJ L 140, 5.6.2009.

[230] OJ L 275, 25.10.2003.

[231] COM(2021) 800 final.

[232] COM(2022)672.

[233] Every 4 years, Member States report to the Commission on the implementation of the CCS Directive 2009/31/EC. Three such reports have been published until now by the Commission, with the publication of the 4th Implementation Report being planned for the end of 2023.

[234] EnTEC (Trinomics, TNO and Fraunhofer Institute ISI), Bolscher, H. et al., *EU regulation for the development of the market for CO2 transport and storage*, European Union, 2023. https://energy.ec.europa.eu/publications/eu-regulation-development-market-co2-transport-and-storage_en

When developing full industrial carbon management value chains, the EU lags behind other economies such as the US and Canada[235]. According to the Global CCS Institute, as of September 2022, there are 196 CCS facilities in the pipeline worldwide, of which 73 are in Europe[236]. As of the end of July 2023, there are not yet any operating CO_2 storage projects in the EU, and business models are still in their infancy. There are a number of projects capturing CO_2 and using it in industry and agriculture, but the volume of CO_2 is limited.

Demand and supply of materials required in the CCS and CCU value chains is a field in need of further study. However, overall, CCS is less exposed to critical raw material risks than other technologies. In 2022, the global CCS market was worth USD 6.4 billion (EUR 6 billion[237]). The US had the highest revenue in this value chain, reaching EUR 1 945 billion in 2021, in large part due to the use of CO_2 injections underground for enhanced hydrocarbon recovery. By comparison, Europe had a total revenue of EUR 92 million[238].

Market research identified 186 key companies worldwide with CCS operations[239]. Of these, 24% of the key players are European or are active in this sector through European subsidiaries. **The EU has several players in the oil and gas sector with long histories of building pipelines, drilling wells and having significant geological competence, which will be useful when developing infrastructure projects for CCS**. Information collected from CCS Directive implementation reports shows increasing interest from potential infrastructure providers, especially for storage: in total, seven exploration permits and two storage permits have been issued, with more than 10 storage permit applications being announced by 2028. Alongside oil and gas companies, new players are emerging, specialising in different parts of the CCS value chain. For instance, shipping companies are expanding into CO_2-shipping, and suppliers within engineering are developing capture solutions for third-party emitters.

CCS is a range of mature, proven and readily available technologies. However, CCS is still very costly and many uncertainties still exist. CCS needs to be deployed at scale to help reach climate neutrality by 2050. Continued research and innovation is still needed to improve the available technologies or develop new innovative solutions. **The key barriers that have been hindering the rollout of CCS are the high up-front investment and operating costs, the fragmented regulatory framework, the complexity of full chain infrastructure projects,**

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[235] Itul, A., Diaz Rincon, A., Eulaerts, O.D., Georgakaki, A., Grabowska, M., Kapetaki, Z., Ince, E., Letout, S., Kuokkanen, A., Mountraki, A., Shtjefni, D. and Jaxa-Rozen, M., Clean Energy Technology Observatory: Carbon capture storage and utilisation in the European Union - 2023 Status Report on Technology Development Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, JRC134999.

[236] Global CCS Institute, *Global Status of Carbon Capture and storage, 2022*, 2022.

[237] Using the average exchange rate of EUR 0.9497 for USD 1 over the year 2022. See: https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html

[238] Itul, A., Diaz Rincon, A., Eulaerts, O.D., Georgakaki, A., Grabowska, M., Kapetaki, Z., Ince, E., Letout, S., Kuokkanen, A., Mountraki, A., Shtjefni, D. and Jaxa-Rozen, M., Clean Energy Technology Observatory: Carbon capture storage and utilisation in the European Union - 2023 Status Report on Technology Development Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, JRC134999.

[239] There is limited available data on the number of companies involved in the CCUS supply chain in Europe. In addition, the majority of the companies have not announced the value of the projects they are involved in. Along with this, the companies are involved in a wide range of stages across the overall value chain, so it is challenging to derive a market share at this instance. Depending on the boundaries set for the value chain, other research suggests about 17 000 companies involved in all aspects of the CCUS supply chain including technology providers, services, legal aspects. European Commission, Kapetaki, Z. et al, *Carbon Capture Utilisation and Storage in the European Union. 2022 Status Report on Technology Development Trends, Value Chains and Markets*. 2022. https://publications.jrc.ec.europa.eu/repository/handle/JRC13066

as well as public awareness. With the Innovation Fund, the Commission already supports the annual capture of more than 10 million tonnes of CO_2 from 2026 onwards, with financial support for selected projects totalling more than EUR 2.5bn. This shows that **public funding – both at EU and national level – will be needed to attract private capital. Furthermore, proposing business models for this emerging market will also be essential.**

3.11 Grid technologies: the example of high voltage direct current systems

Developing energy infrastructure is crucial to integrate renewable electricity generation in the power grid, to enhance the security of supply through cross-border interconnections, to improve access to affordable energy, and to electrify industry and end uses, such as heating and cooling, and mobility. The EU's offshore renewable energy strategy and the TEN-E Regulation[240] call for action to coordinate long-term planning and development of offshore and onshore electricity grids to meet the complex requirements of engineering efficiency, economic viability and environmental sustainability.

A specific challenge for transmission grid development arises from the need to transport electricity over long distances with minimal losses. For example, to link distant renewable power generation hubs (e.g. offshore wind farms) with consumers (e.g. cities and industries), to develop interconnections between neighbouring countries or to so both (e.g. via hybrid interconnections). High voltage direct current (HVDC) systems are becoming a fundamental enabling technology to meet this challenge[241].

HVDC systems (today, mainly composed of converter stations and point-to-point cables) have been proven at industrial scale in operational environments. There is, however, a growing need to move away from vendor-specific technology design and operation concept to multi-terminal, multi-vendor technology with grid forming capabilities[242]. This should allow for better grid observability and control, data accessibility and new energy services. Achieving this requires multi-vendor cooperation frameworks, such as the EU-funded InterOpera project, which seeks to develop a modular and interoperable HVDC control and protection system[243]. HVDC cable technology also continues to evolve, as 525 kV voltage levels are now available for land and offshore applications and higher voltage levels should become available in the future.

Worldwide installed HVDC capacity has tripled since 2010, reaching a total 100 000 km in length and 350 GW in total capacity at the end of 2021[244]. As of 2022, HVDC capacity in Europe amounted to around 43 GW, with an additional 63 GW coming from 51 new projects (mostly at the planning and permitting stage)[245]. Europacable estimates that over the next ten years somewhere between 10 000 and 14 000 km of new HVDC land cables would be laid in

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240 OJ L 152, 3.6.2022.

241 Thanks to higher capacity and lower losses over long distances compared with their alternate current (AC) equivalents, they can efficiently strengthen the interconnectivity of the energy system by linking distant power networks with different frequencies or facilitating the interconnection of large offshore wind plants.

242 WindEurope Intelligence Platform, Workstream for the development of multi-vendor HVDC systems (ENTSO-E, T&D Europe, WindEurope), 21 June 2021.

243 The 'Enabling interoperability of multi-vendor HVDC grids' (InterOPERA) project brings together European TSOs, manufacturers, sector associations and universities to define compatibility and interoperability standards for HVDC. For more information: https://interopera.eu.

244 International Energy Agency (IEA), *Energy Technology Perspectives*, 2023.

245 Power Technology Research (2023, March). IoT innovation: Leading companies in HVDC transmission systems for the power industry. Retrieved from Power Technology: https://www.power-technology.com/data-insights/innovators-hvdc-transmission-systems-power/

Europe[246], significantly more than for new AC assets. New HVDC submarine installations could be even more substantial (between 39 000 and 58 000 km).

The energy transition in Europe and globally is expected to continue driving HVDC deployment and markets. The value of the global HVDC market was estimated at between USD 9 billion and USD 17 billion in 2021 (between EUR 7.6 billion and EUR 14 billion[247]), with potential to grow at a compound annual growth rate of 7.1% to 10.6% over the next 10 years.[248]

The global HVDC converter station market is dominated by six major vendors: Hitachi Energy (formerly ABB) in Switzerland/ Sweden (the market leader), followed by Siemens (Germany) and General Electric (United States), Mitsubishi Electric (Japan), NR Electric & C-EPRI Electric Power Engineering (China) and Bharat Heavy Electricals Limited (India). Except for Hitachi Energy, most convertor station manufacturers procure high-power semiconductors (a key component of converter valves) from external suppliers. This currently represents a relevant risk factor, since production is concentrated in Taiwan Semiconductor Manufacturing (TSMC) [249]. As for HVDC cable manufacturing, the EU is home to some of the world's leading cable makers, including NKT in Denmark, Nexans in France, Südkabel in Germany, Prysmian Group in Italy, Hellenic Cables in Greece, Tele-Fonika/ JDR in Poland and the UK. The main international competitors include Sumitomo in Japan, NBO and ZTT in China and LS Cable in the Republic of Korea.

According to the IEA[250], procurement lead times for converter stations are typically around two to three years. However, the complete delivery of HVDC transmission projects (including planning, permitting, procurement and transportation, installation, final commissioning, and energisation) needs significantly more time, and can take as long as ten years[251]). Strong growth in global demand can stretch these lead times even longer, as developers in all parts of the world compete to secure supply from a limited number of vendors. Project size and smooth permitting are major factors when securing deals (which can become a tough challenge to overcome for relatively small European TSOs).

Upgrading the electricity grid is a major enabling factor for the clean energy transition. Europe has been an attractive market for HVDC project developers and technology providers, mostly thanks to its first-mover status in offshore wind deployment and integration of renewable generation. However, with growing global demand for HVDC converters and cables, **there is an increasing risk that the European market gets undersupplied**, ultimately leading to delays on the decarbonisation timeline. **Fragmentation in the EU market** (with different national standards and many subnational system operators) **could make European demand lose out in international competition for contracts**. Some European TSOs already

[246] A conservative estimate based on the analysis of the ENTSO-E's 2022 Ten-Year Network Development Plan and EU Member States National Development Plans (but without considering latest EU Member State pledges for offshore wind generation).

[247] Using the average exchange rate of EUR 0.8455 for USD 1 over the year 2021. See: https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html

[248] Power Technology Research.

[249] U.S. Department of Energy, *Semiconductors - Supply Chain Deep Dive Assessment*, 2022.

[250] International Energy Agency (IEA), *Energy Technology Perspectives*, 2023.

[251] Europacable, *Electricity transmission of tomorrow*, 2021. Estimates suggest than an average transmission project takes 15 years from planning to competition.

claim to have difficulties winning contracts at favourable terms and timeframes. By contrast, technology and equipment manufacturers may be hesitant to increase capacity in the absence of clear long-term (aggregate) demand signals, due to substantial investment requirements. **Closer cooperation is needed among policy makers, network planners and system operators, as well as industry, at all EU levels, to build robust supply chains able to meet the development needs of the network**. To this end, it is important to support and accelerate the harmonisation and standardisation of HVDC components to encourage EU suppliers to invest in production capacity. Bringing streamlined procurement procedures and voluntary demand pooling for EU buyers could tackle the main supply chain issues and facilitate the acquisition of manufacturer production slots. Lastly, **to maintain and extend the EU's technological lead in this sector, it is important to invest in innovation** (e.g. in HVDC grid-forming capabilities), **to run 'regulatory sandboxes' and to ease access to EU funding for demonstrators and innovative projects.**

4. CONCLUSION

In response to the disruption of the world's energy system - caused by the COVID-19 pandemic first and exacerbated by the Russia's unprovoked and unjustified military aggression against Ukraine – the **EU has accelerated its clean energy transition** and swiftly put forward a package of measures to protect citizens and businesses. Boosting the use of renewable energies, reducing energy use, and diversifying energy supply chains are at the core of the EU's response.

As a result, and given the record energy prices, **net-zero technologies have never been so competitive compared to fossil fuel and their market share has shot up**. In 2022, new wind and solar energy capacity installed in the EU substantially increased compared to 2021. This trend is expected to continue as Member States have increased their renewable energy and energy efficiency targets for 2030 and supported by the Fit-for-55 package. Other major economies are following suit. The IEA estimates that the global market for key mass-manufactured net-zero technologies is set to triple by 2030, with related energy manufacturing jobs expected to double in the same time period.

However, in the global race to net-zero, **EU manufacturers are falling behind, and this could undermine our economic security**. All-time high energy prices, high interest rates, skill shortages, supply chain disruptions, and strong competition from other regions have challenged the EU industry like never before, including in sectors where the EU used to hold a strong position. The EU **wind energy sector**'s market share fell from 58% in 2017 to 30% in 2022, in particular due to the rapid growth of wind deployment in China. The EU's trade balance deficit for individual **heat pumps** more than doubled between 2021 and 2022. Furthermore, **solar PV** prices reached a record low in September 2023 due to intense competition and oversupply of components across the whole value chain, making it more difficult for EU manufacturers to produce profitably. While Europe's share in global investment in **lithium battery production** capacity fell from 41% in 2021 to 2% in 2022, battery factories are being built with increasing speed across Europe and are projected to meet most of EU demand by 2030.

Therefore, **while maintaining its efforts to bring energy prices down, the EU must also simplify its regulatory framework** to make it easier and faster to expand its manufacturing base of net-zero technologies and to attract more investment into the EU.

In parallel, **the EU should continue action to reduce its dependency on imports and effectively diversify its sourcing of components and raw materials**. For most net-zero technologies, the EU depends on China in at least one stage of the value chains.

The EU also needs to raise the skills of its workforce. Despite the positive trend in the employment rate of the EU's clean energy sector, the skills gaps and shortages seen since 2021 are curbing the growth in the clean energy sector growth and may be further protracted due to demographic trends. The EU budget as well as cross-sectoral policy initiatives and several specific measures put forward by the EU are instrumental to accelerate skills development in the green transition, and in the clean energy sector in particular.

In terms of R&I investments, Horizon 2020 and Horizon Europe have provided a vital boost to national public sector investments since 2020. While the EU maintains its strong position in internationally protected patents, increased efforts in the coordinated use of the EU and national programmes and clear definition of national R&I targets for both 2023 and 2050 are instrumental to chart a successful R&I path.

Ensuring access to finance to develop the domestic clean energy technology manufacturing capacity is key to developing value chains in the EU. This includes funding to turn innovation into industrial production. In particular, the EU must ensure that capital keeps flowing to EU innovative start-ups. This requires further efforts to deepen the Union's capital markets.

The EU must also foster clean technology cooperation with its partners abroad, in an open but assertive way. Trade openness and international partnerships will not only help strengthen the competitiveness of the EU by securing more diversified supply chains for the green transition but also open new market opportunities and help all economies meet the aims of the Paris Agreement.

In addition, **the EU must keep pulling demand for net-zero technologies that are both sustainable and resilient** in order to meet its decarbonisation goal while boosting competitiveness and the security of energy supply.

Lastly, **measures to tackle the specific issues faced by certain sectors**, like the wind industry are needed. Looking at the broader economy, **the EU needs to maintain support for its industry throughout the clean energy transition**. This also requires a targeted approach for each industrial ecosystem. To this end, the President of the European Commission announced in her State of the Union address on 13 September 2023 a series of Clean Transition Dialogues to be held with industry. The EU competitiveness is essential for the EU strategic autonomy, and it is crucial to assess how to remain competitive while undertaking the clean transition. This is why the President of the European Commission asked Mario Draghi to prepare a report on the future of European competitiveness.

The future of our clean tech industry must be made in Europe. Therefore**, the Commission calls on the Council and the European Parliament to take note of this competitiveness progress report and to accelerate the adoption of the legislative files that will support the net-zero industry**, notably the Net-Zero Industry Act and the Critical Raw Materials Act.