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The Net-Zero manufacturing industry landscape across Member States

Final Report

Directorate-General for Energy

Rotterdam & Brussels, 05 December 2024

The Net-Zero manufacturing industry landscape across Member States

Final Report

DG ENER Unit TF2 - Relations with the Member States and the Energy Community
Rotterdam & Brussels, 05 December 2024

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Table of Contents

List of figures

List of tables

List of Boxes

Acronyms

Acronym	Description
ACA	Accelerated Capital Allowance
ARERA	Regulatory Authority for Energy, Networks, and the Environment
BIP	Biomethane Industrial Partnership
BoP	Balance of Plant
CAPEX	Capital Expenditure
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon capture and storage
CCUS	Carbon capture, utilisation and storage
CEPII	Centre d'Etudes Prospectives et d'Informations Internationales's
CETO	Clean Energy Technology Observatory
CN	Combined Nomenclature
CRMs	Critical Raw Materials
CSP	Concentrated Solar Power
CSR	Country Specific Recommendations
EBA	European Biogas Association
EBRD	European Bank for Reconstruction and Development
EIB	European Investment Bank
EEA	European Economic Area
ENTSO-E	European Network of Transmission System Operators for Electricity
ESF	European Social Fund
ESMC	European Solar Manufacturing Council
EU	European Union
EVs	Electric vehicles
GHG	Greenhouse gas
GPP	Green Public Procurement
GW	Gigawatt
HgO	Mercury oxide
HHI	Herfindahl–Hirschman index
HS	Harmonised System
IEA	International Energy Agency
IPCEI	Important Projects of Common European Interest
IRA	Inflation Reduction Act
IRENA	International Renewable Energy Agency
JRC	Joint Research Council
LFP	Lithium iron phosphate
MS	Member States
NZIA	Net-Zero Industry Act
OECD	Organisation for Economic Co-operation and Development

Acronym	Description
OSS	one-stop shops
PFAS	per- and polyfluoroalkyl substances
PRODCOM	PRODuction COMmunautaire
PTC	Manufacturing Production Tax Credit
PV	Photovoltaics
R&D	Research and Development
RCA	Revealed comparative advantage
RED III	Renewable Energy Directive
RFB	redox-flow batteries
RFF	Recovery and Resilience Facility
RFNBO	Renewable fuels of non-biological origin
RRP	Recovery and Resilience Plans
RTO	research and technology organisations
SWD	Staff Working Document
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TCTF	Temporary Crisis and Transition Framework
TESSD	Trade and Environmental Sustainability Structured Discussions
US	United States
VET	Vocational Education and Training
WTO	World Trade Organization

1 Introduction and overview of the study

1.1 Objectives

The overarching objective of the study was to assess the state of play and recent developments in key Net-Zero technology manufacturing industries in the EU Member States and support the Commission's work for the preparation of the European Semester, the Progress Report on Competitiveness of Clean Energy Technologies and more broadly, the implementation of the Net Zero Industry Act (NZIA).

The overarching objective is further broken down into the following specific objectives:

- Objective 1: Map the Net-Zero industrial landscape at the Member State level, including Member States´ positioning and approach to Net-Zero technology manufacturing, as well as policies and respective policy frameworks in support of the Net-Zero industries.
- Objective 2: Identify, for each Member State, the main drivers, opportunities, and barriers to Net-Zero industries manufacturing. This aims to provide the evidence base supporting the Country Specific Recommendations in the context of the European Semester 2025 cycle.
- Objective 3: Support the annual monitoring exercise in the context of the Competitiveness Progress Report of Clean Energy Technologies.

1.2 Scope

Following the initial project discussions, and after careful evaluation of the project's timeline and schedule, the original technological scope was maintained, as agreed with DG ENER and shown below.

Table 1.1 Technological scope

Technology category	Definition
Solar photovoltaic and solar thermal	Solar PV refers to technologies that directly convert sunlight into electricity using solar cells. Solar thermal refers to technologies that convert sunlight directly into heat.
Onshore wind and offshore renewables	Onshore wind and offshore renewable technologies refer to wind, wave, and tide, as well as other ocean energy technologies.
Batteries and storage technologies	Batteries are defined by Regulation 2023/1542 as devices delivering electrical energy generated by direct conversion of chemical energy, having internal or external storage, and consisting of one or more non-rechargeable or rechargeable battery cells, modules, or packs of them. They include electric vehicle batteries which are specifically designed to provide electric power for traction and stationary battery energy storage systems which are industrial batteries with internal storage that are specifically designed to store and deliver electric energy to the grid, or end-users.
Heat Pumps and geothermal energy technologies	Heat Pumps are defined by Directive 2010/31/EU as a machine, device, or installation that transfers heat from natural surroundings such as air, and water, or ground to buildings, or industrial applications by reversing the natural flow of heat such that it flows from a lower to a higher temperature.

Technology category	Definition
	Geothermal energy technologies refer to methods and systems used to harness the heat stored beneath the Earth's surface.
Electrolysers and fuel cells	Electrolysers are technologies that perform electrolysis, a process that uses electricity to split water into hydrogen and oxygen. Fuel cells are technologies that generate electricity through an electrochemical process, often described as reversed electrolysis, involving hydrogen and oxygen atoms.
Sustainable biogas/biomethane technologies	Sustainable biogas technologies include methods such as anaerobic digestion of agri-residues or organic wastes, manure, or crops in agricultural or industrial biogas plants, and landfill gas recovery. Sustainable biomethane technologies involve techniques such as CO_2 separation from the biogas stream or gasification followed by methanation.
Carbon Capture and Storage technologies	Carbon Capture and Storage technologies refer to technologies that aim to capture, transport, and permanently store CO_2.
Grid technologies	Grid technologies aim to match the supply and demand of electricity. In the context of Net-Zero technologies, these refer to a combination of physical and digital technologies, including switch-gears and high-voltage cables for the transmission and distribution of electricity, but also sensors and software, used in smart grids and electricity meters.

The following chapters present the comprehensive results of each task.

- Chapter 2 details the mapping exercise, offering in-depth information on the manufacturing capacities of Member States for various technologies.
- Chapter 3 provides an analysis of the regulatory frameworks within Member States.
- Chapter 4 explores the opportunities, bottlenecks, and barriers through a comprehensive SWOT analysis.
- Finally, Chapter 5 offers targeted recommendations based on the findings from the previous tasks.

2 Mapping the Manufacturing Landscape of Member States' Strategic Net-Zero technologies

2.1 Overall findings: overview of the EU and global manufacturing landscape

The European Union (EU) has established itself as a leader and competitive force in several key Net-Zero technologies. In the wind energy sector, despite growing competition from China, EU companies continue to play a dominant role in the global market. The EU also remains a leader in the heat pump industry. EU producers account for over 20 percent of the global market, driven by local demand for energy-efficient heating solutions.[1] European high-voltage AC and DC (HVAC and HVDC) cable manufacturers are also global market leaders relying on several production sites across the EU. Cable manufacturing is essential for several Net-Zero technologies, enabling the grid transmission and distribution of electricity from renewable sources such as wind and solar. In the field of Carbon Capture and Storage (CCS), Europe is at the forefront of research and development (R&D), but it is too early to map the EU's manufacturing position. Europe's biogas production capabilities are also growing.

There are critical technologies, however, where the EU remains reliant on third-country providers. This dependency is particularly evident in the solar photovoltaic (PV) industry—where the EU's footprint has weakened—and for lithium-ion batteries, where the continent depends substantially on technology and imports from China and other global leaders.

The European manufacturing landscape is set for significant growth across several key technologies, each following unique trajectories influenced by global developments:

- The EU solar PV industry is currently undergoing restructuring due to intense import competition from China. China's leadership is driven by a combination of scale economies, lower costs for energy and materials and, to a lesser extent, lower labour costs and higher government subsidies. Although Europe is expected to double its capacity based on announced projects, China is likely to continue to dominate global manufacturing.[2] Germany remains the EU's most important producer, followed by Italy, France, Austria, and Spain.
- European wind energy manufacturing capacity is projected to grow modestly by around 10%, a stark contrast to China's substantial expansion, which is expected to reach 60-80% of global capacity in the medium term.[3] This poses a risk to Europe's competitive advantage in this sector. In the EU, manufacturing is concentrated in a few EU countries with Germany and Denmark hosting major wind turbine manufacturers, and Spain being a large producer, especially in tower capacity (around 50% of EU total). France, Portugal, Italy and Poland also contribute with smaller shares of capacity.
- The European battery market is evolving rapidly, driven by increased industrial production and the opening of gigafactories. Starting from a base of 150-260 GWh in 2023, Europe is expected to add 150-250 GWh in

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1 IEA (2024), *Advancing Clean Technology Manufacturing*, IEA, Paris https://www.iea.org/reports/advancing-clean-technology-manufacturing, Figure 2.8.

2 Solar PV Global Supply Chains – Analysis - IEA

3 IEA (2024), *Advancing Clean Technology Manufacturing*, IEA, Paris https://www.iea.org/reports/advancing-clean-technology-manufacturing, Figure 11; https://www.iea.org/energy-system/renewables/wind retrieved on 9 October 2024.

2024 and 2025, with projections exceeding an additional 500–1000 GWh based on current announcements. Globally, capacity expansions in the EU and the US are expected to reduce Chinese dominance, with both European and American industrial production shares rising from around 5% to 15% of the global market by 2030.[4] At the same time, however, the recent slowdown in electric vehicle (EV) sales across the continent might affect the outlook.[5] Germany, Poland and Hungary hold the largest shares of manufacturing capacities in batteries with France and Sweden also producing on a large scale. Central and Eastern European countries such as Slovakia, Czechia, and Austria, as well as Greece, are emerging as significant production hubs.

- Heat pump production in Europe is expected to see substantial growth, potentially increasing the region's share of the global market. Countries with strong domestic markets, such as Germany, Sweden, and Denmark, are key locations for heat pump manufacturing. However, uncertainties remain regarding the pace and extent of this growth. There have been frequent announcements of manufacturing capacity expansions across Europe but the overall outlook of the sector is influenced by a combination of economic factors. The heat pump sector is facing challenges related to reduced demand and slower deployment, driven, in turn, by higher interest rates, inflation, and installation bottlenecks. According to the IEA[6], these factors are limiting the growth of new capacity, with the slowdown being particularly acute in the EU, the US, and Japan.
- Europe anticipates solid growth in the electrolyser market and capacity is expected to increase from 5.4 GW to 25. GW per year by 2030, reflecting strong investment in hydrogen technologies. The EU's electrolyser manufacturing capacity is projected to meet 14-25% of the total global operational capacity, though the outlook remains uncertain, as only a small proportion of announced projects have received final investment decisions.[7] More than half of the European electrolyser manufacturing is located in Germany, with Denmark, Belgium, Portugal, Italy, Spain and France providing the remaining capacity.
- There is significant growth in grid infrastructure driven by modernisation efforts, which include the integration of renewable energy sources, advanced metering infrastructure, energy storage systems, and the growing demand for electricity linked to the diffusion of EVs and heat pumps. Europe’s industrial production capacities are concentrated in countries such as Italy, which leads in cable production, followed by Sweden and Germany, with substantial contributions from France, Poland, Denmark, Belgium and Croatia. Additionally, countries with advanced grid infrastructure and a strong focus on renewable energy integration, such as Germany, Denmark, and Sweden, host significant manufacturing facilities for smart meters, grid automation equipment, and energy management systems.
- The CCS value chain in Europe is still under development with large-scale industrial production facilities yet to be established. These are expected to be located near production sites in industries familiar with oil and gas production, where proximity to deployment sites can offer a strategic advantage.
- Europe plays a leading role in the global production of biogas and biomethane, driven by the EU's ambitious renewable energy targets and the region's strong focus on sustainable waste management. Biogas production equipment, including anaerobic digesters and biogas upgrading systems, is manufactured by various companies across the EU. Germany and Italy are significant hubs for biogas technology manufacturing, while Czechia, Poland, and Spain also are large players in various industrial components.
- Germany, France, and Italy are international leaders in geothermal technology, with industrial production of key geothermal components concentrated in large industrial hubs within these countries. These components

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4 IEA Advancing Clean Technology Manufacturing An Energy Technology Perspectives Special Report
5 See, for instance, here.
6 Clean Energy Market Monitor – March 2024 – Analysis - IEA
7 IEA Advancing Clean Technology Manufacturing An Energy Technology Perspectives Special Report

include drilling equipment, heat exchangers, and power generation systems, which are crucial for the development and operation of geothermal plants as well as other types of thermal plants.

- Europe is a key player in the global solar thermal energy market. Germany leads in the manufacturing of solar thermal water heaters, contributing significantly to both domestic and international markets. Industrial production of components essential for solar thermal energy systems, such as collectors, pumps, and storage tanks, is spread across various European countries, including Spain, Italy, and Austria.

The findings presented in this chapter are based on a combination of data collection and analysis, desk research, and stakeholder consultations. Data was gathered in four key areas: the first area is industrial production. Industrial production refers to the total annual output of selected components and end-use products within each clean technology's value chain. It is expressed in monetary terms. The figures reported here are based on a selection of relevant components and end-use products. The selection is reported in Annex I.

We used Eurostat's PRODCOM database to collect detailed product-level information on manufacturing production across Europe, mapping industrial production in each EU Member State and Net-Zero technology.

Additionally, data was collected on deployment[8], covering both existing and announced projects and facilities.

Manufacturing capacity data was collected at the company level and then aggregated at the Member State level, sourced from various publicly available sources, complemented by proprietary databases including BloombergNEF and S&P Global Commodity Insights. Manufacturing capacity refers to the annual maximum theoretical output of facilities that produce clean energy technologies. It is expressed either in energy generation capacity (megawatt) or energy storage capacity (megawatt hour). Manufacturing capacity data is available for solar and wind power, batteries, and electrolysers. The fourth data source pertains to international trade, which was collected to assess each EU Member State's international position and dependencies. Annex X provides an overview of the methodology supporting our findings.

2.2 The EU manufacturing landscape across technologies and Member States

In this section, we report findings at both the technology and EU Member State levels. Findings are organised by technology. Detailed results for each Member State are available in the Country Factsheets that accompany this report. Annex X provides an overview of the methodological choices supporting this chapter of the report and the Country Factsheets. For each technology, this section outlines the relevant components of the value chain; presents an overview of the distribution of European industrial production, and, where available, provides a detailed view of the manufacturing capacity landscape, including forecasted capacity and insights from trade data.

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8 We use a range of data sources to analyse the deployment of Net-Zero technologies. This includes the installed capacity of renewable energy sources, such as wind farms, solar PV installations, and geothermal energy production. Additionally, we consider total battery storage capacity, operational hydrogen production, and the capacity of carbon capture facilities. Table A9 presents a full overview.

2.2.1 Solar PV and solar thermal technologies

When it comes to the solar PV industry, the main manufacturing segments and components include polysilicon, ingots and wafers, cells, and modules.[9, 10] Modules are then assembled into panels. Polysilicon is the purified version of silicon, which has been included in the EU's list of critical raw materials (CRMs) since 2014.[11] It is excluded from the scope of this study.[12]

All these manufacturing segments and components in the solar PV industry require specialised machinery. The production of ingots requires casting and grinding machines to pull polysilicon, which is grounded into the required size.[13] Wafering requires machinery such as diamond-wired saws - which are used to cut the ingots into wafers - and laser technology to produce semiconductor wafers. Other processes here include texturing, chemical vapour deposition, welding, and screen printing - all of which require specialised industrial machines.[14] In addition, the assembly of solar cells and panels require several additional components, including high-transparency solar glass and optical components. Finally, connecting PV modules to the grid requires a balance of system electrical components, including inverters and converters.[15]

Concerning solar thermal energy, we focus on two groups of products and components: those used in solar thermal heating, such as water heaters[16], and components that are used for the deployment and functioning of concentrated solar power (CSP) systems. These include integrated electronic circuits that are part of the control units in CSP systems, providing management and monitoring of the CSP power station. Additionally, we include components that are used to connect solar energy - both arising from PV and CSP systems - to the grid, such as converters and inverters.[17]

As of the latest available year (2022), industrial production of PV generators, modules, and cells in EU Member States amounted to EUR 1.8 billion.[18] Germany is the EU's leading producer, accounting for 31% of all industrial production of PV in the EU.[19] This is complemented by substantial industrial production in Italy (14% of industrial

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9 IEA, 2022. Special Report on Solar PV Global Supply Chains. Paris: International Energy Agency (IEA). Available at the following link.

10 It is worth noting that the EU also retains manufacturing capabilities in the buildings-integrated PV industry (BIPV). BIPV systems are designed to serve dual purposes: generating electricity and acting as a construction material. BIPV is considered a niche market. See López Pinto, G., Özaras, F., Andersson, J., Sandén, B., Oller Westerberg, A., & Lindahl, J. 2023. Shining Light on European BIPV: A Survey of Dependence and Fragmentation in the Emerging European Value Chain for Building Integrated Photovoltaics. *Manuscript for the 40th European Photovoltaic Solar Energy Conference and Exhibition*.

11 See the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions On the Review of the List of Critical Raw Materials for the EU and the Implementation of the Raw Materials Initiative, COM/2014/0297. Available at the following link.

12 However, since the EU manufacturing capacities in polysilicon—owing, in particular, to German sector leader *Wacker Chemie*—we do refer to polysilicon in the Country Factsheets.

13 Casting machinery is used across different industries and not just in wafering processes, so we would suggest not to collect data on these machines.

14 For an overview of the machinery and associated CN product codes that are deemed critical for solar PV manufacturing, see Appendix L ("Proposed Exclusions for Certain Solar Manufacturing Equipment", starting on page 191) in the May 2024 report by the Office of the US Trade Representative, "Four-Year Review of Actions Taken in the Section 301 Investigation: China's Acts, Policies, and Practices Related to Technology Transfer, Intellectual Property, and Innovation". The report is available at the following link. The relevant codes are also reported in Annex I of this report.

15 Reinders, A., Verlinden, P., Van Sark, W., and Freundlich, A. 2017. PV Solar Energy: From Fundamentals to Applications. John Wiley & Sons.

16 JRC CETO. 2023. Concentrated Solar Power and Solar Heating and Cooling in the EU. Status Report on Technology Development, Trends, Value Chains, and Markets. Available at the following link.

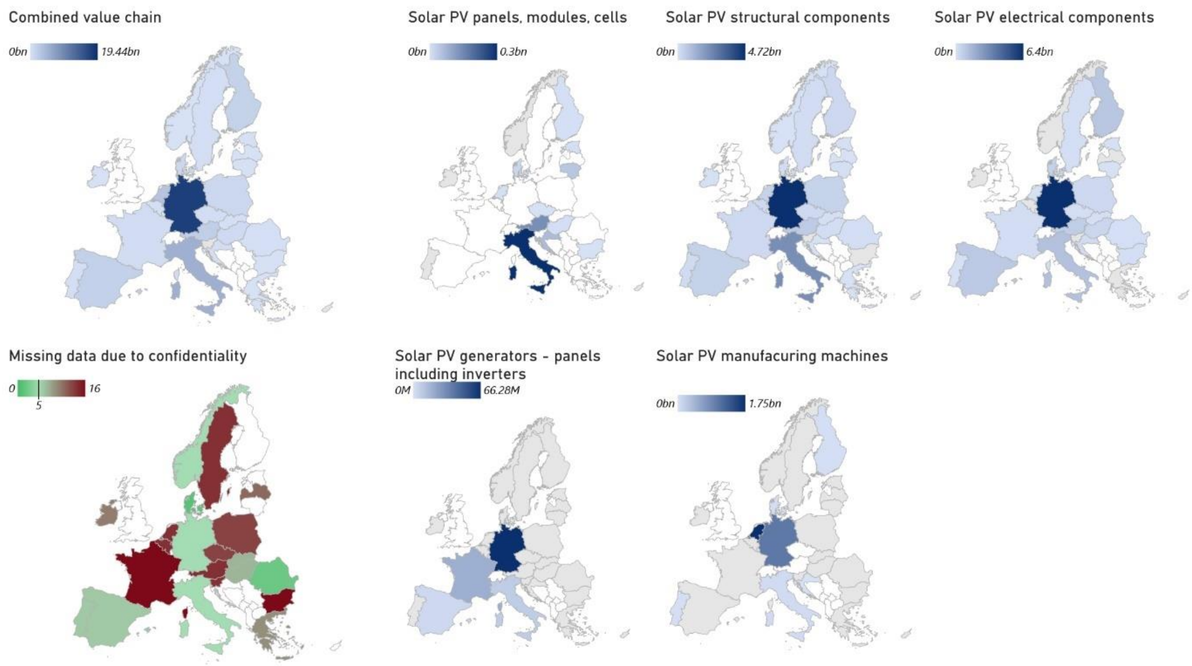
17 WEF. 2022. Accelerating Decarbonisation through Trade in Climate Goods and Services. *Insights report*. World Economic Forum. Available at the following link.

18 Solar cells are defined as silicon photovoltaic cells which convert sunlight directly into electric energy. They are assembled in modules. In addition, photovoltaic generators consist of panels of photocells combined with any other apparatus, for example storage batteries or electronic controls (voltage regulator, inverter, etc.). A separate code for PV generators has only been added to PRODCOM, the CN, and HS in 2022.

19 Germany is also considered an international leader in polysilicon production owing to the presence of *Wacker.*

production), Spain (2%), France, and Austria.[20] Additionally, data is also available on industrial production of electric components. Here, the EU retains strong manufacturing capabilities in the production of inverters, converters and rectifiers (grouped as "Solar PV electrical components" in the Figure below), with industrial production active in countries such as Germany, Austria, Italy, and Spain.[21] According to the industry stakeholders consulted, the manufacturing of inverters is currently the only segment of the PV value chain where the EU retains both manufacturing capacity and a degree of technological leadership, particularly in terms of safety and reliability, relative to Chinese producers.[22]

Figure 2.1 Distribution of production: solar PV



Note: The visual illustrates the industrial production value in euros for the year 2022. Each map depicts a grouping of relevant components or end-use products identified during the research. An overview of included components and products is provided in Annex I, Table A 3. Source: PRODCOM. White areas indicate unavailable data, while grey areas represent an industrial production value of zero. The map highlighting missing data indicates the number of unavailable product codes, which may result in the underreporting of industrial production values for certain countries.

The EU's manufacturing capacity for solar PV components is currently estimated to be between 14 and 22 GW, largely focused on the manufacturing of modules, with smaller shares for the production of cells.[23] This

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[20] Austria and France are under-reporters due to confidentiality reasons. According to available capacity data, they retain annual capacity of up to 800MW/yW and between 500MW/y and 1GW/y (equivalent to between 10 and 20% of EU capacity) respectively.

[21] According to a market analysis carried out by Wood Mackenzie, the world's top five solar inverters producers accounted for over 70% of inverter shipments in 2022. All these producers (Huawei, Sungrow, Ginlong Solis, Growatt, and GoodWe) are headquartered in China. Huawei, however, does have at least one production facility in the EU (in Eindhoven, the Netherlands). See Wood Mackenzie. 2023. Top 10 solar PV inverter vendors account for 86% of global market share, Available at the following link.

[22] Figure 2 also provides information on the production of specialised wafering machinery, corresponding to PRODCOM codes 28992020 and 28992040 (see footnote 18 above). The data does not distinguish between machinery that is used in wafering specifically for the solar PV industry from machinery that is used to produce other types of semiconductor wafers. This explains why the Netherlands—home of AMSL, the world's leading manufacturer of EUV lithography machines that are used in chip manufacturing—appears to be followed by Germany as among the EU's top producers

[23] The data indicates that the production of solar PV cells is approximately 2 - 3 GW, while the production of modules ranges between 14 and 18 GW.

corresponds to between 4% and 7% of the deployment objectives to 2025 as outlined by the EU solar energy strategy.[24] The EU retains limited manufacturing of ingots and wafers. Wafer manufacturing capacity is concentrated primarily in Germany[25] with additional wafer manufacturing taking place in Italy[26] and France.[27] While Norway is not an EU Member State, the recent suspension of NorSun's operations in the country - NorSun produced 1GW in wafers - has dented Europe's position in this segment. Together, the current European wafer manufacturing capacity is estimated to be around 1.7 GW.[28] Capacity increases, however, have been announced in Italy,[29] Germany,[30] and France.[31]

Figure 2.2 below provides an overview of the distribution of capacity across the Union. Provided that announced capacity increases do materialise, the manufacturing of PV cells and modules is expected to rise by 6.5 to 24 GW, possibly doubling the current capacities by 2025. According to announcements, including facilities set to open before 2030, manufacturing capacity could expand by an additional 48 to 58 GW. This would result in an EU capacity exceeding 75 GW of annual production, underscoring the EU's commitment to reducing dependency on non-EU imports. However, uncertainty remains on the extent to which announced facilities will be realised. Additionally, estimates based on announcements often overestimate actual outcomes, as cancellations of plans are typically less publicised in public sources.

Figure 2.2 Distribution of manufacturing capacity: solar PV [32]

Note: expressed MW/y. White indicates unavailable data; grey indicates a manufacturing capacity of zero. This data is updated up until April 2024. Operational capacity refers to the end of 2023. Sources: publicly available information, complemented by proprietary databases including BloombergNEF and S&P Global Commodity Insights.

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24 The EU solar energy strategy aims at deliver over 320 GW of solar PV generation capacity by 2025, and 600GW by 2030. More details on the strategy are available here.

25 German wafer manufacturing capacity is estimated around 1 GW, which is expected to increase to 3 GW by 2025. Further details can be found in the German country fiche.

26 See, for instance, here.

27 See, for instance, here.

28 See Bruegel. 2024. European clean tech tracker. Available at the following link.

29 As reported in a recent announcement by STMicroelectronics.

30 Nexwafe is currently constructing a facility in Bitterfeld. NexWafe aims to produce ultra-thin and highly efficient monocrystalline wafers in the eastern town of Bitterfeld and See here for details on the facility. According to SolarPower Europe's 2023 EU Market Outlook, Nexwafe plans plans to start production in 2025, with 250 MW of yearly wafer production. The report is available here.

31 France's CARBON project is a gigafactory in the Marseille area, with an announced capacity of 5GW and the integration of wafer production alongside the manufacturing of ingots, cells, and modules. See here.

32 The operational distribution of components is currently 2-3 GW for cells, 0.5-1 GW for wafers, and 14-18 GW for modules; for 2024-2025, it is announced to be 1 GW for cells, 0-0.5 GW for wafers, and 5-6 GW for modules; and for 2026 onwards, it is announced to be 10-15 GW for cells, more than 7-10 GW for wafers, and 25-35 GW for modules.

European companies also manufacture machinery that can be used to produce PV cells, including texturing, doping, coating, and printing machines which are produced in Germany[33] and Spain.[34] Finally, when it comes to inverters, Spain's Power Electronics (30-40GW) is one of the leading producers in this segment, as well as Austria's Fronius (10GW).

China has become the largest player in the industry, with the top five solar PV manufacturers globally—whose combined revenue has increased from USD 10 billion in the first quarter of 2017 to over USD 100 billion in the last quarter of 2022—all being headquartered in China.[35] Import competition has led to substantial restructuring in the EU industry, meaning that the distributions we report in Figure 2.1and Figure 2.2 and the situation in individual EU Member States is likely to change substantially over the next two to four years. Recent news reports, for example, suggest that three module producers, Meyer Burger, Solarwatt and Systovi, are due to close module production facilities in Germany and France later this year.[36]

Differences in performance and market shares between China and the EU are largely driven by variations in cost structures. According to IEA estimates, manufacturing costs are 35-65 percent lower in China than they are in the US and the EU.[37] According to an analysis by the European Solar Manufacturing Council (ESMC), producing solar panels (or modules) costs approximately USD 28.6 US cents per Wp in China, compared with USD 32.1 per Wp in the EU; and USD 33.3 per Wp in the US (or USD 12.7 to 19.7 cents per Wp, when factoring in the impact of the Inflation Reduction Act, or IRA).[38]

According to ESMC analysis, the difference is partly driven by government incentives, including subsidies on capital and land, energy and water, and other indirect supply incentives. However, these incentives are estimated to reduce costs by only USD 5.2 per Wp. This estimate, together with the IEA's estimates of the cost drivers for solar PV manufacturing—which indicates that materials and energy costs account for three-quarters of the total levelized cost of industrial production, with capital and labour accounting for the remainder—suggests that China's cost advantage is not driven by subsidies alone. Scale economies, which are driven by China's large internal and export market can reduce costs and increase productivity; and differences in the cost of energy and raw materials are likely to play a more important role.[39]

The EU's weak industrial production outlook is reflected in international trade indicators. Germany, the EU's most important producer, is a competitive exporter of various components in the PV value chain, such as photovoltaic DC generators and electric converters. Yet, like most EU Member States, Germany is increasingly dependent on

[33] Engineering firms that are active in this segment include Cenotherm and US corporation Applied Materials, which has facilities in Germany. Meyer Burger, which acquired specialist supplier Roth & Rau in 2015, should also have the capabilities to produce machinery.

[34] Spain hosts Mondragon Assembly, a producer of turnkey PV manufacturing lines and specialised equipment.

[35] According to IEA estimates based on the S&P Capital IQ Database. See IEA. 2024. Advancing Clean Technology Manufacturing: An Energy Technology Perspectives Special Report. Available at the following link.

[36] See Renewables Now. 23 February 2024. Meyer Burger to close German plant, seeks approval for rights issue; and Clean Energy Wire. 30 April 2024. Solarwatt becomes second solar PV producer to halt production in Germany in 2024.

[37] This estimate takes into account regional differences in the cost of capital, and energy, and labour. See IEA. 2024. Advancing Clean Technology Manufacturing: An Energy Technology Perspectives Special Report. Available at the following link.

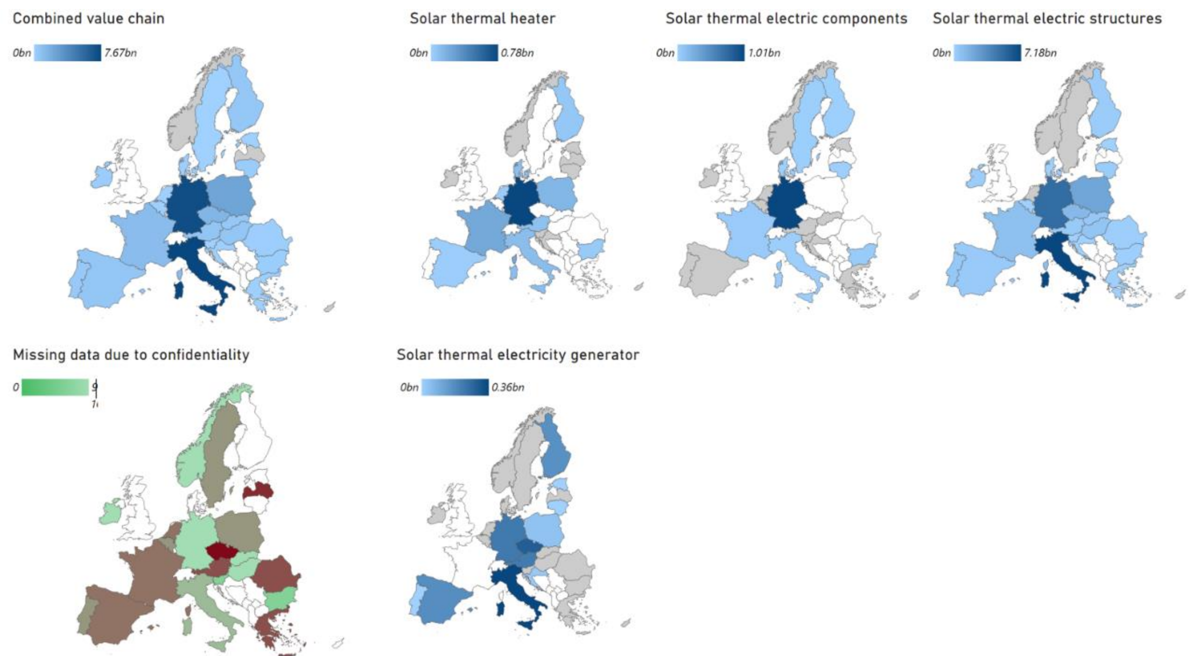
[38] See EMSC. How to address the unsustainably low PV module prices to ensure a renaissance of the PV industry in Europe. Available at the following link.

[39] While labour costs reportedly do not account for a large share of the levelized cost of manufacturing, it is worth noting that according to recent research, around 40 percent of polysilicon used in Chinese PV production is sourced in Xinjiang, where forced labour may be employed in the extraction of the material. See, for instance, Cockayne, J. 2022. Making Xinjiang Sanctions Work: Addressing forced labour through coercive trade and finance measures. University of Nottingham; and Reinsch and Arrietta-Kenna. 2021. A Dark Spot for the Solar Energy Industry: Forced Labor in Xinjiang. Centre for Strategic and International Studies (CSIS). Available, respectively, here and here.

imports of PV components from third countries. In 2022, it imported over 60 percent of all its components from non-EU countries, with over 20 percent coming from a single country, China. While import dependence on third countries for PV components has generally grown, EU Member States retain an edge in the export of specific components.

Unlike solar PV components, the industrial production of solar thermal components remains relatively robust in Europe. This is due to the strong local demand for energy-efficient heating solutions, particularly in the residential and commercial sectors.[40] Additionally, EU manufacturers benefit from the technological expertise of research organisations (such as the European Solar Thermal Technology Platform) as well as available funding for innovation through funding mechanisms such as Horizon Europe. As illustrated in Figure 2.3, Germany leads in the manufacturing of solar thermal water heaters, but industrial production is also spread around Europe. Generally, the diverse range of components essential for solar thermal energy systems is predominantly produced in manufacturing hubs such as Germany and Italy. According to the IEA and Solar Heat Europe, the total operational manufacturing capacity of EU Member States amounts to between 37 and 41 GWth.[41] This constitutes approximately 8 percent of the total capacity available globally. By contrast, China's total capacity stands at 396 GWth, representing 73 percent of the total global capacity in operation. We were unable to find EU-level statistics on manufacturing capacity for CSP, which the IEA estimates globally to be 7 GWth.

Figure 2.3 Distribution of production: solar thermal



Note: The visual illustrates the industrial production value in euros for the year 2022. Each map depicts a grouping of relevant components or end-use products identified during the research. An overview of included components and products is provided in Annex I, Table A-3. Source: PRODCOM. White areas indicate unavailable data, while grey areas represent an industrial production value of zero. The map highlighting missing data indicates the number of unavailable product codes, which may result in the underreporting of industrial production values for certain countries.

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40 Solar-Heat-Worldwide-2023.pdf (iea-shc.org)

41 See Solar Heat Europe. 2024. Decarbonising heat with Solar thermal: Market outlook 2023/2024; and IEA Solar Heating & Cooling Programme. 2024. Solar Heat Worldwide: 2024 Edition. Available here and here, respectively.

2.2.2 Onshore wind and offshore renewable technologies

The manufacturing segments and components required for wind turbines can vary significantly based on the manufacturer and whether they are used offshore or onshore due to differences in design specifications, environmental conditions, and performance requirements. However, there are several common components essential to both types of wind energy use. These include the structural elements of the wind turbine, such as the shaft and blades, internal components such as ball bearings, and motorised components such as the gearbox and electricity generator.[42]

Additionally, precision machinery is required for the final assembly of the wind turbine structure and the tower components, including steel rolling and fibreglass layup machines. Similarly, machinery such as robotic assembly lines and precision machining tools are used to assemble the nacelle components, such as generators, gearboxes, and yaw systems.[43]

With regard to industrial production, in 2022 EU Member States collectively produced approximately EUR 9.2 billion worth of wind turbines - the final product - with manufacturing concentrated in a few key countries (see Figure 2.4 below for an overview of the distribution of industrial production). In the wider wind power value chain, Germany (producing 31% of EU industrial production), Denmark (7%), and Spain (9%) stand out as the EU's leading producers. While the design and assembly of turbines are heavily concentrated geographically, the production of components is more widely dispersed across the EU.

For individual components, Germany (with 28% of EU industrial production in this segment), Denmark (over 20%), and Austria (5%) are important producers of generators. Austria, Czechia, and Italy have suppliers who specialise in the industrial production of the mechanical components that are used in the assembly of gearboxes, including various types of bearings.[44] While France does not disclose specific industrial production data, available manufacturing capacity data suggests it also contributes to the value chain most notably through blade manufacturing[45], which takes place in multiple locations in the country. Italy and Poland hold smaller but notable shares of industrial production capacity.

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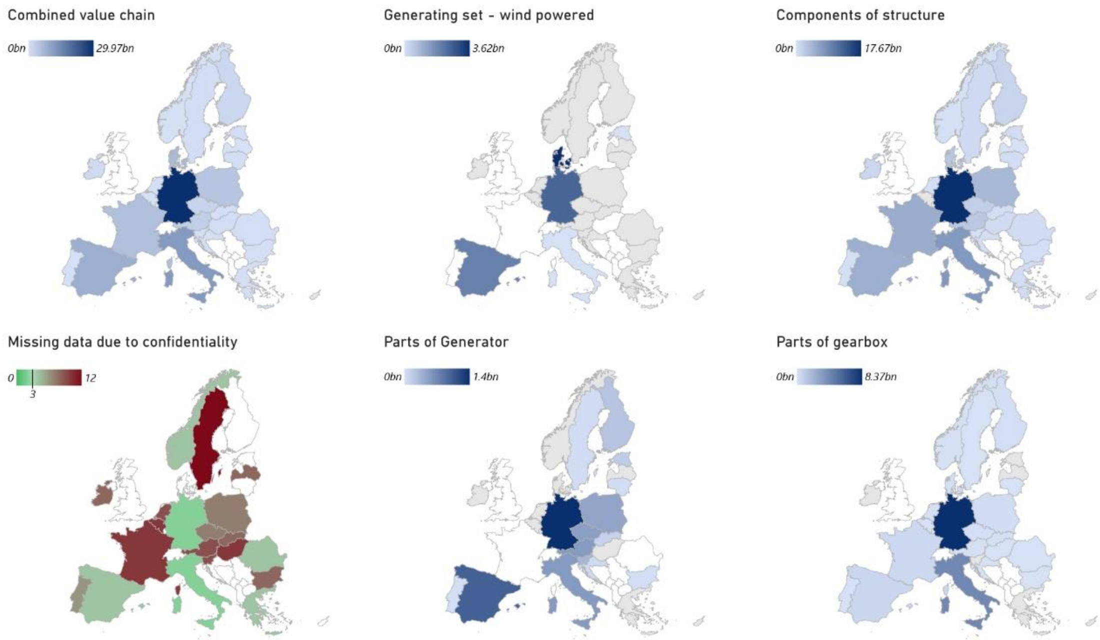
[42] JRC (2023), Clean Energy Technology Observatory: Wind energy in the European Union. Available at the following link. See also, JRC (2020), Critical Raw Materials for Strategic Technologies and Sectors in the EU - A Foresight Study. Available at the following link.

[43] See Ayee, G., Lowe, M. and Gereffi, G. 2009. Wind Power: Generating Electricity and Employment. In "Manufacturing Climate Solutions Carbon-Reducing Technologies and U.S. Jobs". Available at the following link.

[44] Estonia's firms include Maru Metall AS, Bestnet AS, and Marketex Offshore Constructions. Luxembourg's ArcelorMittal is an important supplier of steel components to wind turbine manufacturers, but these are not produced in Luxembourg. Other important producers and exporters of steel structures and components that do not seem to be involved in the industrial production of onshore or offshore wind technologies are Croatia, Romania, and Latvia.

[45] Companies include LM Wind Power (GE), Siemens Gamesa

Figure 2.4 Distribution of production: wind [46]



Note: The visual illustrates the industrial production value in euros for the year 2022. Each map depicts a grouping of relevant components or end-use products identified during the research. An overview of included components and products is provided in Annex I, Table A-3. Source: PRODCOM. White areas indicate unavailable data, while grey areas represent an industrial production value of zero. The map highlighting missing data indicates the number of unavailable product codes, which may result in the underreporting of industrial production values for certain countries.

Data on manufacturing capacity corroborates these findings (see Figure 2.5). Germany and Denmark - home to leading firms such as Vestas and Nordex - lead in both operational and announced capacity. The lion's share in capacity is in Spain, however, which hosts nearly half of the EU's tower manufacturing capacity, hosting facilities operated by Vestas, Nordex, and Siemens Gamesa, among others. However, only limited manufacturing capacity expansions have been announced (see Figure 2.5), suggesting modest growth for the EU wind industry, primarily in countries with already well-established wind sectors. This is in line with the IEA's finding that the EU has seen almost no increase in capacity over the past two years.[47] This slow growth is largely attributed to the substantial investment requirements needed to develop and expand wind technology manufacturing.

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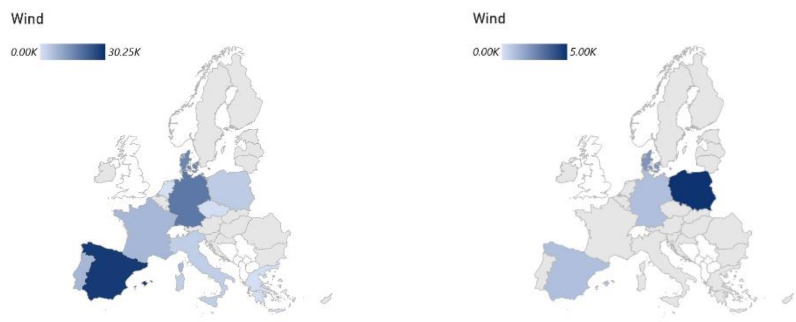
46 *Generating set- wind powered* refers to the nacelle of the wind turbine, but may also include other parts of the construction if produced and sold together.

47 See IEA. 2024. Advancing Clean Technology Manufacturing: An Energy Technology Perspectives Special Report. Available at the following link.

Figure 2.5 Distribution of manufacturing capacity: wind

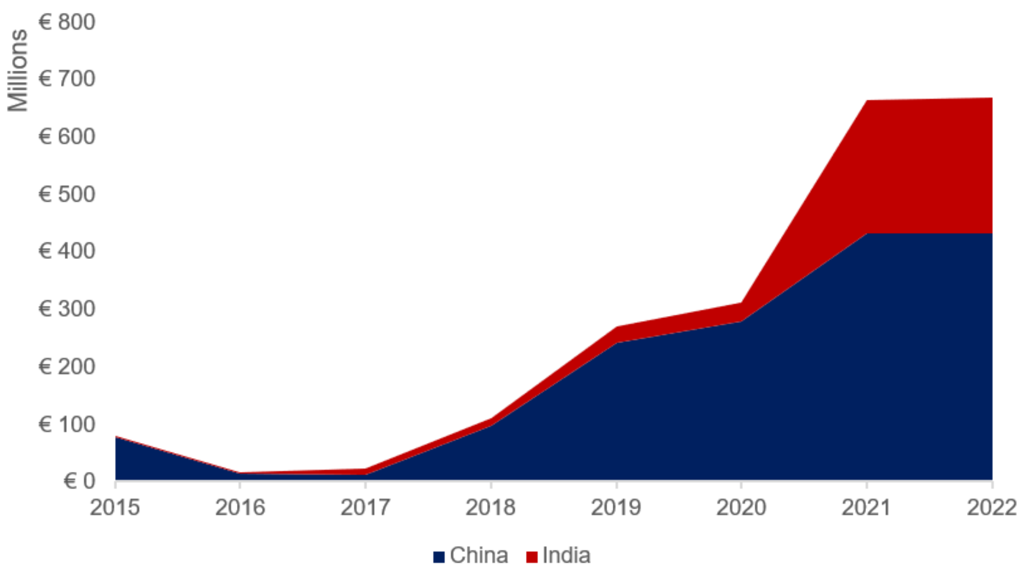
Operational **Announced facilities**



Note: expressed MW/y. White indicates unavailable data; grey indicates a manufacturing capacity of zero. This data is updated up until April 2024. Operational capacity refers to the end of 2023. Sources: publicly available information, complemented by proprietary databases including BloombergNEF and S&P Global Commodity Insights.

International trade data corroborates these trends. The export market for wind turbines is concentrated, with only a few players - Denmark, Germany, Spain, China, and India - being strong exporters worldwide.[48] The fact that three of the five top export performers are in the EU indicates that the EU remains a key player in the global wind industry. However, China's share of the market has grown rapidly in recent years, with its exports of wind turbines increasing by 300 percent since 2017. Indeed, in 2023, China accounted for over 60 percent of the EU's imports of wind turbines and associated components from third countries (see Figure 2.6 below).

Figure 2.6 Evolution of imported wind power components from China and India



Note: Own elaboration, based on BACI data. We focus on HS code 850231.

[48] We proxy export concentration by using the HHI index for wind-powered electric generator sets (HS code 850231), which is the best available proxy for wind turbines even though it does not capture the production and export of the full turbine, as it is likely to exclude components such as the tower. The five top global export performers are the five countries that have the highest RCA in the same HS code.

The rise of China as an emerging global player in the industry is explained, in part, by cost differentials. According to a recent analysis by the IEA, the cost of onshore wind turbines can be estimated at USD 385/kW in China; and between USD 485 and USD 525/kW for the US and the EU. Cost differentials are primarily driven by material costs, which are estimated to account for up to 60 percent of costs.[49] Chapters 4 and 5 also discuss how the lack of standardisation in turbines' design may be hampering EU producers from unlocking economies of scale.

2.2.3 Batteries and storage technologies

Batteries are a key technology in the transition to net zero due to their role in electrifying transportation and stabilising power grids. In schematic terms, the key manufacturing segments and components in battery production include raw and active materials - which are outside the scope of this study - and the production of battery cells and modules.[50] Cells are manufactured using anodes (typically made of a copper foil coated with graphite) and cathodes, composed of an aluminium foil coated with a given chemistry.[51]

At present, both industrial production and manufacturing capacity data are typically only available on the end product - the battery cell itself. PRODCOM reports information on over twenty distinct types of batteries, electric accumulators, and separators—built using various metals and technologies.[52] In addition, at least one segment of cell manufacturing requires highly specialised machinery. This is coating and drying, a process specific to battery cell production.[53]

Figure 2.7 and Figure 2.8 below present the distribution of industrial production and manufacturing capacity related to lithium-ion batteries and other types of batteries across EU MS, respectively. Figure 2.7 distinguishes between lithium-ion batteries, which are critical for electric vehicle (EV) manufacturing, other battery types, and key components such as accumulator parts and separators. Figure 2.8 focuses on manufacturing capacity for lithium-ion batteries specifically.

In terms of lithium-ion battery production capacity, Poland (85-95 GWh), Germany (55-60 GWh),[54] and Hungary (around 40-42GWh) [55] are leading the EU, followed by France (14.5-16 GWh) and Sweden (15.5-16 GWh)[56]. Czechia and Poland, historically known for producing battery separators, have significantly expanded their production of lithium cells and batteries in recent years. In Poland, the industrial production capacity is largely

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49 See IEA. 2024. Advancing Clean Technology Manufacturing: An Energy Technology Perspectives Special Report. Available at the following link.

50 JRC CETO. 2023. Battery Technology in the EU. Available at the following link.

51 Possibilities here include either lithium ferro-phosphate, or a combination of nickel, manganese, and cobalt; or of nickel, cobalt, and aluminium. See CIC EnergiGUNE. 2023. Cathode Composition of Battery Cells: a Three-Way War. It is worth noting that according to a recent IEA analysis, in 2023 China accounted for 98 percent of investments in facilities producing anodes; and 87 percent of investments in facilities producing cathodes. See IEA. 2024. Advancing Clean Technology Manufacturing: An Energy Technology Perspectives Special Report. Available at the following link.

52 JRC CETO. 2023. Battery Technology in the EU. Available at the following link.

53 McKinsey. 2022. Unlocking the growth opportunity in battery manufacturing equipment. Available at the following link.

54 Recent news articles suggest the current capacity of the Tesla Giga factory is around 50 GWh. Yet, other data sources report the nameplate capacity of 100 GWh. We have applied a capacity of 50 MW in this range, but the total capacity may be higher. Information is available at the following link.

55 See Forbes. 2022. *Magyar cégek nélkül épül hazánk legújabb húzóágazata – a környezeti kockázatokat viszont mi viseljük*. Available at the following link.

56 Recent news articles suggest the current capacity of the NorthVolt AB is around 16 GWh. Yet, other data sources report the announced nameplate capacity of 60 GW. We have applied a capacity of 16 GWh as, but the total current capacity may be higher. See: Northvolt outlines revised scope of operations in Sweden

driven by LG's gigafactory in Wroclaw, producing around 70 GWh annually.[57] The town of Cinovec in Czechia is home to the largest hardrock lithium deposit in Europe, where mining and industrial production of lithium hydroxide is expected to commence in 2026. The processing and manufacturing plant built on-site is anticipated to produce 30 GWh of EV batteries per year.[58]

The EU is experiencing a rapid expansion in battery and energy storage production capacities, driven by the growing demand for EVs, renewable energy integration, and the need for grid stability. This expansion is marked by substantial scale-up across the EU, particularly through the development of gigafactories. Current capacities of 150-260 GWh are expected to increase by an additional 150-250 GWh by 2025, with projections of over an additional 500-1,000 GWh in annual capacities beyond 2025.[59] For example, Hungary's lithium-ion battery manufacturing industry is particularly dynamic, with the 2024 National Battery Strategy outlining plans to increase industrial production to 47 GWh by 2025 and 87 GWh by 2030. [60]

A significant driver of this rapid upscaling is foreign direct investment (FDI) from South Korean firms such as LG Energy Solution, SK Innovation, and Samsung, which are key players in Central and Eastern Europe's battery manufacturing sector. China's CATL also announced the opening of a gigafactory in Debrecen, Hungary, in 2022, followed by large government investments in an industrial park to support CATL's operations and stimulate local economic growth.[61] On the other hand, the slowdown in EV sales across the continent has pushed home-grown battery manufacturing start-ups Italvolt and Northvolt to postpone or cancel their planned investments in expanding capacity in Italy and Sweden.[62]

With regard to trends in international trade, together with Poland and Hungary, France and Czechia, the Netherlands, and Romania are all internationally competitive exporters of lithium-ion cells and batteries.[63] EU Member States, however, tend to lag behind other large lithium battery exporters such as South Korea, Japan, China, and the US, and emerging players such as Indonesia.[64] Countries in Southern Europe also contribute to the battery industry, particularly in areas with lower technological advancement. Greece is an internationally competitive exporter of lead-acid batteries, owing to the presence of the Sunlight Techno-system in the country. Italy has a profile that is similar to that of Greece. While lead-acid batteries are traditionally used as starter batteries, their applications also extend to grid energy storage and off-grid household electric power due to their relative affordability, despite being heavy. Finally, Belgium is a key exporter of typical household batteries (MnO_2) likely due to the presence of *Umicore*, a major (battery) recycling company. These alkaline batteries are widely used in various household and portable electronic devices.

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[57] As reported by LG in 2022 here. In the same press release, LG also announces a planned increase to 115 GWh by 2025. We could not verify whether the announcement is on course to materialise.

[58] Cinovec lithium extraction project

[59] It is worth noting that the recent slowdown in EV sales across the continent is likely to affect the outlook for battery manufacturing in the EU. Part of the announcements we report here may therefore be postponed or not realised.

[60] Hungarian Ministry of Innovation and Technology (2024): National Battery Industry Strategy 2030. Available at the following link.

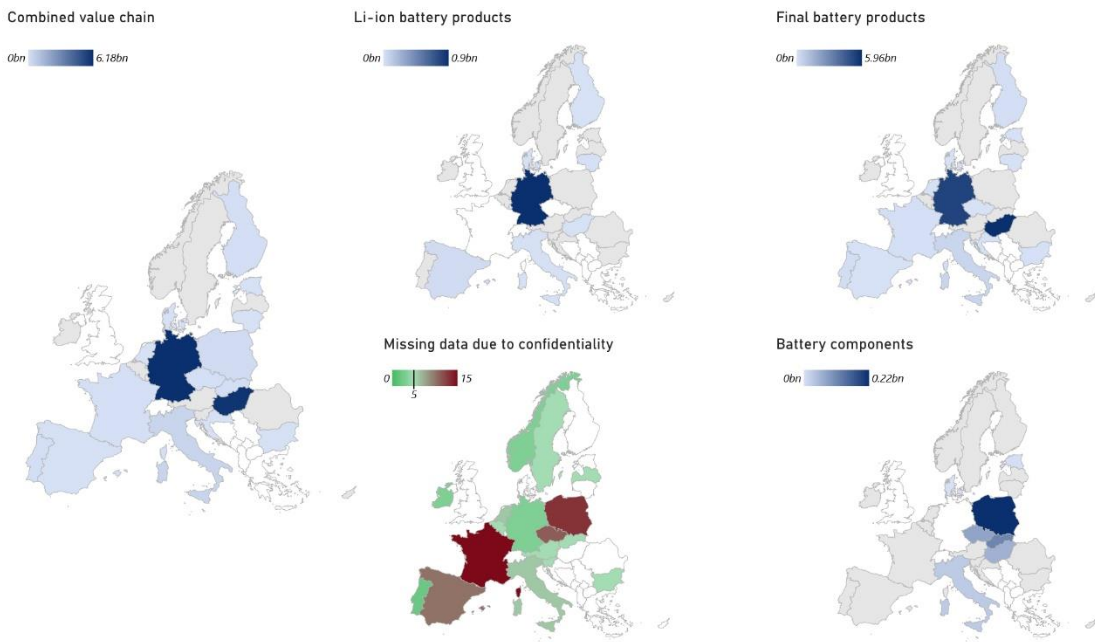
[61] CATL Magyarországon

[62] See, respectively, here and here.

[63] This assessment is based on these countries' RCA indices for the export of lithium-ion cells and batteries.

[64] China's batteries are estimated by the IEA to be approximately 20-35 percent less costly to produce than in the EU and US. See IEA. 2024. Advancing Clean Technology Manufacturing: An Energy Technology Perspectives Special Report. Available at the following link.

Figure 2.7 Distribution of production: battery products



Note: The visual illustrates the industrial production value in euros for the year 2022. Each map depicts a grouping of relevant components or end-use products identified during the research. An overview of included components and products is provided in Annex I, Table A-3. Source: PRODCOM. White areas indicate unavailable data, while grey areas represent an industrial production value of zero. The map highlighting missing data indicates the number of unavailable product codes, which may result in the underreporting of industrial production values for certain countries.

Figure 2.8 Distribution of manufacturing capacity: Battery

Note: expressed MWh/y. White indicates unavailable data; grey indicates a manufacturing capacity of zero. This data is updated up until April 2024. Operational capacity refers to the end of 2023. *Sources: publicly available information, complemented by proprietary databases including BloombergNEF and S&P Global Commodity Insights.*

2.2.4 Heat pumps and geothermal energy technologies

According to several sources, the following manufacturing segments and components are key to the production of air-water or ground-source heat pumps: compressors, controls, heat exchangers, housing, valves, fans, pumps, pipework, and refrigerants.[65] For industrial heat pumps, components are likely to be similar, except for housing. It is worth noting that the assembly of heat pumps does not require advanced or specialised machinery. Assembly lines for regular boilers can be relatively easily adapted to produce heat pumps.

With regard to (deep) geothermal energy technologies, it is worth noting that PRODCOM does not contain any codes relating to geothermal energy specifically. Instead, we rely on components used within geothermal plants above the ground. These include the following: pumps, alternators, turbines and water wheels, boilers and heat exchange units.[66] All these components can have other industrial applications beyond their use within above-ground geothermal plants.

Figure 2.9 provides an overview of the distribution of industrial production across the EU. Across the EU, the industrial production of heat pumps and geothermal components amounted to over EUR 20 billion in 2022, with heat pumps alone accounting for approximately 25 percent of the total.

Countries with strong domestic markets for heat pumps, such as Germany, Sweden, Finland, and Denmark, host a significant portion of heat pump manufacturing.[67] A similar picture emerges when looking at ground-source (geothermal) heat pumps. Sweden is a clear leader in this industry, having 118 geothermal heat pump systems for every 1000 households.[68] Baltic countries report less industrial production data than other EU Member States but have both industrial production and export of heat pumps.[69]

The information that is available on (deep) geothermal energy manufacturing, points to the existence of over 100 facilities producing different components, with industrial production concentrated in large industrial economies such as Germany, France, and Italy. For example, the production of steam turbines is mainly located in Germany and Italy. In addition, suppliers to the oil and gas industry have additional capacity that could, in principle, be used to manufacture components that are relevant to deep geothermal energy.[70] Owing to the similar challenges producers in the two industries face, components reportedly share some technological similarities.[71]

When considering all components used in heat pumps and geothermal energy applications, several EU Member States stand out as competitive producers. In particular, Czechia, Poland, and Slovakia are home to an emerging "heat pump valley", characterised by a high density of manufacturing facilities.[72] Trade data corroborates these

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65 See the JRC CETO Heat pump industry Europe 2023; Sissons, A., Wiley, K., and Williamson, C. 2022. How to reduce the cost of heat pumps. Report. Nesta. Available at the following link; and US Department of Energy. 2016. Heat Pump Systems. Available at the following link.

66 JRC CETO. 2023. Deep Geothermal Heat and Power in the European Union - 2023 Status Report on Technology Development, Trends, Value Chains and Markets. Available at the following link. Inputs from interviews with stakeholders (and particularly industry associations) highlighted that our list is missing an important component—compressors. At the time of writing, we have not been able to identify the relevant code. Additionally, stakeholders in the geothermal industry pointed to the following components— drills; gears; 2- and 3-D seismic measurement systems; biodegradable chemicals to measure flow rates; and plastics for heat networks. These components are either too generic—as in the case of drills and gears—or too specialised to be identified in the data.

67 For overviews of developments in the Nordic heat pump markets, see Johansson. 2021. Heat pumps in Sweden: A historical overview. *Energy*; and Järvenreuna, 2019. Emerging business ecosystems behind the new energy services in Finland. *Smart Energy Transition*. They are available, respectively, here and here. Throughout 2024, however, market news have been rather gloomy with regard to the heat pump market, with slowdowns in sales reported in some of the EU's top producers, including Germany, where sales have reportedly declined by 52 percent during Q1 2024 relative to Q1 2023.

68 Finland and Estonia are currently at 57.1 and 36.7 systems per 1000 households respectively. Austria and Denmark follow, with approximately 30 systems per 1000 households each. See EGEC. 2023. EGEC Geothermal Market Report 2022. Available at the following link.

69 Nordic Energy Research. 2021. Heat Pump Potential in the Baltic States. Available at the following link.

70 This was reported to us by stakeholders in the geothermal industry during a roundtable discussion.

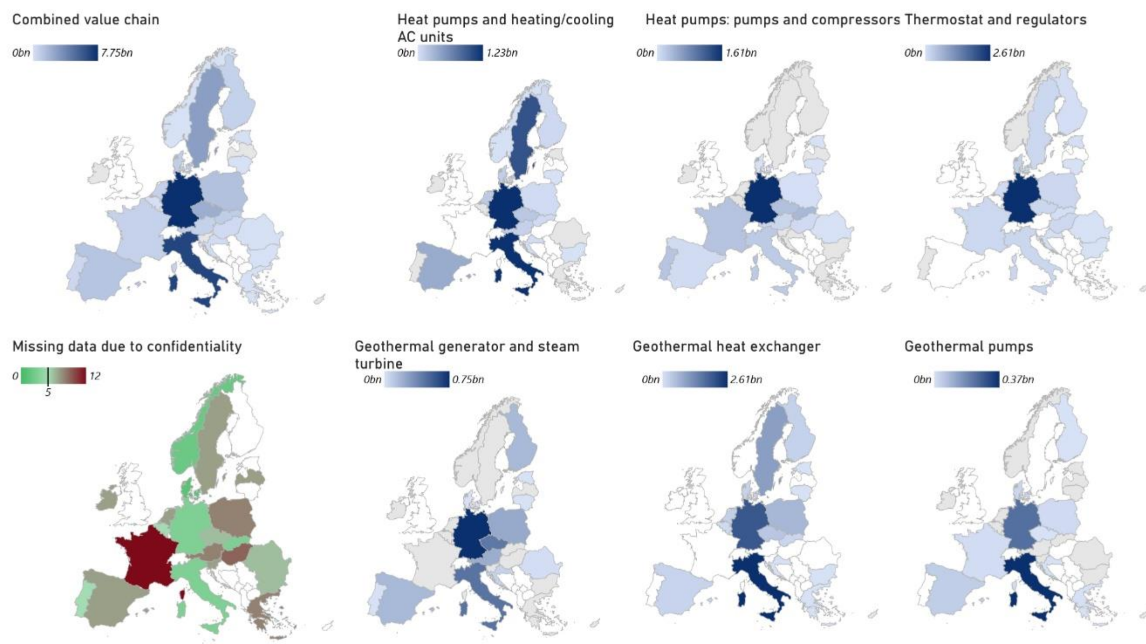
71 This paragraph builds on inputs received a stakeholder in the geothermal industry. Information on capacity could not be verified.

72 As reported by Euractiv in June 2023, see *Europe's 'heat pump valley' takes root in the East*. Available at the following link.

findings, with several Member States emerging as competitive exporters. Sweden is the EU's top export performer in heat pumps specifically, followed by Czechia, Slovakia, and France. Hungary is a competitive exporter of turbines and pumps that can be used in geothermal applications.

Stakeholders consulted all pointed to localisation as a key feature of the heat pump value chain. Industrial production for both residential and industrial use needs to be customised to a high degree of specificity, based on the size and features of each country's residential and industrial buildings. Taken together, these findings suggest that the EU industry is substantially less at risk from foreign competition than in other value chains. At the same time, however, as we discuss in Chapter 3, the heat pump sector is experiencing a slowdown due to several factors: installation bottlenecks, reduced incentives, fluctuating electricity-to-gas price ratios, and decreased new-build construction and renovation activities caused by higher interest rates and increased construction costs. According to the IEA, these factors are decelerating the growth of new capacity. The slowdown is particularly acute in the EU, the US, and Japan.[73]

Figure 2.9 Distribution of production: heat pumps/geothermal



Note: The visual illustrates the industrial production value in euros for the year 2022. Each map depicts a grouping of relevant components or end-use products identified during the research. An overview of included components and products is provided in Annex I, Table A-3. Source: PRODCOM. White areas indicate unavailable data, while grey areas represent an industrial production value of zero. The map highlighting missing data indicates the number of unavailable product codes, which may result in the underreporting of industrial production values for certain countries.

2.2.5 *Electrolysers and fuel cells*

Low-emission hydrogen, including both renewable and low-carbon hydrogen, plays a crucial role in advancing cleaner and more efficient renewable energy technologies. Production of hydrogen can be achieved via multiple

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[73] See IEA. 2024. Advancing Clean Technology Manufacturing: An Energy Technology Perspectives Special Report. Available at the following link.

pathways with different levels of CO_2 emission.[74] In the hydrogen sector, the value chain is typically divided into four areas: production, storage, transmission, and end-use. In what follows we focus on the first two. In the green (renewable) hydrogen value chain, the essential manufacturing segments and components are electrolysers and ancillary components including pumps and compressors, which are required to ensure the correct operations of the plant. Ancillary components are commonly referred to as Balance of Plant (BoP) components. BoP components include pumps and compressors and are crucial for the correct operation of the hydrogen production plant.

Electrolysers transform electrical energy into the chemical energy of hydrogen, a process marked by an efficiency loss referred to as electrolyser efficiency. There are four primary electrolyser types on the market, categorised by efficiency, technological maturity, and capital expenses (CAPEX).[75] Fuel cells are a key product in the value chain. They are electrochemical devices that convert hydrogen gas into electricity, releasing water and heat as their main by-products.

The final part of the value chain is hydrogen storage, serving as a buffer to manage operations by balancing fluctuations and compensating for plant contingencies. Additionally, storage plays a significant role in delivery and transportation. As the EU hydrogen pipeline network (EU hydrogen backbone) is still in development, transporting hydrogen in compressed tanks remains the only viable solution. Hydrogen storage can be above or below ground. Surface storage includes tank storage components—metal containers built for compressed or liquefied gas to store the flammable hydrogen safely. Meanwhile, underground storage is often used for vast hydrogen quantities using subterranean salt caverns.

While the industrial production of electrolysers and other BoP components remains relatively small compared to other technologies, they are steadily increasing across the EU as Member States intensify their focus on decarbonisation. Manufacturing facilities for electrolysers are being established in several countries, including Germany—home to companies such as thyssenkrupp nucera and Siemens—Spain, France, Belgium, Portugal, Italy, and the Nordic Member States. Notably, more than half of the EU's electrolyser manufacturing capacity is concentrated in Germany.

In terms of manufacturing capacity, by the end of 2024, Europe is projected to reach an annual water electrolyser manufacturing capacity of 8–10 GW. According to the Hydrogen Europe Observatory, as of May 2024, 5.4 GW of this capacity is already operational, with an additional 3.5 GW planned to come online.[76] By 2026, considering only projects currently under construction or those with finalised investment decisions, the total electrolyser manufacturing capacity is expected to rise to 10.5 GW per year. However, even by 2030, manufacturing capacity is likely to remain concentrated in a few key countries—Germany, France, Italy, Belgium, Spain, Denmark, and

74 *Grey hydrogen* refers to hydrogen generation through methane steam reforming, where methane and steam are input to produce hydrogen and CO_2. *Blue hydrogen* follows the same process as grey hydrogen but integrates Carbon Capture technology to reduce CO_2 emissions, resulting in a form of low-emission hydrogen. However, blue hydrogen still relies on methane. Although with limited CO_2 footprint, blue-hydrogen embeds a dependence from methane. To overcome the link to natural gas, *green hydrogen* is produced using electricity with zero associated CO_2 emissions. This electricity powers an electrolyser, which splits water into oxygen and hydrogen. It is important to note that current limitations in the PRODCOM code prevent the differentiation of various production methods, thereby hindering the provision of relevant information concerning hydrogen produced via water electrolysis.

75 These include alkaline electrolysers (AEC) are the most established, with widespread use due to their low CAPEX, though they typically offer lower efficiencies of 60-65%. Proton exchange membrane electrolysers (PEMEC) are more efficient than AEC but come with higher CAPEX, despite their significant maturity. Solid oxide electrolysers (SOEC) promise the highest efficiencies and are made from relatively inexpensive materials, which could keep future costs low. However, this technology is still immature and not yet ready for deployment.

76 European Hydrogen Observatory. Electrolyser manufacturing capacity May2024. Available here.

Portugal, as well as, should recent announcements materialise, Estonia, and Greece. Alkaline and Proton Exchange Membrane (PEM) technologies are expected to account for nearly half of the hydrogen production capacity each, with other technologies representing less than one percent.

According to the IEA, the difference in manufacturing costs between the EU and China is not as large as for other Net-Zero technologies. The costs of manufacturing alkaline electrolyser stacks range from 45 to 65 USD/kW, with the upper end being EU and US, and the lower end being China. This is a cost estimate based on a high utilisation rate. [77]

While industrial production data remains partly confidential, international trade data suggests that both Austria and Belgium are important producers and exporters of BoP components for electrolysers and fuel cells, particularly tanks and containers.[78] These components, however, were not regarded by industry stakeholders consulted as being particularly critical. Looking at machinery and apparatus for electrolysis (HS code 854330), Denmark emerges as an important producer and exporter, likely due to companies like Topsoe.[79] Among other EU Member States, Finland has at least one firm active in the production of fuel cells. The country has also recently received an investment from Plug Power, a US firm.

The deployment of hydrogen projects in the EU has witnessed significant growth. According to the EU Hydrogen Observatory[80], there has been a notable increase in hydrogen production capacity, with numerous green hydrogen projects emerging across the EU Member States. Germany, Spain, Sweden, France, and Denmark are among the leading Member States, with the Netherlands, Belgium, and Germany playing important roles in the associated infrastructure linked to ports. Additionally, hydrogen infrastructure, including refuelling stations and pipelines, is expanding rapidly to support the hydrogen economy. Key trends include a focus on large-scale hydrogen valleys, which integrate production, storage, and consumption within regional ecosystems, and cross-border collaboration projects aimed at establishing a cohesive European hydrogen network.

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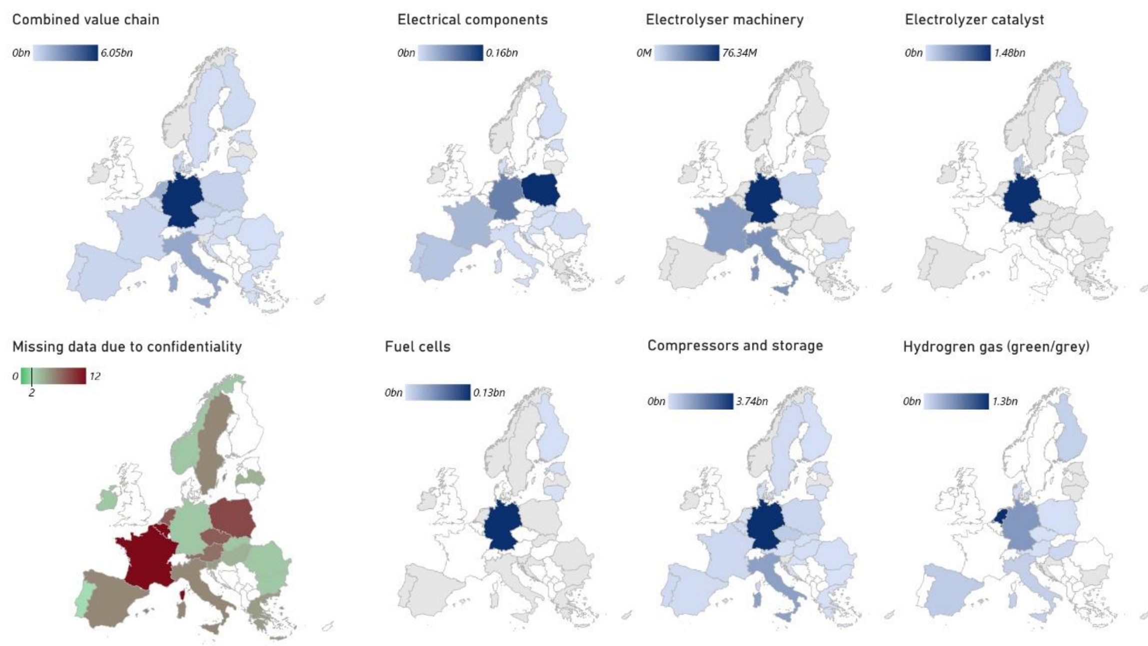
77 See IEA. 2024. Advancing Clean Technology Manufacturing: An Energy Technology Perspectives Special Report. Available at the following link.

78 Unlike Belgium, Austria does not have any manufacturing capacity in electrolysers and fuel cells directly—only in the production of BoP components.

79 Estonia and Bulgaria are also important exporters, but we could not yet verify whether their exports reflect machinery for electrolysis or rather for electroplating or electrophoresis. The three processes are lumped together under a single product code.

80 Homepage | European Hydrogen Observatory (europa.eu)

Figure 2.10 Distribution of production: electrolysers and fuel cells



Note: The visual illustrates the industrial production value in euros for the year 2022. Each map depicts a grouping of relevant components or end-use products identified during the research. An overview of included components and products is provided in Annex I, Table A-3. Source: PRODCOM. White areas indicate unavailable data, while grey areas represent an industrial production value of zero. The map highlighting missing data indicates the number of unavailable product codes, which may result in the underreporting of industrial production values for certain countries.

Figure 2.11 Distribution of manufacturing capacity: electrolysers

Note: expressed MWe/y (megawatts of electricity input). White indicates unavailable data; grey indicates a manufacturing capacity of zero. This data is updated up until April 2024. Operational capacity refers to the end of 2023. Sources: publicly available information, complemented by proprietary databases including BloombergNEF and S&P Global Commodity Insights.

2.2.6 Sustainable biogas and biomethane technologies

Biogas is a mixture of methane, CO_2 and other gases, typically available in small quantities, that are produced by anaerobic digestion of organic matter in an oxygen-free environment. Biomethane is a source of methane produced either by removing CO_2 and any contaminants that are present in biogas (a process known as "upgrading") or through the gasification of solid biomass followed by methanation.[81]

Bioenergy can be produced from a wide range of feedstocks, such as biomass from agriculture (crop residues, bagasse, animal waste, energy crops, etc.), biomass from forests (primary woody biomass like fuelwood and logging residues, secondary sources like wood processing by-products, black liquor from the pulp and paper industry, and post-consumer wood), and other types of biological waste (including food waste, food industry waste, and the organic fraction of municipal solid waste).[82]

Biogas production equipment includes several key components, such as anaerobic digesters and biogas upgrading systems. When it comes to industrial production, as shown in Figure 2.12, Germany and Italy are significant hubs for biogas technology manufacturing, with industrial production values of approximately EUR 5.8 billion and EUR 2.5 billion, respectively. Czechia, the third-largest EU producer, has an industrial production value of EUR 600 million and a strong presence in compressor manufacturing. Meanwhile, Poland stands out in gas storage components, and Spain is strong in producing gas purifiers and liquefiers. However, data also indicate that several Member States lack relevant industrial production capabilities. It is important to note that data availability is limited due to the low number of product codes related to biogas production.

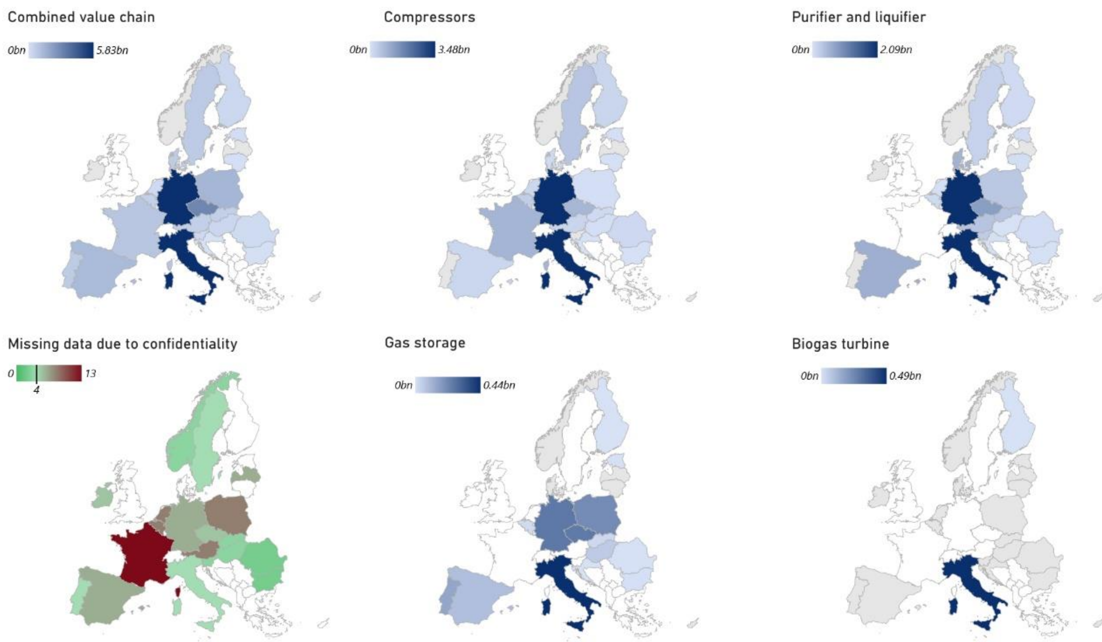
In terms of international trade, the EU is a net exporter of sustainable biogas and biomethane technologies, exporting over EUR 4 billion more than it imported in 2022. Germany and Poland are particularly strong exporters of machinery for filtering or purifying gases while Italy excels in gas turbines, with both countries having higher RCA indexes than other leading exporters, such as China and the USA. Poland's total exports in this segment have increased by over 200 percent between 2015 and 2022, and now amount to EUR 2.9 billion.

From the trade analysis of these components, it is worth mentioning that sustainable biogas and biomethane components are the ones for which EU Member States seem to be the least dependent on a single, third-country, import partner. Indeed, China accounts for only 8.7% of total EU imports. This is also reflected in the market saturation rate of the export market for this technology, which is the lowest among all eight Net-Zero technologies investigated in this study. This indicates that no single country holds a dominant or monopolistic position in the export of these technologies.

[81] IEA. 2020. Outlook for biogas and biomethane: Prospects for organic growth.

[82] Scarlat, N., Dallemand, J.F., and Fahl, F. 2019. Biogas: Developments and Perspectives in Europe. *Renewable Energy*, Vol. 129(A). Available at the following link.

Figure 2.12 Distribution of production: biogas and biomethane



Note: The visual illustrates the industrial production value in euros for the year 2022. Each map depicts a grouping of relevant components or end-use products identified during the research. An overview of included components and products is provided in Annex I, Table A-3. Source: PRODCOM. White areas indicate unavailable data, while grey areas represent an industrial production value of zero. The map highlighting missing data indicates the number of unavailable product codes, which may result in the underreporting of industrial production values for certain countries.

2.2.7 Carbon capture and storage (CCS) technologies

CCS involves the capture of CO_2, generally from sources such as power generation or industrial processes that use fossil fuels or biomass. CO_2 can be used on-site, or the captured CO_2 can be compressed and transported by pipeline, ship, rail, or truck to be used in a range of applications or injected into deep geological formations such as depleted oil and gas reservoirs or saline aquifers.[83]

Countries such as Germany, Sweden, and the Netherlands are at the forefront of carbon capture technology deployment. Key deployment sites for carbon capture and storage (CCS) projects are the Northern Lights project in Norway, which aims to develop an open-source CO_2 transport and storage infrastructure. In the Netherlands, the Porthos project focuses on capturing CO_2 from industry in the Port of Rotterdam and storing it in depleted gas fields beneath the North Sea. Germany's LEILAC (Low Emissions Intensity Lime and Cement) project is working on capturing CO_2 emissions from cement production. Sweden's bio-CCS initiative, led by Stockholm Exergi, targets capturing CO_2 from biomass-fired combined heat and power plants.

Carbon capture relies on a host of different technological solutions.[84] Amine-based carbon capture technologies are considered the most mature. In amine-based carbon capture, the CO_2-containing gas flows into the bottom of a vertical vessel called an absorber column. In the absorber column, the gas flows upwards while in contact

[83] International Energy Agency: Carbon Capture, Utilisation and Storage https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage

[84] CCUS Hub. 2023. A playbook for regulators, industrial emitters and hub developers.

with a CO_2-absorbing liquid in a counter-current fashion. The CO_2-absorbing liquid typically contains amines and water. The scrubbed gas is released at the top, with a large share of CO_2 removed. The amine solvent is then transported to another vessel, called a stripping column, where the solvent is heated up using high-temperature steam. Upon heating, the CO_2 is released from the amine solvent. The released CO_2 undergoes a series of purification processes before the purified CO_2 is then compressed for transport.

Alternative approaches to capture CO_2 after combustion include the use of solid calcium oxide, interacting with carbon dioxide in flue gas to become calcium carbonate, which is then heated to reverse the reaction and generate concentrated CO_2.[85] The materials and components used for the various carbon capture methods tend to be different due to the distinct underlying separation principles.

A general list of manufacturing segments and components for carbon capture technology is, therefore, difficult to develop. However, the different carbon capture processes share some general components mainly used in the compression (after the carbon capture), purification, liquefaction, and storage phases.[52] These components required for compression, filtering, storage, and transport share similarities with equipment used in the oil and gas industry, as well as other manufacturing industries. While specialised CCS components do exist, their industrial production is not yet widespread due to the currently limited deployment of carbon storage and transport technologies. It is important to note the dual-use nature of these components. Compressors, liquefiers, and filtering machinery are also used for other gases, while scrubbers (amine solvents) serve as feedstock for detergents, emulsifiers, polishes, and pharmaceutical products. Consequently, PRODCOM codes used to track EU industrial production offer only limited insight into CCS technology trends.

Classifying the sub-groups of components in CCS reveals that compressors (EUR 9.3 billion) and machinery for filtering and liquefying gases (EUR 7.8 billion) dominate the market. Scrubbers account for around EUR 1 billion of industrial production in 2022.[86] Industrial production data from Member States are often kept confidential, with key producers like France, Sweden, and Poland not disclosing specific figures. Germany, however, stands out as a significant producer, contributing just under 30 percent of the total EU industrial production in scrubbers.

Through the trade analysis, we can identify the EU Member States that are most competitive in exporting goods that are relevant for CCS. These reveal that Romania is amongst the most competitive EU and international exporters of pumps and compressors for air or gas and machinery for filtering or purifying gases. Additionally, Romania's exports of machinery for filtering or purifying gases increased by 762 percent to nearly EUR 500 million between 2016 and 2022, illustrating its growing competitiveness in this technology. Other competitive exporting EU Member States include Poland and Germany, both of which are also found to be more competitive exporters of machinery for filtering or purifying gases than other third countries.

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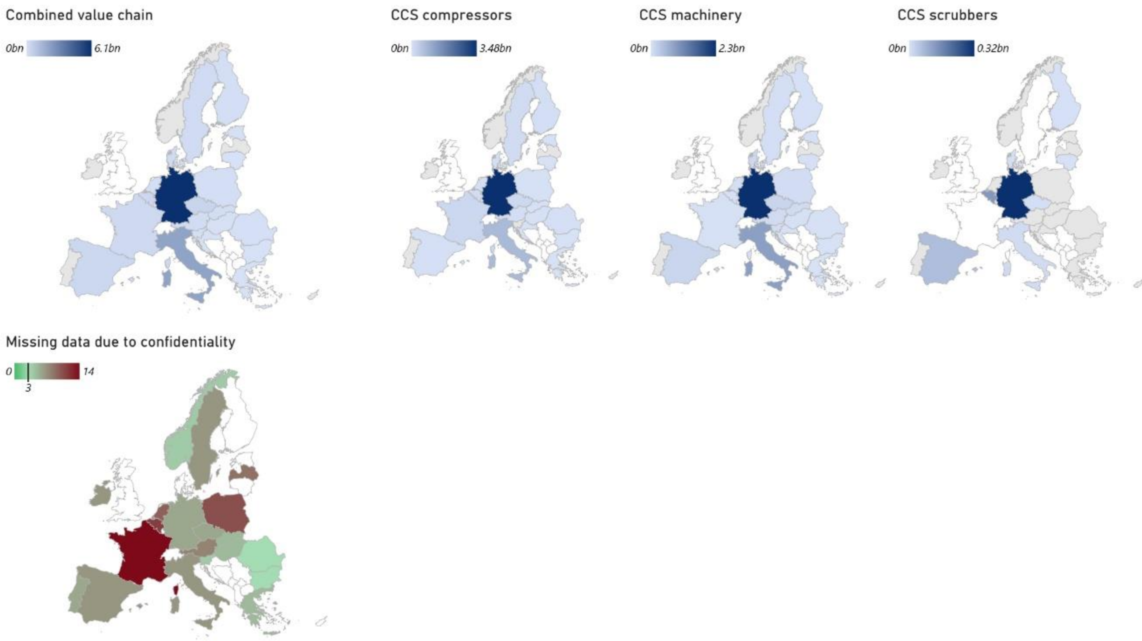
[85] It is worth noting that other technologies under development focus on capturing fuel *prior* to combustion, by treating it at high temperature to derive hydrogen from the process.

[86] It is worth stressing that all these figures capture the total market in the EU, regardless of end-use.

Figure 2.13 Distribution of production: CCS technologies



Note: The visual illustrates the industrial production value in euros for the year 2022. Each map depicts a grouping of relevant components or end-use products identified during the research. An overview of included components and products is provided in Annex I, Table A-3. Source: PRODCOM. White areas indicate unavailable data, while grey areas represent an industrial production value of zero. The map highlighting missing data indicates the number of unavailable product codes, which may result in the underreporting of industrial production values for certain countries.

2.2.8 *Grid technologies*

The increasing importance of deploying smart grid technologies arises from the growing demand for electricity and the widespread integration of variable renewable energy sources, demanding flexibility and efficient utilisation. In the context of Net-Zero technologies, existing literature on smart grid technologies primarily refers to the power grid and smart metering infrastructure.[87]

- Power grid components:
  - Cables, including high-voltage cables (for both AC and DC) used in transmission grids, which carry large loads from production centres to distribution points, and lower-voltage cables for distribution grids, which deliver electricity to households and businesses.
  - Grid components that ensure the safety and reliability of electricity supply and that are used in transmission and distribution (sub)stations. This includes components such as insulators, switchgears, transformers and voltage and current regulators.
- Smart metering, components that aim at efficiently managing electricity supply and demand using information technology and data exchange. This allows end-users (consumers and industry) to actively participate in the smart grid by adjusting their consumption to avoid energy peaks.

[87] IEA.2023. Electricity Grids and Secure Energy Transitions. Available at the following link. JRC.2023.. Smart grids in the European Union: Status report on technology development, trends, value chains and markets. Available at the following link.

Manufacturing activities for each type require several additional components and specialised machinery:

- Power grid: specialised machines such as winding machines, extruders, and coating machines are typically used. These machines are essential for shaping, insulating, and coating the conductors to meet the required specifications for high-temperature superconductivity. Stakeholders in the EU cable industry suggested that the largest cable producers in Europe source their machinery from specialised suppliers, but no information on their suppliers is publicly available.
- Meters: smart meters involve digital technologies, and thus necessitate precision assembly machines and calibration equipment. Additionally, these components rely on semiconductors and circuit boards.[88]

The industrial production of HVAC (High Voltage Alternating Current) and HVDC (High Voltage Direct Current) cables in the EU has seen significant growth, spurred by the rising demand for renewable energy integration and grid modernisation (see Figure 2.14 below). Italy leads in cable production with EUR 1.2 billion, followed by Sweden at EUR 0.8 billion, and Germany at EUR 0.6 billion. Combined, these three countries account for slightly less than 50% of the total EU market, valued at EUR 5.8 billion in 2022. France and Poland are also believed to have substantial industrial production capacities, but specific data for these countries remains confidential. A similar trend is observed for distribution cables, though detailed conclusions are challenging to draw due to confidentiality constraints.

With regard to cables in particular, stakeholders consulted indicated that the EU holds technological and manufacturing leadership globally, particularly in the industrial production of HVAC and HVDC cables. The top EU producers we identified are Prysmian Group (Italy), Nexans (France), and NKT (Denmark).[89] Important regional producers include Tele-Fonika (Poland) and Hellenic Cables (Greece). Cable production facilities are present in Germany, Italy, France, Denmark, Belgium, Croatia and Poland, among other EU Member States.

The industrial production of grid components is distributed across EU countries. With regard to grid applications including inverters, transformers and cables, Italy appears to have a relatively strong industrial ecosystem.[90] Finland and Spain also have a strong presence in producing control-related components such as inverters, rectifiers, and capacitors.

It is challenging to pinpoint specific components or end-use products in smart metering, since metering functions may also be embedded within specific products, such as automated charging systems for electric vehicles. However, electrical control boards can serve as a proxy, yet of course also are used for other (general) purposes.

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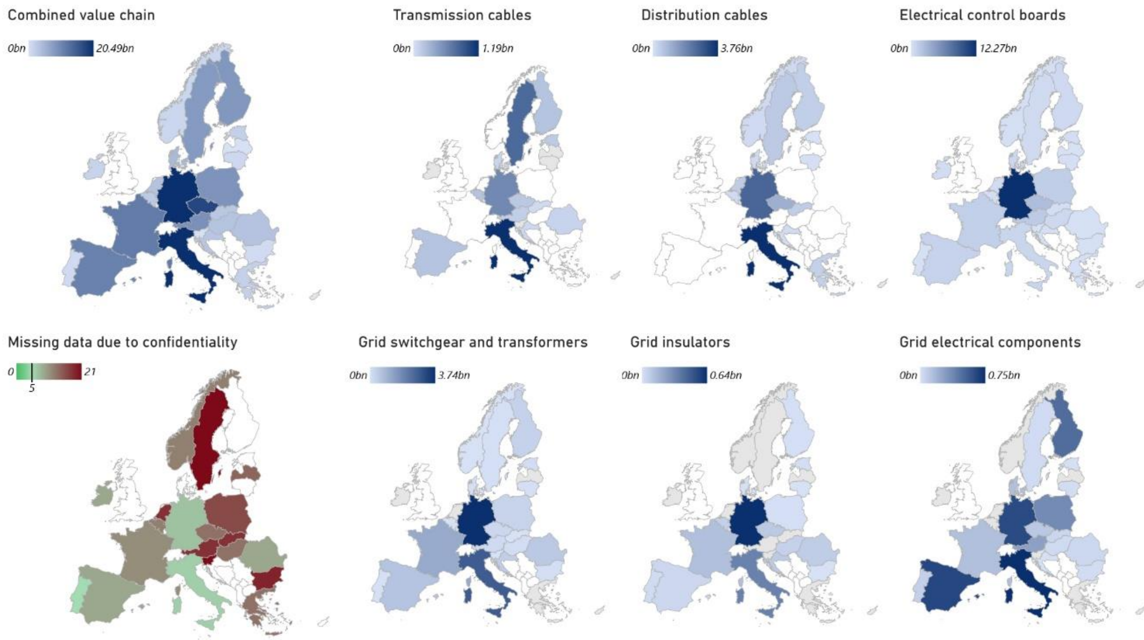
88 Other components which might be relevant to include are those that are used in meteorological stations to ensure accurate forecasts (pyranometers, pyrheliometers and anemometers), which play an essential role in the management of electricity smart grids.

89 According to their reporting, Prysmian and Nexans' sales amounted to 15 and 7 billion EUR respectively in 2023. See here and here.

90 See, for instance, Deloitte and Confindustria. 2024. Le competitività nelle tecnologie verdi Una nuova politica industriale per le imprese italiane Available at the following link.

Figure 2.14 Distribution of production: grid technologies



Note: The visual illustrates the industrial production value in euros for the year 2022. Each map depicts a grouping of relevant components or end-use products identified during the research. An overview of included components and products is provided in Annex I, Table A-3. Source: PRODCOM. White areas indicate unavailable data, while grey areas represent an industrial production value of zero. The map highlighting missing data indicates the number of unavailable product codes, which may result in the underreporting of industrial production values for certain countries.

An analysis of international trade indicators highlights that eleven EU Member States are competitive exporters of cables – with a higher RCA index relative to third-country exporters such as India and China. [91] It is worth noting that the export market concentration for many electrical grid components remains low, suggesting that these are markets where EU producers may face competition in the future (see Figure 2.15 below).

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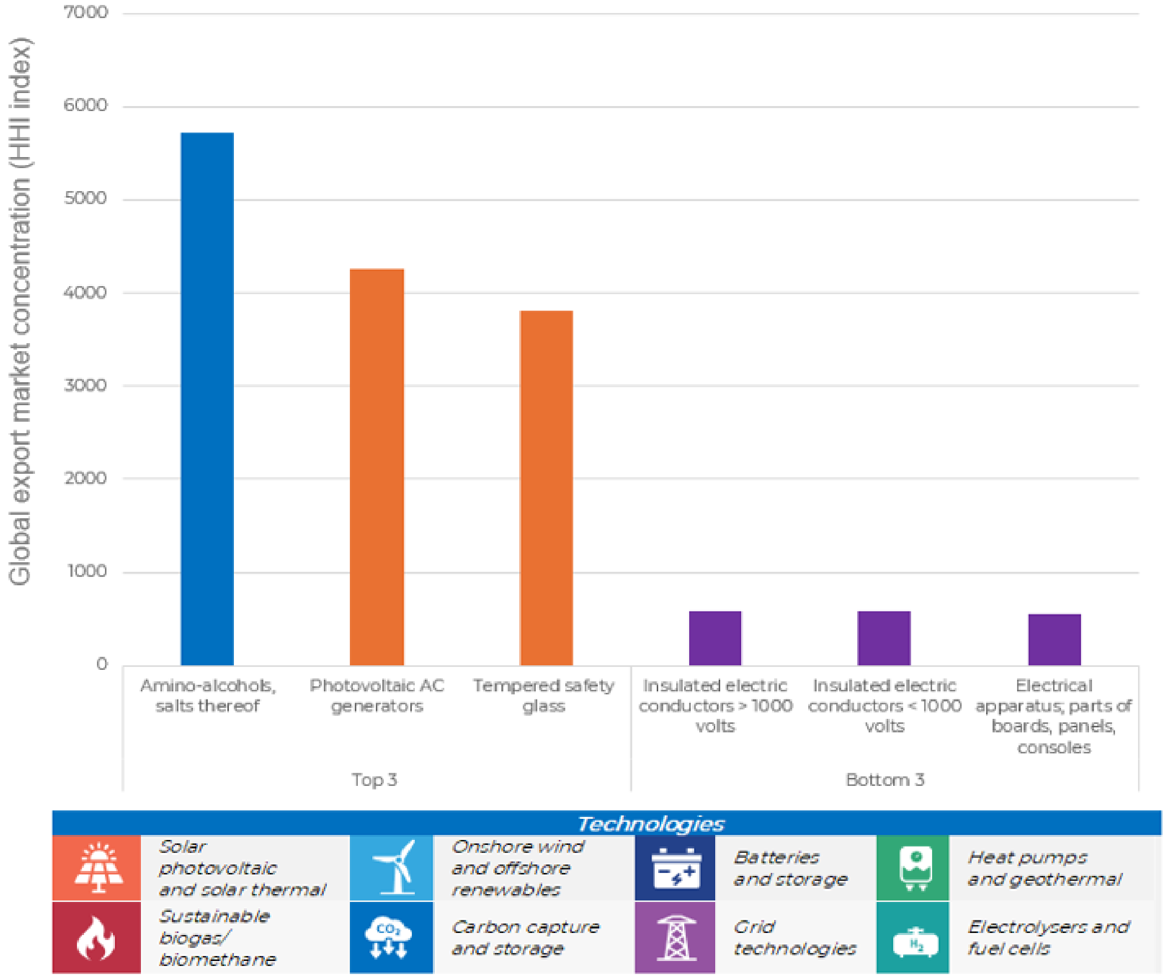
[91] Leading cable manufacturers in Croatia include, amongst others, EuroCable Group, and Elka.

Figure 2.15 Top/bottom three components: export market concentration [92]



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Note: Amino-alcohols are scrubbers used in CCS technologies, amongst other applications (HS codes 292211, 292212, 292214).

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[92] The global export market concentration (measured by the Herfindahl-Hirschman Index, HHI), reflects market saturation levels for each component. Higher concentration (higher HHI) indicates more saturated markets, implying potential challenges for further market entry, while lower HHI suggests open markets with growth potential.

3 Mapping of Member States' existing enabling frameworks to foster manufacturing capacity of Net-Zero technologies

The EU and its Member States have several tools at their disposal to strengthen and shape the development of the manufacturing capacity for Net-Zero technologies and their components. These include EU and national regulatory instruments, economic incentives, skill policies, and simplified and digitalised administrative procedures. Jointly, these tools can provide an enabling framework that steers investments, ensures the availability of necessary skills, and establishes the appropriate regulatory environment to support increased manufacturing capacities.

The impact assessment of the NZIA identifies this framework as one of the key enablers to enhance the manufacturing of Net-Zero technologies within the EU.[93] Consequently, the NZIA complements and builds on existing policy initiatives at the EU level and aims at accelerating the build-up of industrial production capacity. To gain a better overview of the enabling framework for Net-Zero manufacturing across the EU, we complemented the available research on EU-level interventions, by focusing on measures and instruments put in place at the national level. Building on an integrated data collection approach that combines desk research and interviews at the Member State level, this chapter provides an overview of support mechanisms in place across the EU.

Research on the enabling framework mirrors some of the key areas of action as defined in the provisions of the NZIA. Notably, the research explored the regulatory and policy framework in each Member State, identified instruments to induce investment, and mapped relevant skill programmes and policies:

- Regulatory/policy framework: Research focused on the identification of policies and strategies that develop a vision or specify objectives, targets, and milestones relevant to the eight technologies captured by this study. Research also captured relevant legislation that includes provisions in relation to Net-Zero technologies, which usually aim at facilitating investment in and build-up of manufacturing capacities. In line with the ambitions of the NZIA, the mapping put particular emphasis on gathering information on permitting processes, their duration and authorities involved, the presence and design of relevant regulatory sandboxes, as well as on dedicated requirements on Net-Zero technologies in procurement.
- Investment support: The data collection at the national level explored any type of fiscal schemes, tax and support measures that provide monetary incentives to invest in the manufacturing capacity for Net-Zero technologies and their components in the EU, and which help to close a potential financing gap.
- Skills policies: With regards to skill policies, the mapping aimed in particular at identifying relevant re- and upskilling programmes and projects across the Member States that aim to address the skills needed for the industrial production of the technologies and components covered by the study.

The scope of the research encompassed the Member States of the EU and explored existing as well as planned measures. Due to the focus on manufacturing capacity, particular emphasis was put on measures that target the supply side i.e. the industrial production of Net-Zero technologies and their components themselves, rather than

[93] SWD(2023) 219 final

their installation and deployment. However, depending on the technology and the design of the measures, the approach remained flexible to capture relevant instruments more widely. For example, demand-side measures are included in the mapping if they include requirements to install Net-Zero technologies produced within the EU.

As the NZIA is relatively recent, research also included policies and supply-side measures that do not explicitly target Net-Zero technologies but can benefit them due to their design and objectives (support for green transition, and sustainability). For skill programmes, the research focused on programmes that make an explicit link to Net-Zero technologies and the capacity of people to manufacture the respective products. A more detailed description of the methodology is presented in Annex X.

3.1 Overall findings

The map below visualises the findings from the mapping. Research identified relevant measures and instruments in 22 of the 27 EU Member States.[94] Relevant policies or legislative frameworks that (also) support the production capacity of Net-Zero technologies have been identified in 18 Member States. Incentive schemes of various forms are present in 19 Member States, and for 15 Member States, the research identified relevant skills and education programmes.

The research did not yield relevant measures in Greece, Cyprus, Latvia, Malta, and Portugal. Data from the mapping of the manufacturing landscape in the previous chapter suggest that these are Member States where current industrial production levels of Net-Zero technologies and their components are comparatively lower for the technologies covered in this study.[95] In light of the recent adoption of the NZIA and the upcoming implementation efforts of the EU and the Member States, this picture is likely to change in the near future.

For another twelve Member States, research yielded measures across all aspects of the enabling framework explored, which suggests that these countries take a more comprehensive approach to support manufacturing capacities of sustainable products in general and – to some extent – also Net-Zero technologies and their components in particular.

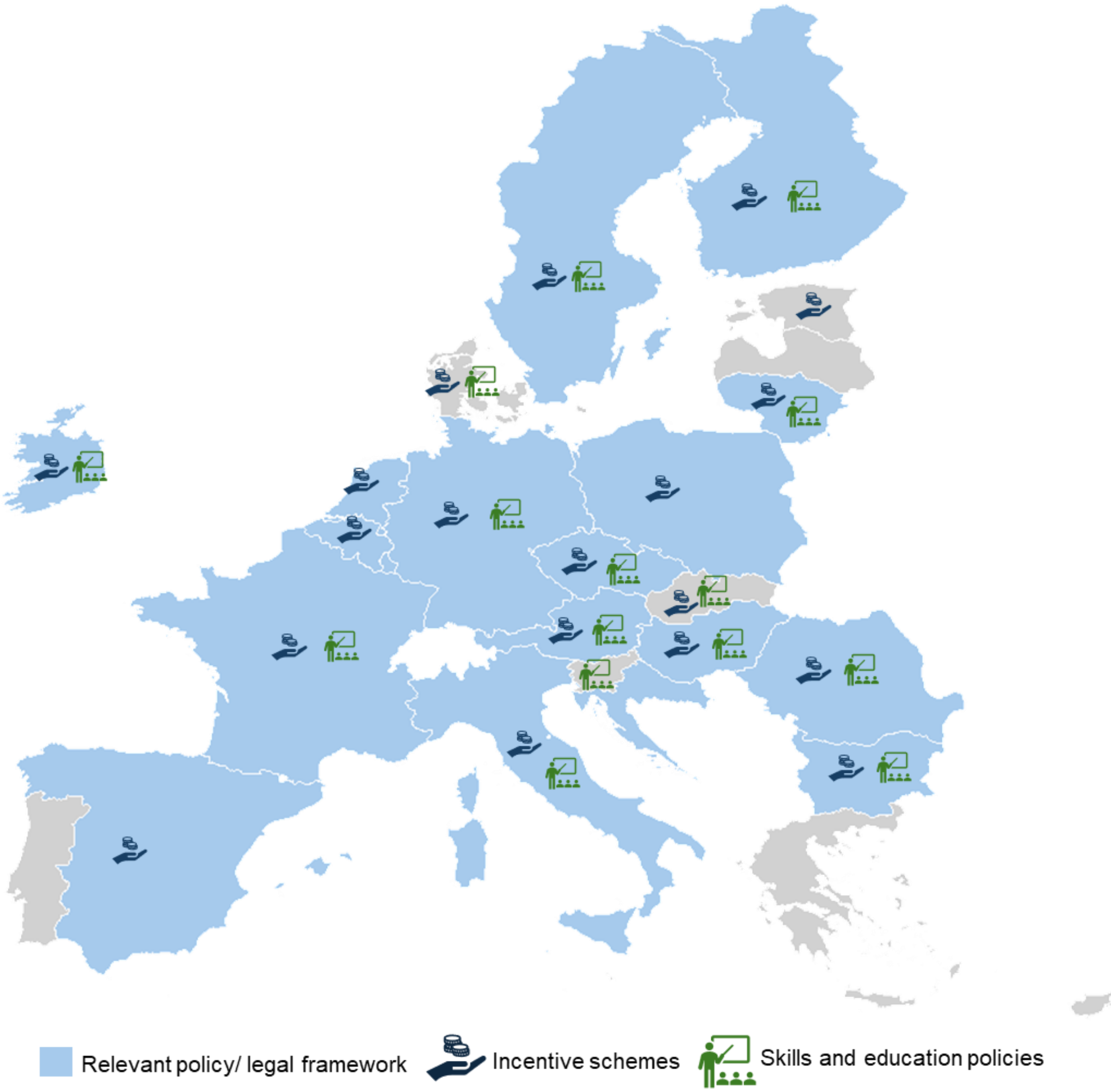
Many of the identified policies are sectoral policies which tend to focus on aspects related to the deployment of Net-Zero technologies but also contain elements such as objectives or targets that link to the manufacturing capacity. Electrolysers and fuel cell technologies, as well as batteries and storage technologies, are the Net-Zero technologies for which the most relevant policies have been identified across the Member States.

Most of the identified incentive schemes offer grants to manufacturers. Especially in recent months, there has been an increasing number of support schemes that target investments in the national Net-Zero technology manufacturing capacities in particular. This trend is linked to an increased number of state aid schemes that the European Commission has approved under the Temporary Crisis and Transition Framework.[96]

The following sections highlight additional findings for each dimension of the enabling framework that has been explored in the research.

[94] The research was performed until June/July 2024.
[95] Although the role of Greek companies in the production of components for grid technology (HV cables) is noteworthy.
[96] https://competition-policy.ec.europa.eu/state-aid/temporary-crisis-and-transition-framework_en

Figure 3.1 Availability of a support framework across the EU



Source: own elaboration

3.2 Regulatory framework

Our research explored the extent to which Member States have strategies and legislation in place to support the manufacturing of Net-Zero technologies and their components. Another area of our research focused on the duration and complexity of industrial permitting processes, often described as a major obstacle to the installation of new manufacturing capacity. The mapping also aimed to identify any initiatives taken by Member States to reduce industrial permitting requirements or to streamline the permitting process. In line with the ambitions of the NZIA, the research further examined dedicated provisions in public procurement and the presence of relevant regulatory sandboxes.

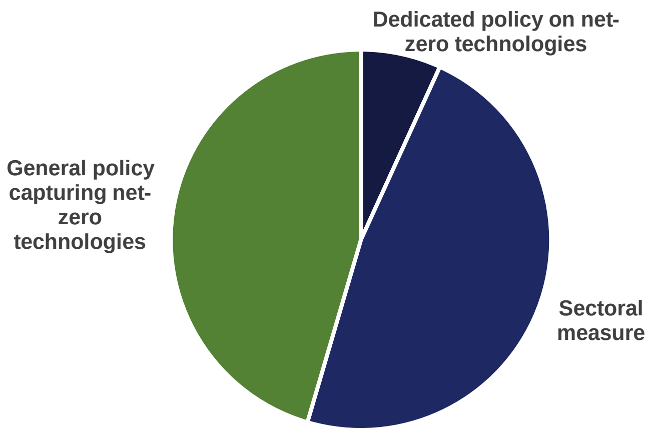
3.2.1 Supporting legislation and policies

As mentioned above, relevant policy initiatives, strategies, and legislation have been identified in more than half of the EU Member States. These include Austria, Belgium, Bulgaria, Czechia, Germany, Ireland, Spain, France, Croatia, Italy, Lithuania, Luxembourg, Hungary, the Netherlands, Poland, Romania, Finland and Sweden.

There are a limited number of dedicated policies that explicitly address and target the manufacturing capacity for Net-Zero technologies as such. Consequently, the research also included policies that are broader in scope, but still have a clear focus on sustainability and the manufacturing of sustainable products, which are expected to benefit Net-Zero technologies as also defined in the scope of this study. In many instances, the research also yielded relevant sectoral strategies, i.e. those that are designed for one or some of the relevant technologies. The figure below provides a breakdown of the identified policies and legislation.

It shows that of the 44 policies identified, 25 policies address either one or several of the Net-Zero technologies covered by the study directly. In most cases, these are sector-specific policies (21 instances). The remaining 4 policies are dedicated to Net-Zero technology manufacturing as such (i.e. they cover most or all technologies of this group explicitly). The other 19 policies are usually wider in scope. Some are technology-agnostic, while some cover several Net-Zero technologies. For most of these policies, the supply-side dimension is not very well-developed, measures remaining high-level.

Figure 3.2 Number of policies by type



Source: own elaboration

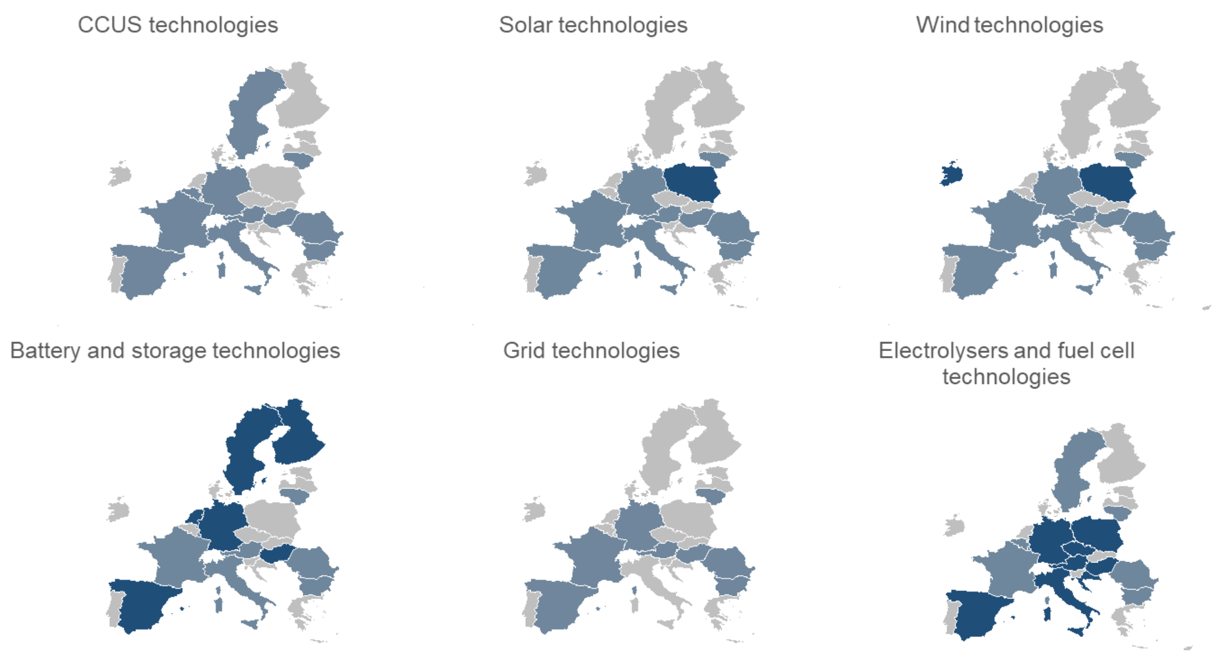
The table below reports on the relevant technologies that are targeted by the individual measures identified. Partly due to the prevalence of hydrogen strategies across EU Member States, electrolysers and fuel cells are addressed through 27 strategies, including the nine strategies that have been identified that target all Net-Zero technologies. This is followed by batteries and storage technologies (22 measures), wind (19 measures), and photovoltaic (18 measures). The least strategies address grid technologies as well as sustainable biogas and biomethane.

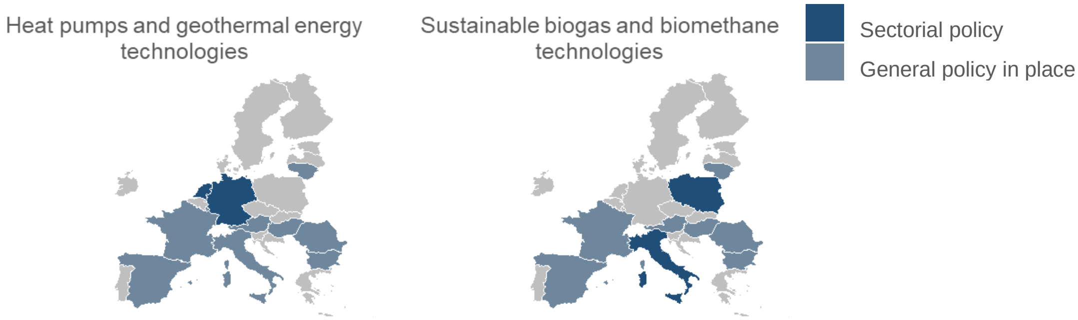
Table 3.1 Overview of policies by technology and number of Member States covered

Technology	Number of policies	Number of Member States
Electrolysers and fuel cells	27	15
Battery and storage technologies	23	13
Wind technologies	20	12
Photovoltaic and solar thermal technologies	19	11
Heat pumps and geothermal energy technologies	17	11
Carbon Capture and storage (CCS) technologies	16	11
Grid technologies	13	8
Sustainable biogas and biomethane technologies	12	9

The maps below show where our research found relevant policies across the EU by net-zero technology. Policies for electrolysers and fuel cells can be found in about half the Member States, and policies for CCS technologies, photovoltaics and solar thermal technologies, wind, and batteries reach similar numbers of Member States.

Figure 3.3 Country coverage through relevant national policies





Source: own elaboration

Sectorial policies

Electrolysers and fuel cells are commonly addressed through national hydrogen strategies (Austria, Czechia, Germany, Spain, Croatia, Hungary, Italy, and Poland). While these strategies primarily focus on the deployment and utilisation of hydrogen, some also emphasize the industrial production of associated technologies. For example, Croatia's strategy aims to integrate the country into the European and global hydrogen technology markets by enhancing its manufacturing capabilities for electrolyser layers, fuel cell bundles, and related measurement, control equipment and sensors.[97] Similarly, Spain's strategy aims to develop and create a new innovative industrial value chain linked to hydrogen technologies.[98]

Another technology for which several Member States have relevant sectoral strategies in place is batteries and energy storage technologies (Germany, Spain, Finland, Hungary, the Netherlands, and Sweden). Hungary's strategy notably aims to develop financial instruments to support sustainable technologies for innovative clean technology companies in the battery value chain and to provide workforce training along the technology's entire value chain.[99] In Spain, the national action plan for electric vehicles encompasses proposals addressing original equipment manufacturing (OEM) and assembly, the manufacturing of hydrogen batteries and cells, as well as other essential components adapted to electric and connected vehicles.[100] The Finnish battery strategy sets out objectives and proposes actions to strengthen the position of Finnish companies, products and services in global competition.[101] This includes for example steps to grow and renew existing battery clusters, incentivise investment and enhance competitiveness, but also actions to raise awareness for Finnish products in third countries and measures to enhance the sustainability of the sector itself, strengthening circular economy components.

Other sectoral strategies target wind technology (Ireland and Poland), heat pumps (Germany and the Netherlands), photovoltaic (Poland), and biogas and biomethane (Poland and Italy). For example, Ireland's offshore wind industrial strategy foresees several measures to strengthen its manufacturing capacities.[102] These include the establishment of an Offshore Wind Centre of Excellence (OWCE) to facilitate collaboration between supply chain companies, government agencies, and education institutions to access and implement new technologies, such as floating offshore wind and digital solutions, to address industry challenges and enhance

97 Ministry of economy and sustainable development (2022). Hydrogen strategy of the Republic of Croatia until 2050, available here.
98 Ministry for the Ecological Transition and Demographic Challenge (2020). Hydrogen roadmap, available here.
99 Ministry of Technology and Industry (2022). National Battery Industry Strategy 2030, available here.
100 Ministry of Industry, Trade and Tourism (2021). Strategic Projects for Economic Recovery and Transformation (PERTE) on Electric and Connected Car, available here.
101 Ministry of Labor and the Economy (2021). National battery strategy 2025, Available here
102 Department of Enterprise, Trade and Employment (2024). Ireland's Offshore Wind Industrial Strategy, available here.

sector competitiveness. The strategy will also investigate Green Energy Industrial Parks, aiming to provide comprehensive property, utility, and infrastructure solutions on a large scale. The Polish cooperation agreement between the state and sectorial actors aims at identifying barriers and opportunities to strengthen the build-up of a national photovoltaic equipment industry.[103]

General policies

The research across Member States also yielded a number of strategies and legislation which address Net-Zero technologies more broadly. This includes measures typically focussed on green transition, clean energy production, climate action plans, or industrial strategies. Related policies have been identified for 13 countries (Austria, Belgium, Bulgaria, Germany, Spain, France, Hungary, Italy, Lithuania, Luxembourg, Poland, Romania, and Sweden). For example, in Lithuania, the national energy independence strategy aims "to reduce its dependency on imported energy technologies to instead become a country creating and exporting energy technologies".[104] Through its Green Nation strategy, France also refers to its ambition to become the first European green (industrial) economy by 2040 to master and produce Net-Zero technologies in France through the Green Industry Law and the 2030 Investment plan.[105] The Italian National Recovery and Resilience Plan foresees a number of measures on different Net-Zero technologies.[106] This includes investments to support the productive system for the ecological transition, competitiveness and resilience of strategic supply chains, including the industrial production of Net-Zero technologies, such as batteries, solar panels, wind turbines, heat pumps, electrolysers, and devices for carbon capture and storage. In Austria, the master plan for environmental technologies defines actions until the year 2030. Several have effects on manufacturing, even though an explicit objective on this is not defined. These include incentives for clean technologies for example through supporting innovation and pilot projects, targeted financial support programmes and platforms for collaboration between environmental technology companies.

Germany, Spain, France, and Italy have established specific and dedicated legislation to enhance and support the country's manufacturing capacities of Net-Zero technologies. In France, the French Green Industry law adopted in October 2023 aims to reduce the length of permitting procedures for all industrial sectors, including Net-Zero technologies.[107] In addition and for Net-Zero technologies specifically, the law foresees simplifications which are detailed in the following sections. It also foresees incentives to encourage the manufacturing of all eight strategic Net-Zero technologies in France, also detailed further below. In Germany, the revised industrial policy is the overarching relevant policy of the German federal government published in October 2023. The strategy aims to diversify the value chains for Net-Zero technologies and to develop industrial production capacities in Germany and the EU.[108] The strategy lists incentive instruments and financial guarantees for different Net-Zero industrial sectors. It also proposes the addition of qualitative criteria to public procurement that support sustainability and industrial resilience. The German federal government provided the legal basis to translate the state aid scheme approved by the European Commission under the Temporary Crisis and Transition Framework into specific measures to enhance the production capacities of Net-Zero technologies.[109] Luxembourg is currently working on a bill to accelerate administrative procedures related to the manufacturing

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103 Available here

104 Ministry of Energy. National Energy Independence Strategy, available here.

105 French government (2022). France Nation Verte, available here.

106 Available here

107 Ministry of economics and finance (20230. Green Industry Law, available here.

108 BMWK (2023). Industriepolitik in der Zeitenwende, available here.

109 BKR-Bundesregelung Transformationstechnologien, see here.

of renewable energy, distribution and storage, heat pumps, electrolysers and fuel cell technologies.[110] In Spain[111] and Italy[112], the respective national recovery and resilience plans cover the manufacturing of Net-Zero technologies explicitly. Both plans provide the policy framework under which the respective measures are designed that provide financial incentives and investment support to enhance the production of relevant Net-Zero technologies.

3.2.2 *Industrial permitting*

Permitting can create bottlenecks at two important stages for Net-Zero technologies, namely at the manufacturing stage (industrial permitting) as well as at the installation and deployment of the technologies. Research in the scope of this study suggests that most of the information focuses on the deployment stage, which is however outside the scope of this study.

Net-zero technology manufacturing projects undergo lengthy and complex permit-granting processes which can last several years, depending on the Member State, the technology and value chain segment[113]. Industrial permitting is often seen and characterised as a major obstacle to the installation of new industrial production capacity for Net-Zero technologies, as also pointed out in the impact assessment for the NZIA.[114] Due to the extensive time required for obtaining permits, which can vary unpredictably across different segments of the value chain and can take up to 4 years or more for projects in sensitive areas, the EU currently faces a competitive disadvantage compared to other regions globally.[115]

This notion echoes wider discussions on red tape which can be linked to more stringent environmental requirements and rules on public consultations for large investments, such as infrastructure and industrial production facilities. Furthermore, a recent cross-sectoral survey performed by Business Europe among 240 companies in 2023 suggests that 83% of the respondents identified permitting as an obstacle to investments in the EU. The data presented suggests that the permitting process took between one and three years for 47% of the respondents, and three to six years for another 12% of respondents.[116] Frequently mentioned challenges experienced by the surveyed companies include the complexity of procedures, the number of authorities involved in the permitting processes, the time it takes authorities to respond, as well as the (human) resources available.[117]

Experts from EU industry associations, national industry associations and research and technology organisations (RTO) consulted through roundtable discussions confirmed permitting challenges as a priority issue across various technologies both for manufacturing and deployment. For onshore wind and offshore technologies, permitting issues have slowed down progress also for their deployment, reducing demand for manufacturers, while China surged ahead, installing two-thirds of the new wind energy capacity worldwide.[118] Also, for biogas and biomethane, lengthy permitting procedures were identified as a key issue to address. A recent survey

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110 Chamber of Commerce Luxembourg. Projet de loi n°8284, available here
111 See here.
112 See here.
113 Net-Zero Industry Act
114 SWD(2023) 219 final.
115 SWD(2023) 219 final.
116 https://www.businesseurope.eu/sites/buseur/files/media/reports_and_studies/2024-02-13_businesseurope_permitting_swot_analysis_-_final_report.pdf.
117 https://www.businesseurope.eu/sites/buseur/files/media/reports_and_studies/2024-02-13_businesseurope_permitting_swot_analysis_-_final_report.pdf.
118 Global Wind Energy Council (2024), Global Wind Report 2024, available here

conducted among the Biomethane Industrial Partnership (BIP) members active across Europe showed that permitting procedures for deployment can take two to three years on average, with peaks of five to seven years.[119] These delays likely impact manufacturers of biomethane technologies, as slower project deployment reduces demand for the equipment and technologies needed for industrial production facilities, thus increasing the risks and costs for project developers, and affecting industrial production cycles, innovation, and scaling of new technologies.

Permitting process

Our country research indicates that in most countries, there is a broad range of permits that may be required. Generally, there are no specific permitting procedures reserved exclusively for the manufacturing of Net-Zero technologies, which tend to follow the same administrative steps and requirements as any manufacturing facility. Nevertheless, the specificities of certain technologies may require specific ad-hoc permits. This is evident in some countries where additional environmental considerations, such as treating chemical waste and fire hazard requirements, are prescribed for batteries, e.g., specific provisions found in Bulgaria, Finland, Netherlands, Romania, and Sweden.

The exact number and type of permits depend on various factors, typically related to the complexity of the project, including the scale and size of the industrial production site, the type of activity, and the expected environmental impact of the intended manufacturing plant, which can lead to a high number of permits required. Common permits across countries include environmental impact assessments and various other environmental permits, such as those for emissions to air, pollution of the ground and water, noise, waste management etc, as well as building permits and urban planning permits, which are generally within municipalities' remit. These permits are typically issued by authorities at different administrative levels. Competencies may vary between national, regional and local authorities, particularly based on the scale of the manufacturing facilities involved. Furthermore, specific permits may be mandated under certain conditions, such as in the presence of environmental constraints (e.g. zones of archaeological interest as seen in France, Italy and Hungary), or contingent upon the technology (e.g. for handling dangerous waste in the case of batteries, as seen in various countries), and size of the manufacturing plant.

In many countries, the permitting procedures are partially or fully digitalised (Bulgaria, Croatia, Finland, France, Germany, Greece, Hungary, Italy, Ireland, Lithuania, Netherlands, Romania, Spain, and Sweden), with various efforts being undertaken to further modernise and digitalise the administrative steps. For instance, Bulgaria recently digitalised the 'integrated permit' procedure, Czechia introduced a new permitting law that foresees a completely digitalised process, and Slovenia is developing a new e-building platform for permitting through digital means.[120]

However, further efforts are required to ensure that digitalisation consistently improves efficiency across all administrative steps. The new World Bank's Business Ready (B-READY) initiative[121], which replaces the previous Doing Business project, provides additional insights into the business environment across countries. Notably, the *Business Location* topic assesses key aspects such as regulatory and governance quality, as well as the transparency and operational efficiency of services related to property transfers, building permits, and environmental permits. The indicator on the digitalisation of public services shows a wide variation in the level of

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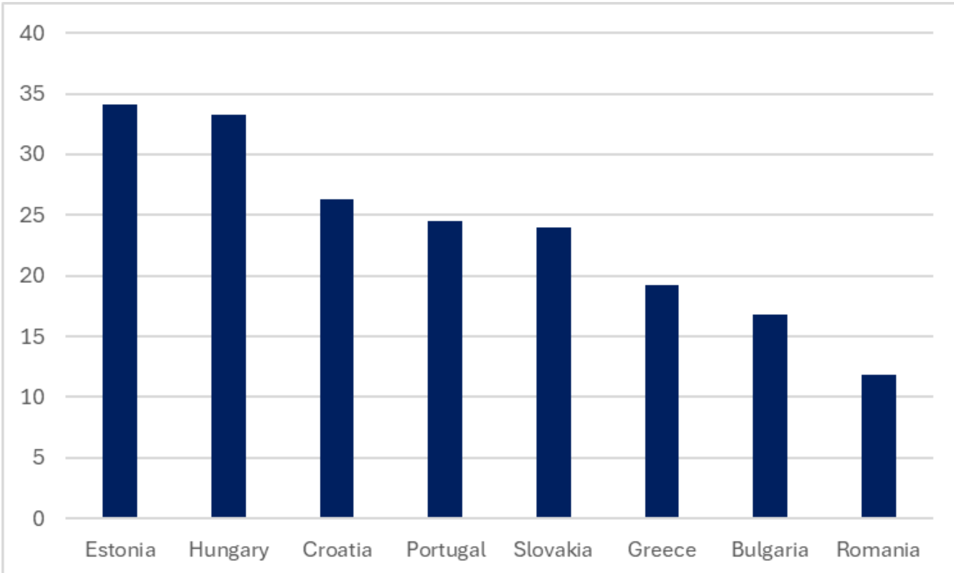
[119] BIP (2023), Accelerated Biomethane Permitting, available here

[120] Available here

[121] World Bank Group (2024), available here

digitalisation across both EU countries for which data are available (see the figure below) and types of permits. Some countries appear to perform relatively well based on the overall scores, however, there still seems to be room for improvement for most of them. In particular, the sub-indicator for digital public services related to environmental permits shows relatively lower scores on average (3.3 out of 8), although with significant variation across countries (ranging from 0 to 7.2 out of 8)[122].

Figure 3.4 Availability and Reliability of Digital Services across countries (max score = 40)



Source: World Bank, Business Ready (B-READY) 2024. Note: The scores in the graph range from 0 to 40, with higher scores indicating greater digitalisation of public services. A score of 40 represents a fully digitalised process, while a score of 0 indicates no digitalisation. The final score is an aggregate of five sub-indicators, each scoring from 0 to 8: 1) Property Transfer – Digital Public Services; 2) Property Transfer – Digital Land Management and Identification System; 3) Property Transfer – Coverage; 4) Building Permits – Digital Public Services and; 5) Environmental Permits – Digital Public Services.

Our country research also shows differences within and across countries. For instance, according to some industrial stakeholders in Austria, physical document submissions are still the standard for industrial permits,[123] while in Sweden some steps have been taken, such as the possibility to send and sign forms digitally, but no digital interactive platform has yet been established.[124] In Germany, 9 out of 16 federal states have cooperatively developed a digital tool for the creation and submission of applications, called ELiA.[125] In Lithuania, documents can be submitted digitally. However, there is no integrated information system through which the permits can be requested (currently being developed through a project funded by the Cohesion Fund[126]). In Italy, most procedures are digitalised, with the permitting procedure for Environmental Impact Assessment allowing for requests and documentation to be submitted through digital means. In some other countries, digitalisation varies by type of permit. For instance, in Poland, building permits can be submitted electronically,[127] but environmental

[122] World Bank, Business Ready (B-READY) 2024

[123] Stakeholder interview

[124] Stakeholder interview

[125] Available here

[126] Interview with competent authority

[127] Available here

permits are mostly on paper, similar to Croatia (for location and construction permits). In Greece, all environmental licensing procedures are carried out through the Digital Environmental Register.[128]

Permitting duration

The duration of permitting procedures for setting up or expanding the manufacturing of Net-Zero technologies varies widely across countries, ranging from a few months to several years. Despite the established timelines for procedure lengths outlined in relevant national legislation, delays and extended permitting procedures are frequently encountered in practice across various countries. Authorisation processes often extend for multiple years beyond the legal limits, making accurate and systematic cross-country comparisons of permitting timelines highly complex. Typically, across all countries certain circumstances can significantly prolong the duration of these procedures, such as in the case of litigations, several requests for supplementary investigation and information by the competent authorities, or when an activity may require a preliminary "screening decision" on whether it shall be subject to an environmental impact assessment. Therefore, processing times vary widely across countries, depending on which steps of the process are included in the calculation. For instance, concerning the "screening decision" for environmental impact assessments (EIA), the legal duration may vary between one month in Finland, 60 days in Sweden, 90 days in Denmark,[129] and 90 days in Italy (more in case of requests for supplementary information).[130] In some countries, for instance, permit decisions are also challenged either by the applicant or the public concerned, with the appeals stages significantly affecting the overall procedures' duration. Consequently, estimates of permitting times and cross-country comparisons should be approached with caution, as they are highly context-specific.

The differences in permitting timelines are not driven by the type of technology used, but rather by the scope and nature of the economic activities involved. Projects with larger scales or those that pose higher environmental risks, such as those involving significant emissions, tend to undergo more stringent and lengthy permitting processes.

While it appears that there is a lack of reliable and comparable sources or data on the exact duration of permitting procedures, our research (completed before the adoption of NZIA) suggests that the permitting process in many countries currently still exceeds the time limits set by the NZIA for Net-Zero strategic projects (9 to 12 months) and Net-Zero technology manufacturing projects (12 to 18 months).[131]

The figure below aims to provide an overview of the information collected through country research on the duration of various permitting procedures and puts these into relation to the ambitions of the NZIA for the permitting duration. Note that, as discussed above, the comparability of the data across countries is limited. Reported durations refer to different types of permits across countries for which data were available, as detailed further in the text. The figures presented below are sometimes derived from information gathered through interviews with relevant authorities in Member States and, as such, constitute anecdotal evidence. Additionally, in some countries, the available information does not provide a detailed breakdown of administrative steps included in the overall calculation.

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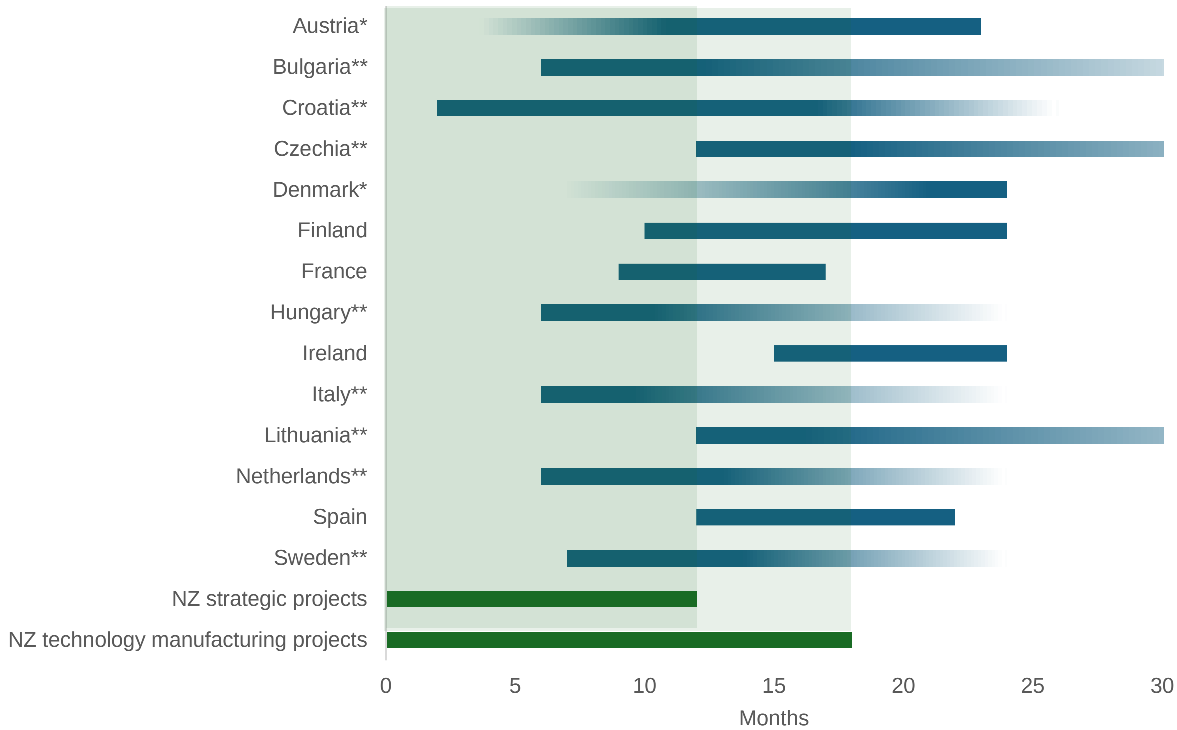
[128] Available here

[129] Nordic Council of Ministers (2023), *Nordic Environmental Permitting processes*, available here

[130] Ministero dell'Ambiente e della Sicurezza Energetica, *Indicazioni operative per la procedura di Verifica di assoggettabilità alla VIA,* available here

[131] However, Article 9(4) NZIA specifies that "Where an environmental impact assessment is required pursuant to Directive 2011/92/EU, the steps of the assessment referred to in Article 1(2), point (g)(i), of that Directive shall not be included in the duration of permit-granting process referred to in paragraphs 1 and 2 of this Article."

Figure 3.5 Duration of permitting procedures



** No clear lower bound available; ** No clear upper bound available.*

Source: own elaboration. Note: Research was conducted before entry into force of NZIA.

A recent report from the Nordic Council of Ministers highlights that in Finland, the duration for obtaining permits depends on their type, with EIA and chemical permits typically taking approximately 10 to 13 months[132] (with our country research showing, on average, that these timelines may extend beyond this range[133]) and other permitting, such as building permits, potentially taking weeks to 13 months. The report also finds that the EIA procedure typically takes between 12 to 24 months in Denmark, when other permitting procedure per se can last less than 7 months.[134] In Sweden, despite large variation between individual cases, environmental permitting can take between 1 - 1.5 years for first-time applications, or 2 - 3 years for appeal procedures (from first application until the decision of appeal).[135] Additionally, 7 to 8 or 12 to 18 months in Sweden may be required for other permits, depending on the authorities delivering them.

Our country research found that in Austria, for projects requiring an environmental impact assessment, the average process duration is 22 to 23 months.[136] In Czechia, permitting processes can currently take from 12 months up to several years depending on specific circumstances (e.g. delaying factors such as local spatial

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132 Nordic Council of Ministers (2023), *Nordic Environmental Permitting processes*, available here

133 Interview with national authority.

134 Nordic Council of Ministers (2023), *Nordic Environmental Permitting processes*, available here

135 https://www.naturvardsverket.se/4acdf4/globalassets/vagledning/miljobalken/miljoprovning/uppdrag-att-analysera-statistik-for-miljotillstandsprovningen-2022.pdf

136 Environment Federal Office (2023), Duration of the EIA approval procedures between 2014 and 2023, available here

planning decisions and lengthy EIA processes).[137] In Bulgaria, the permitting procedure can take from 6 months to multiple years, depending on the complexity of the project, indicating a relatively lengthy process.[138]

France's permitting process for new factories typically ranges from 9 to 17 months.[139] Italy's Environmental Impact Assessment procedures can take anywhere from 5 to 6 months to more than a year to complete, depending on the complexity of the project and specific circumstances (e.g. need for pre-screening, request for integration of information etc.).[140] However, in practice delays can occur leading to overall durations of multiple years, as pointed out by industrial reports on renewable energy projects[141].

In the Netherlands, an extended procedure applies to environmental impact assessments, with the competent authority deciding within 6 months of an application. However, objections and appeal procedures can extend this period substantially (by 1 or 2 years). In Lithuania, the duration can vary greatly (1 to multiple years) for all the necessary permits and there is no standard length of the procedure, as it depends on various factors.[142]

Hungary's process varies depending on circumstances but typically spans at least a year.[143] In Ireland, licensing procedures can take up to 15 to 24 months. In Spain obtaining a favourable environmental impact statement can take 18 to 22 months, while in Croatia this can take 2 to 6 months, with substantial deviations (according to industrial stakeholders, this can take up to 2 years).[144]

Furthermore, evidence suggests additional common factors contributing to the length and potential delays of permitting procedures. The extended duration of environmental impact assessments, driven by multiple administrative steps such as consultations, ad-hoc studies, and objections, along with lengthy appeal procedures, is a significant factor contributing to the prolonged permitting process, as found in different countries. This is also in line with findings from a recent survey performed by Business Europe, showing that for 63% of companies, the EIA process regularly causes delays in the permit-granting process. The main challenges faced by companies during the EIA process include: (1) authorities not respecting mandatory deadlines or tacit approval requirements, (2) the slow pace of public consultations, with stakeholders opposed to the project failing to engage constructively, and (3) the complexity of EIA provisions arising from multiple overlapping EU and national legislation[145].

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137 Interview with national authority
138 Interview with national authority.
139 Interview with national authority.
140 Italian Ministry of Environment and Energy Security, available here
141 See for example Elettricità futura (2021). *Il disegno del sistema autorizzativo per decarbonizzare e rilanciare gli investimenti*, available here
142 Interview with national authority
143 Interview with a legal expert
144 Stakeholder interview
145 https://www.businesseurope.eu/sites/buseur/files/media/reports_and_studies/2024-02-13_businesseurope_permitting_swot_analysis_-_final_report.pdf.

Limited administrative capacity and insufficient human resources within public administration, sometimes exacerbated by the absence of dedicated organisational units, are noted in several countries, including Austria, Bulgaria, Croatia, Finland, France, Italy, Lithuania and Romania. A recent study also highlighted this as a factor negatively affecting processing time in Nordic countries.[146] This issue is particularly evident also in cases involving planned "fast tracks" for green transition projects, which necessitate shorter timeframes for granting permits.

Bottlenecks are also identified due to the involvement of multiple levels of governance and numerous institutions, as well as the absence of a single competent and centralised authority overseeing the entire process, as observed in various countries (e.g. in France, Hungary, Ireland and Italy). This results in a cumbersome, complex, and decentralised system, lacking adequate coordination and uniformity of direction. Often, despite regulations stipulating identical procedures in every region or province, actual practices and timelines vary, with each region or province adopting specific and sometimes divergent approaches. The table below summarises some key obstacles in the permitting process identified in our country research.

Table 3.2 Drivers of delays in permitting procedures across Member States

Country	Obstacles/ key drivers of the permitting procedure's length
Austria	Environmental Impact Assessments (EIA) with expert studies and consultations are a major driver. Local spatial planning and limited administrative capacity also contribute to delays.
Croatia	Key challenges include limited administrative capacity, a lack of necessary by-laws, and inconsistent regulations across sectors. High staff turnover and excessive regulations further complicate processes.
Czechia	Local spatial planning varies by municipality, and EIAs for environmental permits often cause delays due to the time required for specific studies.
Denmark	Lengthy processes due to local environmental impact assessments.
Finland	Appeals can take up to two years and may restart the process. The limited administrative capacity of competent authorities also causes delays.
France	Delays due to the involvement of multiple bodies (courts, environmental authorities) at different governance levels and limited administrative capacity.
Germany	Delays in commencement of construction, the requirement for administrative hearings (Erörterungstermin), lengthy document assessments, and restrictions on submitting non-critical documents at a later stage.
Ireland	Delays due to limited resources, application prioritization, and the quality of submitted applications.
Italy	Fragmented processes across regions, lack of centralized authority, unclear regulations for new solutions (batteries, heat pumps), and limited administrative capacity hinder permitting.
Lithuania	Delays stem from poor-quality submissions, public opposition during EIAs, and limited administrative and technical capacity to assess new technologies.
Netherlands	Appeals to permits by stakeholders can take up to two years due to court processes, delaying construction starts.
Romania	Administrative capacity, public acceptance, and the understanding of new technologies are key obstacles.
Spain	Permits involve various authorities (municipal, regional, national) depending on project location, adding complexity and potential delays.
Sweden	Highly sensitive areas (e.g., ecosystem services) increase the risk of appeals, and limited authority resources slow down processes.

146 Nordic Council of Ministers (2023), *Nordic Environmental Permitting processes*, available here

Country	Obstacles/ key drivers of the permitting procedure's length
Slovenia	Delays are mainly due to the numerous administrative steps required before submission and difficulties in gathering all required documents.
Slovakia	Appeals challenging decisions at multiple stages are one of the main drivers of delays in the permitting process.

Source: Country research

Member States initiatives

According to the Commission Staff Working Document[147], some Member States, including Belgium,[148] Denmark,[149] the Netherlands,[150] and Germany (albeit only at a regional/cluster level), have implemented some forms of one-stop shops (OSSs). Our country research reveals additional examples of OSSs already established or under development. However, the adoption of OSSs remains limited in both scope and geographic distribution across the EU.

In Italy, an example of a one-stop shop exists, albeit not specifically targeted at Net-Zero technologies. Notably, the one-stop shop for business activities (Sportello Unico per le Attività Produttive - SUAP) is a specialised office established in each municipality. It oversees all procedures related to the initiation and operation of productive activities and service provisions, including actions concerning location, construction, transformation, restructuring, expansion, or relocation, as well as the cessation or reactivation of productive activities.[151]

In France and Germany, leading and coordinating competent authorities, such as DREAL in France, gather input from other relevant authorities. However, the specific competent authority responsible depends on the location of the industrial facility.

In Romania, there is an Industrial License Office in charge of the rationalisation, simplification and digitisation of the specific procedures in order to grant a single industrial license.[152]

In Finland, an ongoing project aims to develop a one-stop shop to streamline the permitting of projects impacting the environment. This initiative involves establishing a single nationally competent authority responsible for permitting, guidance, and supervision. The new one-stop shop is expected to become operational by 2026.

In Czechia, a recent law sets up a permitting OSS, with the local building authority which will act as OSS for industrial construction permits (local spatial planning is still separate due to constitutional rights given to municipalities).[153]

Other mechanisms for expediting permitting procedures for potential producers of Net-Zero technologies have been identified. The most common measure involves granting special status and priority to strategic projects.

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[147] SWD(2023) 219 final.
[148] https://permis-environnement.spw.wallonie.be/home.html
[149] https://ens.dk/sites/ens.dk/files/Globalcooperation/one-stop_shop_oct2020.pdf
[150] https://business.gov.nl/regulation/environment-and-planning-permit/
[151] Italian Parliament, *Sportello unico per le attività produttive*, available here
[152] https://lege5.ro/Gratuit/gezdqmrwgizti/oficiul-pentru-licenta-industriala-ordonanta-de-urgenta-140-2022?dp=guydemrqgm4tqni#google_vignette
[153] Interview with national authority

In Finland, temporary priority is being given to processing permits for green transition projects by the Regional State Administrative Agencies between 2023 and 2026.[154] Similarly, the Hungarian government can classify projects as priority investments for the national economy, allowing for an easier permit process and shorter administrative deadlines.

In France, the introduction of the new Green Industry Law foresaw the need to reduce the length of permitting procedures. This will be achieved by allowing parallel processing of the instruction process and public consultation, which previously had to be conducted sequentially. Moreover, for projects deemed to be of national interest (e.g., those contributing to the green transition or enhancing the resilience and autonomy of the French industry), specific procedures apply. These procedures facilitate a quicker compatibility process between local and regional urban planning documents and include provisions for derogations (e.g., rules on protected species).

In Italy, a dedicated technical commission is responsible for conducting environmental impact assessments for strategic projects falling under national jurisdiction included in the National Recovery and Resilience Plan (such as those promoting manufacturing of Net-Zero technologies) and the implementing projects of the National Integrated Plan for Energy and Climate. A fast-track process was recently introduced through a simplification decree law for these projects, reducing the permitting procedure's duration from the current approximately 360 days of the ordinary process to 175 days of the expedited process.[155]

In Germany, for certain types of facilities, a simplified procedure (V-Verfahren) without public participation is applicable. The applicable procedure depends on the type and size of the industrial facility. Accelerated permitting processes are used in Germany, an example of this is the newly built battery production site for batteries by TESLA in Germany, for which permitting took 843 days.[156]

In Spain, Law 7/2021 on Climate Change and Energy Transition introduces several measures to speed up the transition to a low-carbon economy, including the priority processing of strategic projects that support this objective.

In Slovakia, the Action Plan for implementing the National Hydrogen Strategy outlines several measures, including the development and approval of legislative intentions to streamline permission processes for hydrogen technologies. This initiative aims to simplify procedures such as environmental impact assessments, planning processes, and building permit approvals by 2024. The Ministry of Economy, in collaboration with various institutions, is responsible for overseeing this effort, which is funded through the Recovery and Resilience Plan.[157]

Furthermore, under the Investment Promotion Act in Bulgaria, projects that meet certain requirements (incl. thresholds for investment size and/or jobs created) can receive different statuses in law. Such investment projects benefit from a range of measures, including faster administrative procedures (up to 1/3 reduction in time), individual administrative procedures (one-stop-shop), financial assistance, tax relief, and others.[158]

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154 Ministry of the Environment (2023), *Legislative project for one-stop services,* available here

155 Italian Parliament, *La Commissione tecnica per la VIA dei progetti PNRR-PNIEC,* available here

156 https://www.brandenburg.de/cms/detail.php/bb1.c.732543.de.

157 Ministry of the Economy of the Slovak Republic, *Action Plan measures for the successful implementation of the national hydrogen strategy* , available here

158 FAO (2022), available here

3.2.3 *Public procurement*

The NZIA aims to create the necessary conditions to facilitate investments in Net-Zero technology manufacturing. One of the key points of access to markets for Net-Zero technology manufacturers is public procurement procedures. Although EU legislation on public procurement allows contracting authorities and entities to incorporate qualitative, environmental, and social aspects into award criteria as part of the most economically advantageous tender notion, these authorities and entities rarely utilise these possibilities, with more than half of public procurement contracts being awarded based solely on the lowest price criteria.[159]

The purchase of goods, services and works by governments and public bodies makes up a major part of the European economy. In particular, the purchasing power of contracting authorities in Member States is estimated to total EUR 2 trillion annually, accounting for roughly 14% of the EU's Gross Domestic Product (GDP).[160] Public procurement can play a crucial role in promoting environmental sustainability by influencing both consumption and production practices. By choosing goods and services powered by renewable energy, the public sector can directly and indirectly support Net-Zero technologies. Additionally, through the endorsement and implementation of green public procurement (GPP), public authorities can encourage the development of these technologies within the industry.

In the country research, we investigated two questions relating to procurement, namely rules on the mandatory inclusion of non-price criteria in public procurement of Net-Zero technologies, as well as mandatory rules that favour the purchase of Net-Zero technologies.

Based on the results of our country research, requirements focusing on rules of origin and sustainability for the manufacturing of Net-Zero technologies are extremely limited in public procurement, with France having the most comprehensive measures, current and planned. In some public procurement procedures for renewable energy projects, there are requirements on the carbon footprint of the technology. This is usually considered in the score of the tenders with a weight of approximately 30% of the overall score.[161] As for rules of origin, for the moment, some public procurement tenders include a local content criterion which is an indicator measuring the percentage of supplies or services produced by the project promoter or subcontractors on industrial production sites located in the EU. This criterion, included for solar PV and wind energy technologies, does not influence the awarding of tenders. However, France has announced it may establish binding requirements for the source of origin.[162] Furthermore, the French Solar Pact is a new initiative launched by the government and signed by 29 companies committing to enhance the public procurement of European solar PV. The strategy of the Pact is to deploy or buy at least 30% of solar PV certified InduScore A to D from 2025, including 5% solar PV certified InduScore A to C. The categories of the InduScore are based on the number of industrial steps conducted in the EEA area and range from A (4 steps) to E (no steps).[163] In Denmark, minimum environmental requirements for offshore wind installations are in place. These include requirements that the concession holder must obtain third-party verified environmental product declarations for the main components and that the concession holder must prepare a third-party verified life cycle assessment covering the installation, operation, and dismantling of the offshore wind

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159 SWD(2023) 219 final.

160 https://single-market-economy.ec.europa.eu/single-market/public-procurement/digital-procurement/public-procurement-data-space-ppds_en#:~:text=Every%20year%20in%20the%20EU,the%20transparency%20of%20the%20procedures.

161 More information available here.

162 ibid.

163 More information available here.

farm. In addition, reusable turbine blades must be used, and offshore wind farms must be established with a so-called nature-inclusive design adapted to the local area.[164]

Moreover, public procurement rules favouring the purchase of Net-Zero technologies have been identified in Austria, Italy, Lithuania and Latvia. In Austria, federal ministries are required to procure 100% of electricity from renewable sources, including a minimum share from photovoltaics.[165] In Italy, there are minimum environmental criteria for various phases of the public procurement process. These criteria are mandatory in public procurement tenders and are integral to Italy's Green Public Procurement (GPP) policies. These are established by the Ministry of the Environment and cover various sectors including construction, waste management, energy services, and office products. Particularly relevant are the criteria for construction, which favour local renewable energy sources to meet the electricity demand.[166] Recently, Lithuania initiated a public procurement reform aimed at reducing the nation's carbon footprint by integrating environmental considerations into procurement decisions. The Ministry of Environment supported this effort by issuing a decree that established Green Public Procurement (GPP) criteria (including the use of renewable energy) and mandated regular progress reporting. To track progress, the Lithuanian Public Procurement Office (LPPO) utilises open procurement data through a user-friendly public dashboard, prompting authorities to improve their adoption of green practices. Additionally, initiatives such as green fairs, catalogues, and outreach events for vendors have been launched to encourage environmentally friendly procurement habits among government buyers.[167] Latvia has specific public procurement rules to ensure sustainability, requiring compliance with environmental standards and promoting the use of EU-origin technologies where possible.[168]

3.2.4 *Regulatory sandboxes*

Regulatory sandboxes support innovation by allowing businesses to test innovative Net-Zero technologies in a controlled environment under the supervision of a regulator.[169] They usually provide derogations from certain regulatory requirements for a limited amount of time. Regulatory sandboxes provide an opportunity for mutual learning on the part of the regulator and the businesses alike and as such can contribute to innovation and sound policy making.[170]

Research for this study aimed to identify regulatory sandboxes relevant to the manufacturing of Net-Zero technologies. While multiple Member States are planning to implement or have already implemented regulatory sandboxes in the energy sector, many of them are not relevant for the industrial production capacities of Net-Zero technologies, but rather target their deployment (e.g. connecting them to the grid with fewer requirements, applying different tariffs, etc.).[171] Overall, regulatory sandboxes within the scope of the research are in place or planned in nine countries. Although most of these sandboxes are not specifically designed for manufacturers of Net-Zero technologies, manufacturers could still potentially fall within their scope and benefit from the flexible environment they offer for testing and developing innovations.

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164 https://www.kefm.dk/Media/638210640644991461/One-pager%20om%20b%C3%A6redygtighedskrav-ENDELIG.pdf

165 More information available here.

166 Criteri Minimi Ambientali (CAM). More information available here.

167 OECD (2024), *Harnessing Public Procurement for the Green Transition - Good Practices in OECD Countries,* available here.

168 https://www.varam.gov.lv/lv/zala-publiska-iepirkuma-piemerosanas-vadlinijas.

169 The Danish Energy Agency, available here and JRC (2023) *Making energy regulation fit for purpose. State of play of regulatory experimentation in the EU*. Available here.

170 European Commission (2023) *Regulatory sandboxes in the energy sector*. Available here.

171 JRC (2023) Making energy regulation fit for purpose. State of play of regulatory experimentation in the EU. Available here and European Commission (2023) Regulatory sandboxes in the energy sector. Available here.

In Denmark, the regulatory sandbox scheme operates under the Energy Agreements of 29 June 2018,[172] providing a framework for temporary exemptions from specific regulatory barriers hindering the progress of innovative projects in the energy sector. So far, evidence suggests that regulatory sandboxes have primarily been granted to deployment-focused projects, but the framework remains open to any type of project within the energy sector. Various derogations from regulatory obligations can be obtained, as long as they are under the remit of the Ministry of Climate, Energy and Utilities[173]. Lithuania's National Energy Regulatory Council operates a regulatory sandbox for innovative activities and products in the gas, district heating, and electricity sectors, which is open to any party. It envisions a relatively broad possibility for derogations, including from certain licensing and permitting requirements.[174] Though manufacturers are not directly targeted, the scope suggests that both deployment and manufacturing may benefit. In Greece, the Hellenic Competition Commission (HCC) has introduced a Sustainability Sandbox, offering a controlled environment where businesses can develop initiatives that significantly support sustainable development. This sandbox spans a wide range of sectors with a strong emphasis on advancing environmental sustainability, including also technology, environment and energy. While not exclusively aimed at Net-Zero manufacturers, it tackles the broader challenge of modernising Greece's industrial base[175].

In Hungary, In 2021, a modification to the Electricity Act (VET) established the legal foundation for a regulatory sandbox initiative. This initiative is designed to foster the deployment of innovative solutions that promote the sustainable and cost-efficient operation of the electricity system while addressing consumer demands and enhancing supply security. The policy defines energy innovation as the creation or domestic adoption of any technically and commercially founded products, services, technologies, business models, or other concepts that have yet to be implemented in Hungary[176]. This is a broad instrument that targets sustainable electricity-generating technologies without narrowing the target to the supply or demand side. However, according to an interview conducted with a Hungarian stakeholder, while the country did introduce the underlying regulation for the regulatory sandbox, the specific acts implementing the policy have not yet been issued, therefore the system is not yet in use.

In Italy, the Regulatory Authority for Energy, Networks, and the Environment (ARERA) has recently promoted regulatory sandboxes, tailoring the tool to large-scale experiments in the regulated industry. However, these were not so far targeted to manufacturers of Net Zero technologies specifically, but rather to promote the improvement of network reliability, system innovation for the development of renewable gases and hydrogen and innovation in infrastructure.[177] More recently, another initiative, "Sperimentazione Italia" ("*Experimentation Italy*"), allowed start-ups, businesses, universities, and research centres to obtain temporary exemptions from regulatory provisions to experiment with technologically innovative projects. The initiative covers sectors such as generic manufacturing activities and the supply of electricity and gas. While not targeted directly, some manufacturers of NZ technologies may potentially fall within the scope and benefit from these existing initiatives.

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[172] Available here.
[173] JRC (2023) *Making energy regulation fit for purpose. State of play of regulatory experimentation in the EU*. Available here.
[174] European Commission (2023) *Regulatory sandboxes in the energy sector*. Available here.
[175] The Hellenic Competition Commission, see here
[176] JRC (2023) *Making energy regulation fit for purpose. State of play of regulatory experimentation in the EU*. Available here.
[177] JRC (2023), *Making energy regulation fit for purpose. State of play of regulatory experimentation in the EU*, available here.

According to information from interviews, additional regulatory sandboxes are planned in Bulgaria, Latvia, Portugal, and Sweden. Targeting Net-Zero technologies, in particular, these sandboxes were planned recently, partly in reaction to the NZIA.

3.3 Supporting measures

3.3.1 Incentive schemes

Forecasted investment needs associated with boosting EU Net-Zero manufacturing in line with the Act's ambition amount to EUR 92 billion from 2023 to 2030 in total.[178] Meeting this level of support requires actions both at the EU and national level. While several EU programmes and funds contribute to support this effort, these need to be complemented by the Member States and private investments.[179] Therefore, national incentive schemes should play an important role in inducing investment in Net-Zero technologies and boosting the manufacturing of Member States.

Thus, the country research strived to identify and describe the existing funds, grants, and financial instruments that help close financing gaps and can leverage additional public and private investment to accelerate the manufacturing capacities for Net-Zero technologies. Our research focused on measures that target the supply side of Net-Zero technologies, therefore excluding schemes supporting the earlier stages of technology development (e.g. R&D) as well as the demand side (e.g., installation and deployment of the technologies).

The results of the mapping identified 41 incentive schemes. These schemes are either national instruments or under shared management with the EU[180]. Schemes were identified across 19 countries[181]. As depicted by the figure below, our findings show a high concentration of support schemes in Germany and France, followed by Austria, Estonia, Italy, the Netherlands, and Poland – countries which represent more than half of the EU's industrial production.[182].

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178 SWD(2023) 68 final. Note that the EUR 92 billion refer to the baseline scenario. Estimates suggest investment needs ranging between about EUR 52 billion in the status quo scenario to around EUR 119 billion in the scenario with no dependence on imports.

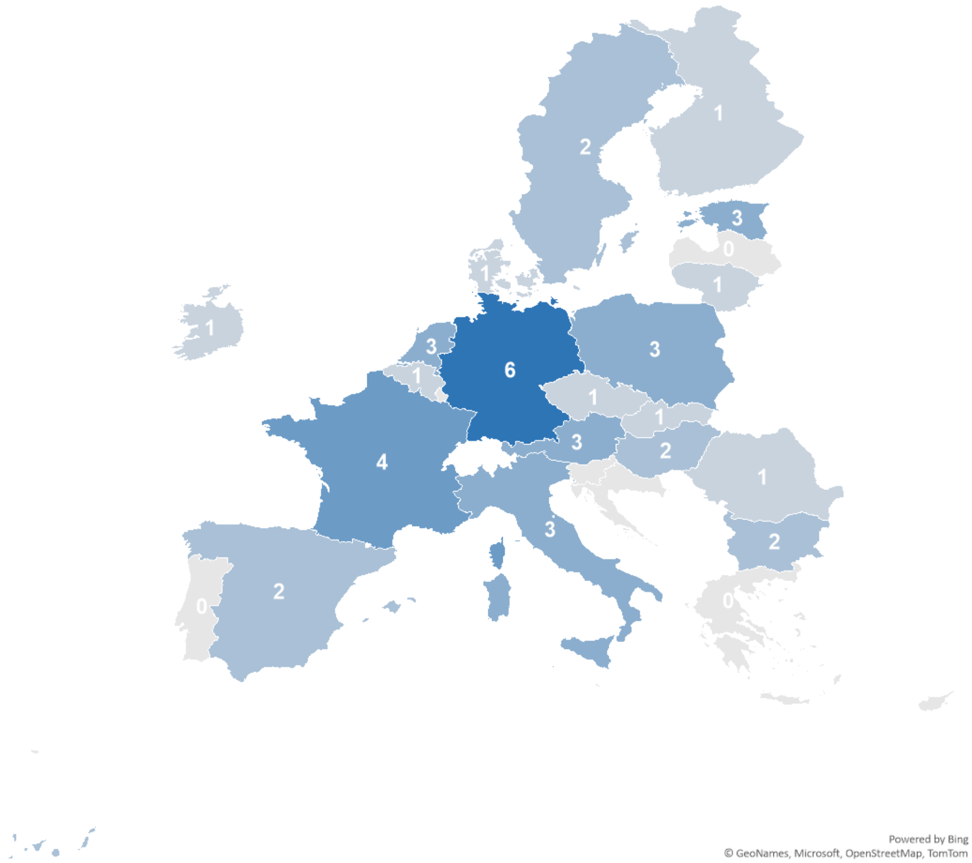
179 SWD(2023) 68 final

180 One identified scheme is implemented by Wallonia (a region in Belgium). However, in this analysis it is considered as a national initiative due to the regional competences in Belgium.

181 Austria, Belgium, Bulgaria, Czechia, Germany, Denmark, Estonia, Spain, Finland, France, Hungary, Ireland, Italy, Lithuania, the Netherlands, Poland, Romania, Sweden, and Slovakia.

182 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Industrial_production_statistics#Industrial_production_by_country

Figure 3.6 Number of incentive schemes



Source: own elaboration, The map reflects individual measures, including those identified as deriving from RRPs

In the sections below we provide an overview of what the different schemes address per Net-Zero technology, as well as an overview of the different types of schemes being implemented by Member States.

Overview of schemes per Net-Zero technology

Batteries and storage technologies, as well as electrolysers and fuel cell technologies, are the technologies which are targeted through the highest number of schemes and in a plurality of Member States. Twelve countries have instruments in place that incentivise investments in electrolysers and fuel cells (17 schemes in total) and 13 countries have instruments that offer support for investments in the manufacturing of battery and storage technologies (17 schemes). The lowest number of schemes were identified for sustainable biogas and biomethane (3 schemes in 3 Member States) and grid technologies (1 scheme).

At the same time, the research identified 13 schemes in 11 Member States that could potentially benefit all technologies covered by this study. Their scope is wide and these schemes do not specifically refer to any Net-Zero technologies, but instead offer support more generally to e.g. 'clean' or 'low-carbon' technologies. The table below provides an overview of these results.

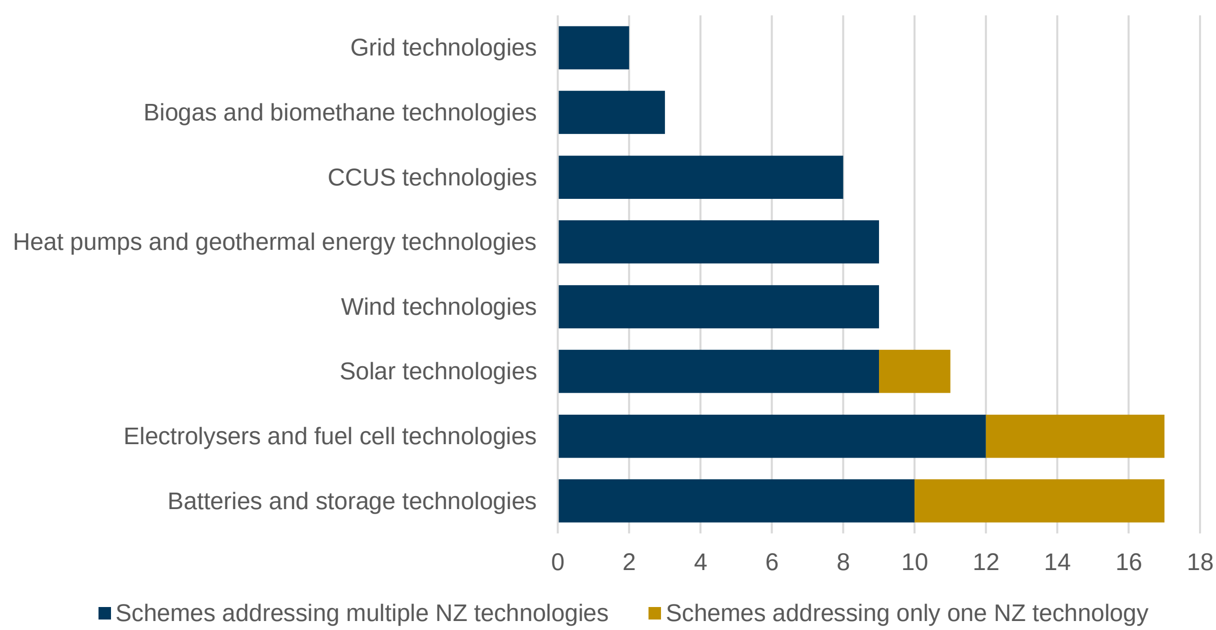
Table 3.33 Overview of schemes by technology and Member States covered

Technology	No. schemes	No. Member States	Member States
Batteries and storage technologies	17	13	AT,BE,CZ,DE,EE,ES,FR,HU,NL,PL,RO,SE,SK
Electrolysers and fuel cell technologies	17	12	AT,BG,DE,DK,ES,FR,HU,IT,NL,PL,SE,SK
Solar technologies	11	8	AT,DE,ES,FR,HU,NL,PL,SK
Wind technologies	9	6	AT,DE,DK,ES,FR,HU,PL,SK
Heat pumps and geothermal energy technologies	9	7	AT,DE,ES, FR,HU,PL,SK
CCUS technologies	8	7	AT,DE,FR, HU,PL,SE,SK
Biogas and biomethane technologies	3	3	BG,DE,SE
Grid technologies	2	2	DE, FR
Covering potentially all	13	11	AT,BG,DE,EE,FI,HU,IE,IT,LT,PL,SE

Note: Some schemes target multiple technologies at the same time. Therefore, the aggregated number of schemes per technology is higher than the total number of schemes listed.

In addition to the 13 schemes that cover potentially all Net-Zero technologies, half of the targeted incentive schemes cover multiple Net-Zero technologies at the same time. This is for example the case in Italy, Sweden, and Spain which support several or all Net-Zero technologies through grants mobilised as part of their recovery and resilience plans. More targeted schemes which address only one Net-Zero Technology include those for Electrolysers and fuel cell technologies (5 schemes; AT, DE, FR, IT, PL), batteries and storage technologies (7 schemes: BE, CZ, DE, EE, ES, NL, RO), and solar thermal and PV technologies (2 schemes; DE, NL).

Figure 3.7 Coverage of incentive schemes



Source: own elaboration

Note: This figure does not include the 13 schemes which do not refer to a specific NZ technology (but instead are more generally to 'clean' or 'low-carbon' tech).

Incentive schemes aiming to support the manufacturing of electrolysers and fuel cell technologies are often implemented in Member States where dedicated hydrogen strategies and roadmaps have been developed. This is for example the case in Germany, Spain, Italy, Poland and Sweden, which each have national policies on hydrogen. In Italy, support for hydrogen technologies is provided through the national recovery and resilience plan which dedicates EUR 250 million in grants to support the installation of gigafactories manufacturing electrolysers and EUR 100 million to support the industrial production of components for electrolysers.[183] In the Netherlands, an investment subsidy scheme (IMKE) is supporting companies' investments to produce (essential parts of) electrolysers, batteries and solar panels to reduce the country's dependence on imports from third countries.[184]. EUR 50 million of the total EUR 142 million available under the fund have been reserved for investments in the manufacturing capacity of electrolysers and fuel cell technologies.

Several schemes supporting the manufacturing of batteries and storage are specific battery initiatives (BE, CZ, DE, EE, ES, NL, RO)[185]. For example, a programme has been initiated in the Netherlands under the National Growth Fund. It has a direct subsidy component of EUR 296 million and partly aims to develop and scale up sustainable battery technology (materials, components and equipment)[186]. It also aims to reduce dependency on international suppliers of necessary raw materials (supply of raw materials through refining and battery recycling), as well as improve battery systems for transport applications and grid stability (heavy transport and large-scale pilots and demos for bulk batteries). In Germany, non-repayable grants of EUR 344.9 million supplement private investments that create or expand industrial production capacities in Germany for the supply chain of battery cells[187]. This support scheme was made possible through a state aid scheme of up to EUR 3 billion that was approved by the European Commission in July 2023.[188] In Belgium, the Wallonia government launched an open call in April 2023 for industrial projects to produce (i.e. manufacture, recycle or recondition) batteries, announcing plans to provide EUR 50 million in subsidies, as the global race steps up to manufacture batteries for electric vehicles and devices[189]. Sweden[190] and the Czech Republic[191] both have initiatives to strengthen coordination efforts with the private sector for battery and battery-powered vehicles. These involve a 'public-private partnership' (between SMEs, large companies, research and public agencies) and a 'mission' (for large establishments of battery factories) respectively. However, for both, it is not clear if monetary support is available.

The schemes identified for solar PV and thermal energy technologies mostly address multiple Net-Zero technologies. However, some dedicated initiatives include for example the Dutch government which is investing EUR 412 million in a national program for the large-scale production of solar cells[192]. The aim of the program is not just the development but also the industrialisation of three innovative solar technologies: 1) high-efficiency silicon "heterojunction" solar cells, 2) flexible solar foils based on the novel material perovskite, and 3) tailor-made solar products for integration in buildings and automotive applications[193]. In Germany, a dedicated scheme

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183 Interview with national authority and see here.
184 See here.
185 The remaining schemes address multiple Net-Zero technologies.
186 See here.
187 Information on the support measure are available here, the budget of the measure can be retrieved from the state budget here.
188 Information on the approved state aid scheme are available here.
189 See here.
190 See here.
191 See here.
192 See here.
193 More information are available here.

aims to promote lighthouse projects in the field of the industrial production capacities of photovoltaics.[194] The goal is to establish a total production capacity of around 10 GW/year along the value chain.

The remaining Net-Zero technologies are only addressed in schemes which are relevant for multiple technologies. Examples of these are given below.

- On- and offshore wind: For example under the Temporary Crisis and Transition Framework, Austria,[195] Germany,[196] Poland,[197] and Slovakia[198] are establishing measures to further accelerate investment support for the manufacturing of strategic equipment, including wind turbines.
- Heat pumps and geothermal: There is generally more reference to heat pumps than geothermal technologies. The French 2030 plan for 'Support for the industrialisation of solutions to decarbonise industry' supports projects addressing compressed air, ventilation and pumping[199]. France also currently has an open call for projects[200] which encourages offers from manufacturers for heat pumps (water/water or air/water) as well as geothermal drilling equipment with the best performance (in surface geothermal energy). A scheme in Hungary encourages the industrial production of technologies that enable the manufacturing of renewable energy devices such as heat pumps.[201]
- CCUS: One notable example is the French 2030 plan for 'Support for the industrialisation of solutions to decarbonise industry'. The scheme aims to enhance the autonomy and resilience of the country's industrial sectors, supporting the creation of new industrial production units as well as investments in existing ones to increase the manufacturing capacity of technologies and components to capture, store, transport and use CO_2.[202]
- Sustainable biogas and biomethane: In Bulgaria, a scheme supports the design of pilot projects enabling the introduction of biogas with application in industrial productions. Investment support will be provided only for new machinery, equipment and facilities (not research and development).[203] In Sweden, a scheme supports the scaling up and commercialisation (close to market projects) of strategically important initiatives such as new technology or innovations including biofuels.[204]
- Grids: In Germany, this includes a scheme to provide equity capital to start-ups in various areas of the economy, including new energy, energy storage, and grid technologies[205]. In France, this includes a scheme providing investment support for the industrialisation of the industrial production and/or assembly of components and innovative network technologies[206].

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194 More information are available here and here.

195 The investment scheme aws growth investment TWIN TRANSITION focuses provides support in the form of grants to a range of relevant investment projects of a minimum size of EUR 4 million. More information can be found here.

196 The German development bank KfW introduced a dedicated line of loans to support investments into Net-Zero technology manufacturing capacities, see here.

197 Support aims at large investment projects of a volume of at least EUR 100 million. More information are available here.

198 See here.

199 These projects must be mature in a sense that they create new industrial production units or invest in existing industrial production units to increase their industrial production capacities, make them more productive and more flexible or to diversify. See here

200 Investment support for the renewable energy industry. See here.

201 More information are available here.

202 These projects must be mature in a sense that they create new production units or invest in existing production units to increase their production capacities, make them more productive and more flexible or to diversify. See here.

203 See here.

204 More information on the Swedish scheme of the "industrial Leap" are available here and here.

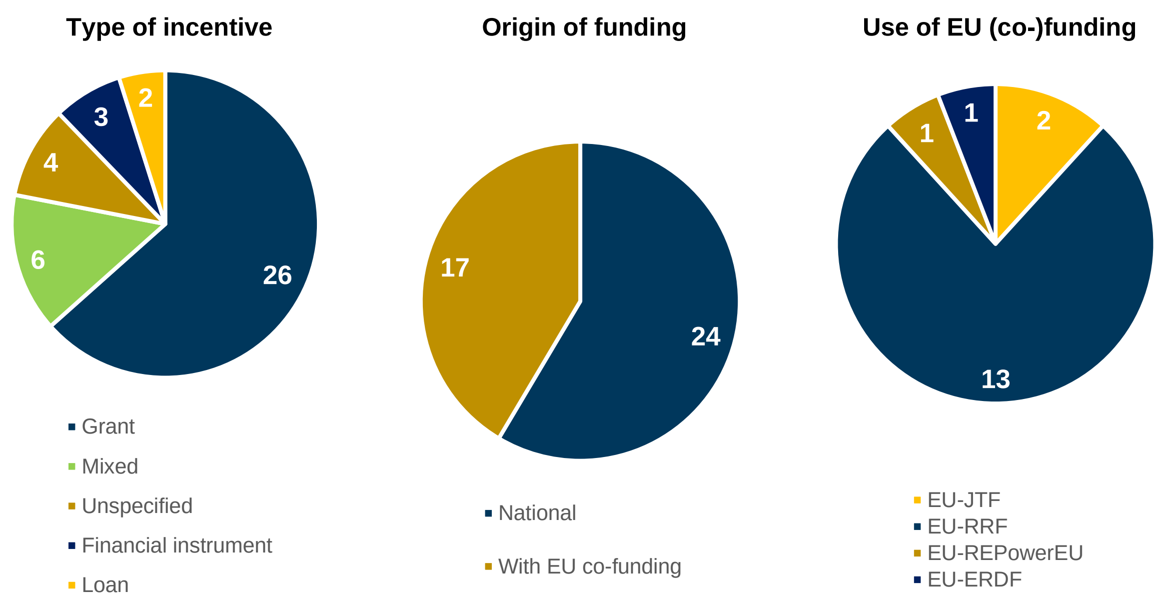
205 The support through the Deep Tech and Climate Fund aims especially at start-ups. See here.

206 See here.

Overview of the types of schemes

The majority of incentive schemes identified are provided as grants to the manufacturing of Net-Zero manufacturing technologies (26 schemes). As shown in the figures below, the remaining schemes involve loans (2 schemes), financial instruments (3 schemes), and mixed (6 schemes). Mixed schemes usually combine grants and loans, while the financial instruments include venture capital and loan guarantees. For four schemes, the exact type of support remains unspecified at the time of writing. The DeepTech and Climate Fund in Germany, for example, offers equity capital investments to start-ups at various stages of maturity in relevant sectors. The investments can range between EUR 1 million and EUR 30 million.[207]

Figure 3.8 Types of incentive schemes



Source: own elaboration

The amount of support available through grants is usually tailored to the size (micro, small, medium and large) of the company. For example, in France, the two France 2030 support schemes for offshore renewable energy, hydropower, heat pumps, geothermal energy, grids and carbon, CCS technologies cover between 15% and 35% of the investment costs depending on whether the stakeholder-supported is an SME or a large company. Their eligibility criteria require a minimum investment of EUR 1 million for SMEs and EUR 2-4 million for larger companies or collaborative projects.[208] Some schemes distinguish support depending on the location of an investment (PL, SK, HU, DE, BG, AT). For example, some schemes distinguish between cities and district capitals (SK[209], HU[210]) and others for certain regions within a state (for example in Austria[211]). In most cases for schemes for information are available, the support is limited to 10% to a maximum of 35% of eligible costs. The eligibility of costs differs across schemes. However, many schemes appear to focus on CAPEX costs, i.e. investments in equipment and physical equipment, rather than running costs (OPEX).

207 See here.

208 See here and here.

209 More information on the eligibility criteria are available here.

210 Support in Budapest cannot exceed 15% of the eligible costs, compared to up to 35% in other parts of the country, see here.

211 The regional support scheme in Styria is only available in some parts of the *Bundesland*, see here.

An overview of examples of amounts of available support per project is provided in the table below for a selection of incentive schemes.

Table 3.4 Examples of national grants for Net-Zero technologies

Member State	Support per project	Name of national grant	Technologies covered
DE	Up to EUR 200 million	Joint task “Improving the regional economic fabric” [212]	Batteries, solar, wind, heat pumps, electrolysers, CCUS
EE	EUR 300,000 million	Support for the development of green technologies[213]	All or nearly all NZ technologies
HU	Up to EUR 350 million	New subsidy scheme under Government Decree No. 210/2014 (VIII.27.)[214]	All or nearly all NZ technologies
PL	Up to EUR 150 million and EUR 350 million depending on location and company size	Aid scheme for the implementation of investment projects of strategic importance for the transition to an economy with net-zero emissions[215]	batteries, PVs, wind turbines, heat pumps, electrolysers and carbon capture and storage equipment

Note: For comparative purposes, the examples in the table are illustrative of the grants at the national level (rather than specific to a certain region in a Member State) which are relevant for multiple NZ technologies.

17 of the schemes identified benefit from the support of an EU programme or fund. Particularly, Member States’ Recovery and Resilience Plans (including their REPowerEU chapters) are the most recurring EU instruments that support incentives in this regard. The schemes supported by such programmes usually benefit from larger amounts of support, ranging from several hundred million euros to more than a billion euros in some cases. This is for example the case of Spain, where EUR 4.2 billion worth of grants and loans will support the country’s manufacturing capacities of batteries and storage technologies[216] and of Italy where about EUR 2.25 billion is allocated to support large-scale investments in the production chains of devices useful for ecological transition.[217]

Additionally, half of the Member States (Austria, Belgium, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Italy, Poland, Portugal, Slovakia and Spain) provide support to electrolysers and fuel cell technologies through the project of common interest for hydrogen (IPCEI Hy2Tech)[218]. Involving more than 40 projects across 35 companies, the IPCEI Hy2Tech aims to scale up the manufacturing capacities for hydrogen technologies and their critical components.[219]

212 https://www.bmwk.de/Redaktion/DE/Downloads/B/202309013-beschluss-grw-koordinierungsausschuss.pdf?__blob=publicationFile&v=8
213 See here.
214 The support ceiling of EUR 350 million applies to regions outside of Budapest. In Budapest, the support can amount to up to EUR 150 million, see here.
215 See here.
216 The scheme aims to enhance investments in the industrial production capacity for batteries intended for electric vehicles, their essential components, and the production or recovery of critical raw materials needed See here,
217 See here.
218 More information on IPCEI Hy2Tech is available here.
219 Note, however, that IPCEI provides a framework and is not a budgetary programme in itself.

Support schemes under the Temporary Crisis and Transition Framework

Under the Temporary Crisis and Transition Framework (TCTF),[220] Member States can receive approval from the European Commission for state aid schemes to strengthen investment projects of strategic importance for the transition to an economy with net-zero emissions. Until the end of October 2024, The European Commission has approved 17 state aid schemes in 13 Member States that benefit investments in the manufacturing capacity of Net-Zero technologies. It is noteworthy that these approved schemes do not present budgetary programmes in themselves, but offer Member States the legal opportunity to create support schemes at the national level. This has happened for a number of the TCTF state aid schemes already (for example in Belgium, Poland, Germany, or Denmark). The total amount of investment support that can be provided through state aid amounts to almost EUR 15.6 billion, which would benefit investments in the manufacturing capacity of Net-Zero technologies in their entirety. The table below provides an overview of the state aid schemes which are directly relevant to the manufacturing of Net-Zero technologies.

Table 3.5 Overview of TCTF support schemes for the manufacturing of Net-Zero technologies[221]

MS	EUR mln	Solar	Wind	Batteri es	Electro lysers	Heat pumps	CCUS	Form of support	EU funding
AT	60	X	X	X	X	X	X	Direct grants	None
DE	3,000	X	X	X	X	X	X	Direct grants; tax advantages; subsidised interest rates on new loans; or guarantees on new loans	None
DK	240		X		X			Direct grants, subsidised loans or guarantees	None
ES	1,100	X	X	X	X	X		Direct grants	Full (RRF)
ES	120	X	X	X	X	X	X	Not specified	None
ES	837			X				Direct grants and loans	Partial (RRF)
HU	2,360	X	X	X	X	X	X	Direct grants and/or tax advantages	None
IT	100				X			Direct grants	None
IT	1,100	X	X	X	X	X	X	Direct grants	Partial (RRF)
NL	158	X		X	X			Direct grants	None
SK	1,000	X	X	X	X	X	X	Direct grants, income tax reliefs, transfers or leases of immovable property for a price below market value	None
PL	1,200	X	X	X	X	X	X	Direct grants	None
PT	1,000	X	X	X	X	X	X	Direct grants	None
PT	350	X	X	X	X	X	X	Direct grants	Full (RRF)
LU	20	X	X	X	X	X	X	Direct grants	None
FR	2,900	X	X	X		X		Tax credit	None
BE	50			X	X			Direct grants	None

[220] https://competition-policy.ec.europa.eu/system/files/2023-12/State_aid_TCTF_decisions.pdf

[221] For a full overview of all approved schemes, please see here.

In terms of the coverage of Net-Zero technologies, batteries and electrolyser technologies are addressed most frequently (15 state aid schemes) with biomethane/sustainable biogas as well as grid technologies not being addressed at all. In terms of EU funding, each of the four cases receiving either partial or full EU funding came from the Recovery and Resilience Facility (RFF). Another relevant finding is that four schemes (in DE, FR, HU, and SK) allow for the use of tax advantages.

3.3.2 Taxation and fiscal schemes

The European Commission, in its Guidance on Recovery and Resilience Plans[222], has recently encouraged Member States to incorporate a range of tax measures into their revised national Recovery and Resilience Plans to support clean tech industries and value chains, including via tax benefits.[223] Since taxation is a prerogative of each Member State, there are no EU-wide tax regimes in place specifically aimed at incentivizing the manufacturing of Net-Zero technologies.

Our research indicates that, within the EU, the majority of taxation and fiscal interventions are currently concentrated on earlier stages of technology development, such as R&D tax credits, as well as on the demand side, with numerous instruments supporting investments in renewable energy installations and adoption. However, a couple of examples relevant to manufacturing within the EU are listed below.

When examining fiscal incentives specifically targeted at supporting the manufacturing of Net-Zero technologies, our country research yielded only one relevant measure. Notably, France has recently introduced the *Crédit d'impôt au titre des investissements dans l'industrie verte* (C3IV), an investment tax credit aimed at supporting companies intending to invest in the industrial production of batteries, wind, solar PV and heat pump technologies.[224] This tax credit provides up to 20% of investment spending for the industrial production of equipment, components and critical raw materials. The credit amount is directly deducted from the company's corporate income tax for the year or financial year in which the investment plan expenditure occurs. In specific cases, such as support in certain regions and for SMEs, the tax credit can be increased to up to 40%. Projections indicated that this incentive could drive EUR 23bn investments and create 40k direct jobs by 2030. As of March 2024, there have been 20 applications filed, totalling EUR 1,8bn[225].

The Accelerated Capital Allowance (ACA) in Ireland is a tax incentive scheme that promotes investment in energy-efficient products & equipment[226]. It is relevant for the industrial production of equipment for specific sectors: wind technologies, heat pumps, and photovoltaic systems. The ACA is based on the long-standing 'Wear and Tear Allowance' for investment in capital plant and machinery, whereby capital depreciation can be compensated through a reduction in an organisation's tax liability. The ACA scheme allows a sole trader, farmer or company that pays corporation tax or income tax on trading or professional income in Ireland to deduct the full cost of the equipment from their profits in the year of purchase. As a result, the business's taxable profits are reduced by the value of qualifying capital expenditure.

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222 European Commission (2023), Guidance on Recovery and Resilience Plans in the context of REPowerEU, available here
223 European Commission (2023), *Green Deal Industrial Plan for the Net-Zero Age,* available here
224 https://presse.economie.gouv.fr/entree-en-vigueur-du-credit-dimpot-au-titre-des-investissements-dans-lindustrie-verte-c3iv/
225 https://presse.economie.gouv.fr/entree-en-vigueur-du-credit-dimpot-au-titre-des-investissements-dans-lindustrie-verte-c3iv/
226 https://presse.economie.gouv.fr/entree-en-vigueur-du-credit-dimpot-au-titre-des-investissements-dans-lindustrie-verte-c3iv/

There is a planned tax reduction for green investments in Finland which will allow relevant companies to pay less on their future profits[227]. This will apply to large industrial investments that support the transition to a net-zero economy, such as battery and hydrogen projects and fossil-free steel. The projects supported may relate to renewable energy production (including hydrogen and hydrogen fuels), electricity and heat storage, and storage of renewable hydrogen, biofuels, bioliquids, biogas and biomass fuels; low-carbon and energy efficiency measures in industrial production processes; investments in the industrial production of equipment (e.g. batteries), key components and related critical raw materials essential for the transition to a net-zero energy economy.

Another example of a relevant tax incentive scheme is in Lithuania, which involves a package of investment and corporate income tax laws offering a new instrument for attracting large-scale investment projects[228]. The initiative provides a much faster and simpler establishment for investors. There is no specific green component requirement for this scheme, and while no tax incentives were identified which would specifically focus on Net-Zero technologies, the tax incentives scheme for large-scale investment benefits Net-Zero technology manufacturing.

International experience shows that other countries have only recently begun to implement fiscal incentive schemes to capitalise on Net-Zero manufacturing opportunities. This underscores the novelty of such instruments and indicates a trend that is just beginning to gain momentum. For instance, the United States' 2022 Inflation Reduction Act (IRA) introduced a Manufacturing Production Tax Credit (PTC) to expand the domestic supply chain of critical components used in advanced energy production. In particular, qualifying manufacturers can claim a credit for the industrial production (within the US) and sale of certain eligible components including solar and wind energy components, inverters, qualifying battery components and applicable critical minerals[229]. Tax credits can be claimed on tax returns through tax year 2029, with partial benefits extending through tax year 2032[230].

Similarly, in Canada, the Department of Finance recently presented a draft legislative proposal for the introduction of a Clean Technology Manufacturing Investment Tax Credit[231]. According to the proposal, the refundable tax credit equals up to 30% of the capital of eligible new manufacturing equipment for key clean technologies, with the rate being progressively reduced starting from 2032 and fully phased out after 2034[232]. To be eligible for the tax credit, the clean technology property is required to consist of new equipment located in Canada and intended solely for use within the country[233].

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227 https://yle.fi/a/74-20084956

228 https://eimin.lrv.lt/en/sector-activities/investment/

229 Internal Revenue Service (2023), *Treasury, IRS issue guidance for the advanced manufacturing production credit*, available https://www.irs.gov/newsroom/treasury-irs-issue-guidance-for-the-advanced-manufacturing-production-credithere

230 Bakertilly (2024), *The section 45X tax credit - A financial catalyst for manufacturers in the advanced energy supply chain*, available here

231 PWC (2024), *Tax Insights: Finance releases draft legislation for the clean hydrogen and clean technology manufacturing investment tax credits*, available here

232 PWC (2024), *Tax Insights: Finance releases draft legislation for the clean hydrogen and clean technology manufacturing investment tax credits,* available here

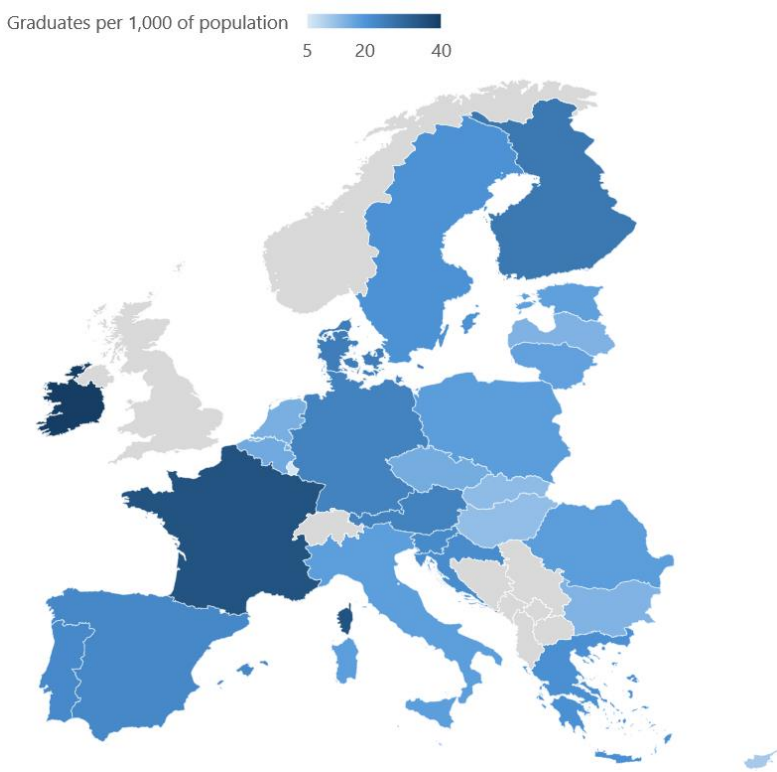
233 EY (2024), *Canada's proposed clean technology manufacturing investment tax credit,* available here

3.4 Skills and education policies

The scarcity of skilled workers in key value chain segments of Net-Zero technologies has been identified as a pressing challenge to the competitiveness of the EU.[234] An estimated 800,000 skilled workers will be needed to meet the EU's ambitions in the battery industry by 2025 alone.[235] In the solar PV industry, an estimated 66,000 workers will be needed by 2030.[236] The nascent EU hydrogen industry is expected to require an additional workforce of 180,000 engineers, technicians, and trained workers by 2030.[237]

An important factor for the provision of skilled workers is formal education. According to Eurostat data[238], there were 56 tertiary education graduates in relevant fields of education (including science, mathematics, computing, engineering, manufacturing, and construction) in Luxembourg and more than 400 graduates in France for every 10,000 people in the respective countries (see also map below).

Figure 3.9 Graduates in tertiary education



Source: own elaboration

More disaggregated data from Eurostat suggests that there are some 350,000 engineering graduates and another approximately 45,000 manufacturing graduates from tertiary education per year across the EU-27. This

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[234] COM(2023) 652 final. Report from the Commission to the European Parliament and the Council Progress on competitiveness of clean energy technologies, pp. 14-16.

[235] European Commission (2023). *ESF+ powers skills for the battery industry*. Available here.

[236] European Commission (2024). *First Net-Zero Academy to train 100,000 workers in the EU solar photovoltaic value chain*. Available here.

[237] Clean Hydrogen Joint Undertaking (2022). *Work Programme 2023.* Available here, p. 120.

[238] Eurostat (2024). Students enrolled in tertiary education by education level, programme orientation, sex and field of education. Available here.

adds to about half a million people graduating from secondary- or post-secondary education in engineering and manufacturing each year.[239] As certainly only a fraction of these graduates will move to companies producing Net-Zero technologies and their components, these estimates showcase the need for additional efforts for re- and upskilling the workforce in relation to the growing needs for skilled workers as discussed above.

While formal education is an important factor in bridging the skills gap, continuing education and dedicated retraining programmes will remain crucial to achieving the EU's ambitions.[240] One of the reasons is that in the greening energy sector, the demand for manual workers and technicians will remain dominant.[241] Thus, Member States must offer access to dedicated training for the Net-Zero technologies manufacturing industry. While EU programmes such as Erasmus+, ESF+, and the Just Transition Fund can help bridge that gap, more specific initiatives are needed.[242] For this reason, the Net-Zero Industry Act will set up dedicated training programmes through Net-Zero Academies and will facilitate the portability of qualifications in regulated professions.[243] The first Net-Zero Academy was launched in June 2024 and will aim to train 100,000 workers for the solar PV industry.[244] A Hydrogen Academy[245] that was launched in January 2024 was announced to be transformed into a Net-Zero Academy by the European Commission in June as well.[246] Previous academies launched at the EU level entail a batteries academy in 2022[247] and an academy on raw materials[248] by the European Institute of Innovation and Technology. Yet, Member States also have a crucial role to play in bridging the gap.

One of the areas of the country research consisted of mapping relevant skills and education policies available within the Member State. The country research strived to identify policies and programmes that aim to enhance jobs and skills capacities to manufacture Net-Zero technologies and therefore excluded policies that exclusively target skills for the deployment of Net-Zero technologies (e.g. for installation of solar panels). However, policies that may target skills for the manufacturing of Net-Zero technologies were included in our research.

The country research identified 20 relevant skills and education policies across 15 Member States. Romania has three relevant initiatives, Bulgaria and Lithuania have two each, while France, Italy, Austria, Czechia, Denmark, Finland, Hungary, Ireland, Sweden, Slovenia, and Slovakia have one relevant measure each.

Out of the 20 policies, seven have a general scope and could potentially be relevant to all technologies in scope. For example, the Environmental Foundation (Umweltstiftung) in Austria offers a skills programme that includes vocational training in chartered professions. Example courses include metallurgy, welding, and forging, which are potentially relevant for the manufacturing of all technologies in scope.[249] Another example of such a programme is Denmark's Green Skills Development Programme, which aims to adapt existing vocational education and training (VET) programmes to meet the rising demand for green skills and to develop new lines of

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239 See Eurostat [duc_uoe_grad02].

240 Asikainen, T., Bitat, A., Bol, E., Czako, V., Marmier, A., Muench, S., Murauskaite-Bull, I., Scapolo, F., Stoermer, E. The future of jobs is green, EUR 30867 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-42571-7, doi:10.2760/218792, JRC126047.

241 ibid.

242 SWD(2023) 68 final. Investment needs assessment and funding availabilities to strengthen EU's Net-Zero technology manufacturing capacity.

243 See Chapter V of the NZIA.

244 European Commission (2024). *First Net-Zero Academy to train 100,000 workers in the EU solar photovoltaic value chain*. Available here.

245 See here.

246 See here.

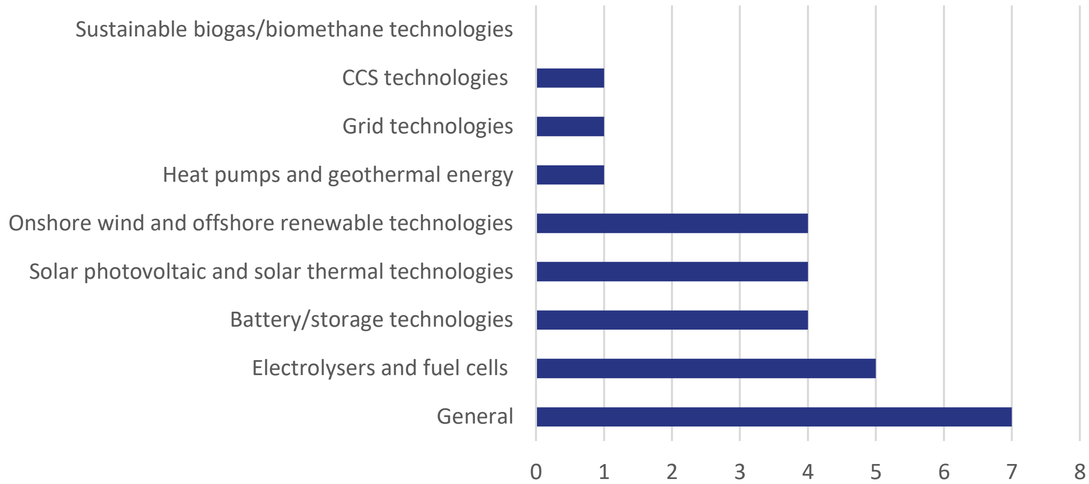
247 The European Battery Alliance Academy, see here.

248 See here.

249 More information available here.

vocational education related to emerging jobs in the green economy. [250] The other 12 policies target one or more specific technologies. The breakdown of policy measures per technology is visualised in the graph below.

Figure 3.10 Number of relevant skills & education policies



Source: own elaboration

An example of a targeted policy is Bulgaria's Institute for Sustainable Transition and Development, which organises trainings related to the hydrogen economy. Its website provides information about two current trainings (secondments) - "Hydrogen Technologies: Fuel Cells and Electrolyzers" and "Hydrogen Electrical Mobility". The initiatives are part of the project KICstartH.[251] Another example is Germany's BattFutur initiative, which supports young scientists in the area of battery cell research. It provides grants for the creation of research groups with a concrete connection to industrial applications. The support also extends to the founding of a business.[252]

250 More information available here.
251 More information available here.
252 More information available here.

4 Analysis of opportunities, bottlenecks, and barriers

In the report on the future of European competitiveness, Mario Draghi highlights three major transformations faced by Europe:

1. Accelerating innovation and finding new growth engines;
2. Bringing down high energy prices while continuing to decarbonise and shifting to a circular economy; and
3. Adjusting to less stable geopolitics where dependencies become vulnerabilities[253].

While the analysis presented in this chapter was done before the publication of Mr Draghi's report on the future of European competitiveness, it nevertheless touches upon these three major transformations. Regarding the first transformation, to address Europe's competitiveness challenge and accelerating growth, we identify drivers and obstacles for the EU's Net-Zero manufacturing industries. This links also to the second transformation as there lies an opportunity in Net-Zero technologies to enable Europe's decarbonisation, while these industries themselves are affected by the high energy prices, the requirements of decarbonisation and the need to enable a circular economy. Finally, the third transformation is related to one of the main threats to Net-Zero technologies as European manufacturers are becoming increasingly dependent on materials, components and innovation from third countries. These dependencies are also reflected further down the value chain, as Europe is becoming increasingly dependent on third-country manufacturers for the deployment of technologies such as solar PV and batteries.

4.1 SWOT assessment results per technology

Building on the findings of the previous tasks, we assessed the strengths, weaknesses, opportunities and threats (SWOT) of the eight technology groups. Although a SWOT assessment is not an analytical tool in itself, it can be used to synthesise findings and guide strategy development. This approach enabled us to structure the findings from our data analysis on industrial production, deployment, and manufacturing capacity (Chapter 2), Member State research (Chapter 3), stakeholder consultations (see Annexes III, IV and V) and the literature review (Annex VIII). Specifically, in this chapter, we highlight the main opportunities, bottlenecks and barriers to the manufacturing of Net-Zero technologies in the EU and its Member States. Deployment of these technologies is not within the scope of this assessment and is only covered where there is a clear link such as the slow deployment affecting the demand or lead time of manufacturers.

In the following sections, we explore each of the eight technology groups, identifying first their cross-cutting key issues before highlighting Member State-specific challenges. Member State-specific challenges are also presented in the separate country factsheets of this report.

A summary of the key issues is presented in the Figure on the next page, while the complete SWOT assessment for each technology group is provided in Annex V[254].

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[253] Mario Draghi, 2024, The future of European competitiveness. Part A | A competitiveness strategy for Europe.

[254] The technology-specific SWOTs took as a starting point the 2022 JRC assessments on the overall strategic analysis of clean energy technology in the European Union. These were enriched and updated through interviews, a survey and additional desk research.

Figure 4.1 Overview of common EU challenges

Solar photovoltaic and solar thermal technologies

The EU's PV industry has been faced with intense competition from China, which has become the dominant player in the global market driven by scale economies and lower material and labour costs (see also Chapter 2). Germany, Italy and France, are the largest Solar PV producers in the EU, however, companies in these countries have had to restructure or go into liquidation. In contrast, the industrial production of solar thermal components remains relatively robust in Europe, with Germany leading in manufacturing solar thermal water heaters and significant industrial production occurring in Italy and other EU countries.

According to the NZIA, the EU should increase the competitive edge and security of supply for PV technology manufacturers by targeting at least 30 gigawatts of operational PV manufacturing capacity by 2030.[255] This aligns with the goals of the European Solar Photovoltaic Industry Alliance and the EU's Solar Energy Strategy.[256] The NZIA does not set specific objectives for solar thermal technologies.

Despite the importance of the EU as the second largest market for solar PV and solar thermal, the EU solar manufacturing landscape is currently grappling with several substantial challenges that hinder its growth and global competitiveness, inhibiting it from achieving the NZIA manufacturing capacity goal. These challenges can be categorised into four primary areas.

In terms of trade balance, the EU relies heavily on imports, especially from China, leading to a persistent trade deficit, specifically in solar PV components. China has established itself as the global leader in PV manufacturing, reinforced by extensive manufacturing capacity, which dwarfs that of the EU. This imbalance is exacerbated by the fact that many European companies, although headquartered in the EU, manufacture their products in China. Moreover, solar cell capacity in China has outgrown global demand, leading to oversupply and driving prices down, putting European manufacturers out of business. This overcapacity is persisting and will likely lead to further exports by Chinese manufacturers, which are struggling themselves.[257]

The second key issue is the sector's reliance on imported critical raw materials (such as silicon, silver, germanium, gallium and rare earth elements), many of which are sourced from China.[258] This reliance poses a risk to supply chain stability. The concentration of raw material sources outside the EU compromises the region's energy security and its ability to achieve long-term sustainability goals.

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[255] EC (2024) The Net-Zero Industry Act: Accelerating the transition to climate neutrality. Available at the following link.

[256] EC (2022) EU Solar Energy Strategy https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A221%3AFIN

[257] Excessive government subsidies have lead to overcapacity among Chinese manufacturers causing also problems for Chinese manufacturers and driven down prices. See: Reuters, 16.07.2024, Solar giant illuminates China's overcapacity bind; and: Shiwei Yu, Tingwei Lu, Xing Hu, Lancui Liu, Yi-Ming Wei, Determinants of overcapacity in China’s renewable energy industry: Evidence from wind, photovoltaic, and biomass energy enterprises, Energy Economics, Volume 97, 2021, https://doi.org/10.1016/j.eneco.2020.105056.

[258] EC, JRC. (2023). Study on the Critical Raw Materials for the EU 2023 – Final Report. Available at the following link.

Regulatory fragmentation across EU Member States is the third main issue. It can create an uneven playing field for PV manufacturers, with varying levels of support and incentives. In contrast, countries such as the USA, India, and China have support schemes that significantly boost their domestic PV manufacturing. The USA's IRA[259] and India's Production-Linked Incentive (PLI)[260] scheme provides direct and targeted support. The USA's IRA offers attractive incentives, while India, despite lower financial support, uses high import taxes to protect its industry. The USA's approach mirrors China's, albeit a decade behind. It became apparent during the interviews and our roundtable discussion that, stakeholders would like to see the EU make a clear decision over whether to join the global subsidies race or regulate foreign subsidies.

Cost competitiveness is another important challenge. Even without considering current overcapacities, European PV manufacturers face higher production costs driven by higher labour and energy costs as well as stricter environmental regulations, making it difficult to compete with lower-cost imports from Asia. While the energy cost in China and the US is, on average, at 28,5 and 19 euros per kW, European manufacturers face energy costs as high as 57 euros per kW.[261] This makes it difficult for EU manufacturers to compete in the global market. For example, while the EU's manufacturing capacity for modules and inverters is limited, the cost of producing these components domestically is significantly higher than importing them from China. This price disparity affects the profitability and sustainability of the EU's PV manufacturing sector.

Box 1 Opportunities and bottlenecks in Member States for solar PV and solar thermal

Regarding PV cells and modules, Germany remains the EU's most important producer, followed by Italy, France, and Austria. Manufacturing on a smaller scale is present in various other EU countries.

Solar thermal component manufacturing is concentrated primarily in Germany and Italy with several other EU manufacturing locations.

Germany remains a key player in the EU's solar industry, leading in the production of PV cells, modules, and solar thermal water heaters. It is also home to various leading solar research institutes[262] and innovative start-ups such as the wafer start-up NextWafe, which aims to advance the production of ultra-thin, highly efficient wafers. Focusing on research and innovation could help maintain technological advancement and global competitiveness in the sector. However, Germany faces significant challenges, including a high import dependency (62%)[263] and recent closures of industrial production facilities for solar modules due to price competitiveness issues with Chinese manufacturers. The high cost of labour and energy, and the lack of scale compared to China are major drivers behind these closures. Import competition has led to restructuring in the solar PV industry, notably with Meyer Burger and Solarwatt closing their module production facilities in Germany as they cannot compete on price. Additionally, the overreliance on Wacker Chemie as the sole European producer of polysilicon poses a risk, particularly after the closure of REC Solar in Norway.

259 See for example the list of incentives provided for the US-based solar PV manufacturers under the IRA via: US Department of Energy. (2024). Inflation Reduction Act of 2022. Available at the following link.

260 See for example the list of incentives provided under the Indian PLI scheme via: Ministry of New and Renewable Energy. (2024). Production Linked Incentive (PLI) Scheme: National Programme on High Efficiency Solar PV Modules. Available at the following link.

261 Solar Power Europe. (2024). Rebuilding European solar manufacturing. Available at the following link.

262 Such as the Fraunhofer Institute for **Solar** Energy Systems, the Institute for Solar Research and the Solar Energy Research in Hamelin.

263 See Germany's Country Factsheet and section 2.2.

Italy plays a crucial role, particularly in solar thermal component manufacturing for thermal electrical structures and for Solar PV in electrical components and polymers. Italy is an internationally competitive exporter of solar PV and solar thermal such as plastic plates, sheets, film, foil and strips, crucial for solar technologies. Opportunities come in the form of Italian state aid schemes supporting investments in equipment necessary to foster the transition to a Net-Zero economy and in PV deployment.[264] A catalyst for reshoring PV production to Europe could also be the extension of Enel's 3Sun solar PV factory to a gigafactory.[265] Finally, in terms of demand, Italy has also become one of the largest growing solar markets in Europe thanks to support schemes such as the Superbonus,[266] Italian companies face however similar challenges to their German counterparts due to a lack of price competitiveness and access to materials with companies just dealing with assembly[267]. The 3Sun solar PV factory could start reversing this dependency by producing PV cells, however, it will have to do this in a market with massive overcapacities.

Similarly, France launched an investment tax credit and a Solar Pact initiative through which an *Induscore* will be launched to reflect European content in solar PV. Combined with recent regulatory changes putting more attention to solar PV and solar thermal deployment[268], both initiatives could be an opportunity to support French industrial production. There are several promising manufacturing projects in France, with two planned solar gigafactories by Carbon in Fos-sur-Mer and by the Holosolis consortium in Hambach.[269] France could also leverage its potential in crystalline silicon solar panels thanks to its strong silicon production capacity.[270] Meanwhile, French solar PV manufacturers face severe difficulties. Several companies have gone into liquidation (such as Systovi and Recom-Silia) or are looking for a buyer (Photowatt[271]) due to the price competition with China. Chinese manufacturers can offer prices four times lower compared to their European counterparts as they dominate the industrial production and processing of polysilicon for PV modules.

Austria is also producing inverters and critical components such as electric static transformers and converters. Austria is a competitive exporter of converters and inverters and the Austrian company Fronius is a technology leader in inverters. Austrian inverter production has notably steadily increased since 2019 and reached a new record with 5,397 MW in 2023.[272] Cross-border cooperation with Italy and Germany could help Austria scale up the industrial production of solar PV and create a knowledge hub with opportunities for learning and testing, which could lead to technological advancement.[273] Notable challenges are the severe worker shortage, with 30,000 jobs needed in the Austrian PV industry for 2030 (notably electricians), and the slow national power grid expansion.[274] Moreover, Austria's sector is limited in scale compared to leading global players and needs to expand to improve its global

264 EUR 1.1 billion for direct grants to companies producing equipment necessary for the net-zero transition (see here). EUR 1.7 billion supporting the construction and operation in Italy of new agrivoltaic plants (see here).

265 EIB, 24 January 2024, Italy: Europe's biggest solar gigafactory 3Sun secures €560 million financing from EIB and pool of Italian banks led by UniCredit and backed by SACE. Available at the following link.

266 Solar Power Europe (2023) EU Market Outlook for Solar Power 2023-2027. Available here

267 G. Brambilla, 05.05.2024, Concorrenza cinese, costi alti e assenza di political industrial: dentro la crisi del fotovoltaico in Europa – L'inchiesta, available here.

268 An Act was introduced offering more state-owned land and lifting construction restrictions as well as other legislative changes, see here: Eran Chvika, 25.04.2023, Solar power in France: regulatory changes and market opportunities, available here.

269 For example, the French startup Carbon will set up a 500MW pilot plant for modules in autumn 2025, which will later be extended to a gigafactory for 5GW of cell and 3.5 GW of module manufacturing capacity (see here). Similarly, Voltec Solar has secured funding for a pilot plant manufacturing perovskite-silicon tandem solar panels, which will later be extended (see here). See also Révolution Énergétique, 09.05.2024, Hécatombe dans l'industrie solaire française : une nouvelle usine placée en liquidation judiciaire, available here.

270 IEA (2021), France 2021, IEA, Paris, https://www.iea.org/reports/france-2021, Licence: CC BY 4.0

271 Révolution Énergétique, 14.09.2024, Qui reprendra le dernier grand fabricant français de panneaux solaires Photowatt ?, available here.

272 Biermayr, P., & Prem, E. (2023) Innovative Energietechnologien in Österreich Marktentwicklung, Technologiereport Bauteilaktivierung. Available here.

273 European Environment Agency (2020) Cross-border cooperation on renewable energy, Briefing no. 23/2020. Available here.

274 Solar Power Europe (2023): Global Market Outlook For Solar Power 2023 – 2027. Available here.

competitiveness. The share of Austrian-manufactured modules in residential PV systems was estimated around 14% in 2021 and 9.5% in 2022, with the majority of components imported from Asia.[275] Between 2022 and 2023, this number fell further to 2.4% as the result of a drop in the module output produced in Austria by 27% despite the growth of the domestic market.[276] Similar to other countries, the significant decrease in global market prices for PV modules due to oversupply and competition among manufacturers has put pressure on local production in Austria. To correct this imbalance the Austrian government has recently introduced a “Made in Europe” bonus scheme which subsidises solar PV projects that contain a proportion of European manufactured components.[277]

Spain and the Netherlands are also producing and exporting PV manufacturing machinery and semiconductor components, which are higher value-added activities. The Netherlands is also investing in innovation through the National Growth Fund (SolarNL initiative), which supports new solar PV technologies, while Spain has set up a State aid scheme supporting investment in the Net-Zero economy. Focusing on innovation and high-value-added activities such as specialised machinery for next-generation solar modules rather than competing on scale, could be a growth opportunity. In terms of challenges, both Spain and the Netherlands face similar challenges to other Member States and are reliant on extra-EU imports (42% and 67% respectively).[278] Specifically, Spanish PV manufacturers face potential supply chain risks as the country is dependent on imports, notably for rare earths and metals, which could be barriers to scaling up manufacturing activities.[279]

For more opportunities and bottlenecks, see the individual country fiches (Annex II) and Annex V.

Onshore wind and offshore renewable technologies

As detailed in Chapter 2, the manufacturing of onshore and offshore wind technologies in Europe is led by Germany, Denmark and Spain. However, since 2017, China's market share in this sector has significantly increased, reducing Europe’s previous dominance. Specifically, China has become dominant for components such as gearboxes and power converters as the country produces 66% and 77% of global output respectively.[280] To meet the REPowerEU target of 425 GW installed capacity by 2030, the EU must build, on average, 33 GW wind energy capacity per year (18.3 GW in 2023)[281].

While Europe retains leadership in turbine assembly, our assessment identified the following key issues slowing down progress for the European onshore wind and offshore renewable technologies:

275 Solar Power Europe (2023): EU Market Outlook For Solar Power 2023 – 2027. Available here.

276 Between 2022 and 2023, the domestic market grew by 158% and net imports increased by 168.4%. Due to the lack of information from some domestic producers, exports, resale in Austria and stocks for 2023 were extrapolated on the basis of the available feedback from those domestic producers who provided information. See Biermayr, P., & Prem, E. (2023) Innovative Energietechnologien in Österreich Marktentwicklung, Technologiereport Bauteilaktivierung. Available here.

277 Parlamentskorrespondenz Nr. 730 (2024): Photovoltaik: Zweidrittelmehrheit für "Made in Europe"-Bonus zu Investitionszuschüssen noch offen https://www.parlament.gv.at/aktuelles/pk/jahr_2024/pk0730

278 See the Netherlands’ and Spain’s Country Factsheets.

279 Lucía Salinas Conte (2022) The dependency on China of Spain’s supply chains, available here.

280 Mario Draghi, 2024, The future of European competitiveness. Part B | In-depth analysis and recommendations.

281 Wind energy in Europe 2023 Statistics and the outlook for 2024-2030, 2023 Wind Europe, available here.

Administrative barriers and lengthy permitting processes are major obstacles to the deployment of new wind installations, especially for onshore projects. Slow deployment negatively affects the demand and creates uncertainties for manufacturers and difficulties in planning their investments.[282] This was therefore also identified as a main weakness in our SWOT assessment (See Annex V). While the situation is gradually improving following considerable efforts under REPowerEU[283] to streamline and shorten permitting durations (Member State initiatives are detailed in Section 3.2.2.), survey respondents and interviewees noted that challenges persist. Among the key issues are a lack of administrative capacity and the high number of authorities involved. The delays in deployment have led to a drop in orders for new turbines creating uncertainties in domestic markets for European manufacturers who in turn have reduced investments.

The lack of standardisation for wind turbines was noted as a threat to manufacturers as it prevents economies of scale, which is crucial for reducing costs and enhancing competitiveness globally. Furthermore, it creates inefficiencies in manufacturing as companies must design and produce different components to meet varying standards or specifications, depending on the market or project. Globally, there is also a trend for wind turbines to grow in size which increases the capacity for generating energy but makes transportation and installation more challenging as well as requires manufacturers to update their manufacturing facilities.

Europe's leadership in wind technology is under threat due to fierce international competition from China, which has rapidly increased its market share (300% increase in exports since 2017) and is installing the majority of new wind energy capacity globally. Potential competition might also come from India, which, according to the IEA, is emerging as an export hub.[284] Supply risks were also identified as wind energy manufacturing requires access to a number of raw materials including iron, nickel, manganese, aluminium, copper, lead, molybdenum, balsa wood and neodymium magnets. The EU is reliant on third-country producers, particularly China, to access many of these critical raw materials and this is a key challenge for all EU producers.

During the roundtable, several stakeholders remarked that price pressures could result from the introduction of the auction-based system, potentially undermining the market's potential by placing undue strain on manufacturers. Stakeholders remarked during the roundtable that the lack of market demand for electricity is a key factor that affects cost competitiveness as it makes investments into manufacturing more challenging. Additionally, stakeholders pointed out that without concurrent development of grid infrastructure to manage energy injection fluctuations from renewable sources, scaling up industrial production would be problematic. Stakeholders highlighted that electrification and the expansion of manufacturing in the wind sector need to proceed in lockstep.

282 Nick Ferris, 2022, What the closure of Germany's only wind blade factory says about its energy transition, Energymonitor, available here.

283 Under the REPower EU Plan, several recommendations and guidance documents were adopted to streamline permitting procedures for renewables. See Commission Recommendation (EU) 2024/1343 and European Commission (2024): Staff Working Document on good practices to speed up permit-granting procedures for renewable energy and related infrastructure projects (SWD/2024/124).

284 IEA. 2024. Advancing Clean Technology Manufacturing: An Energy Technology Perspectives Special Report. Available at the following link.

Another key issue is the lack of skilled workers for manufacturing and deployment of on- and offshore wind technologies. To reach the 2030 target of 420 gigawatts of wind energy, European Member States will need an additional 200,000 workers to be recruited and trained.[285] A skilled workforce with high-quality knowledge also helps improve the industry's resilience and reduces the probability of plants closing.

Box 2 Opportunities and bottlenecks in Member States for onshore wind and offshore renewables

For onshore wind and offshore renewables, the leading EU Member States in terms of industrial production are Germany, Denmark and Spain. Additional manufacturing capacities can be found across several EU Member States including France, Portugal, Poland and Italy. Additionally, small-scale manufacturing activities take place in Czechia, Austria, Netherlands (nacelles) and Greece (towers).

As a key player in both onshore and offshore wind, Germany is the largest European exporter of wind turbines, supported by major manufacturers such as Nordex and Vestas and smaller producers such as Enercon. Germany has a relatively low import dependency with only 11% of extra-EU imports[286] thanks to its well-developed ecosystem of manufacturers and suppliers.[287] The country has also successfully reduced permitting times through the Overriding Public Principle from the EU Renewable Energy Directive, which will help reduce the backlog in wind energy projects thereby reducing uncertainties on the domestic market for manufacturers. Moreover, a state aid scheme supports companies producing Net-Zero equipment including wind turbines[288] and guarantees are available for wind energy manufacturers through EIB and Deutsche Bank.[289] However, a significant bottleneck is the demographic shift, which exacerbates the shortage of skilled workers needed for manufacturing and installation.[290] Germany's onshore and offshore wind sectors were also affected by rising energy prices and reduced demand due to a complex permitting process and restrictive zoning that have led to slower deployment.[291] This slowdown, combined with increasing price competition from Chinese manufacturers[292], puts German manufacturers in a difficult position.

Denmark boasts substantial manufacturing capacity for both onshore and offshore wind turbines and is among the top five European exporters. Based on our assessment of Denmark's economic fundamentals, the country has an untapped export potential of EUR 189 million for wind turbine structures. This is due to its strong domestic market, long history in the sector, presence of leading firms with good support ecosystems, leading-edge technology and skills.[293] The Danish company Vestas has also developed a chemical process to recover epoxy-based blades, which creates a new source of raw materials and adds value to recycling activities. Despite its strong market, Denmark faces a shortage of skilled technicians and engineers, with an estimated need for 45,000 additional full-time

285 According to the Employment and Social Developments in Europe 2023 report (European Commission, DG EMPL), between 31,000 and 40,000 additional workers will be needed for manufacturing by 2030. The latter figure corresponds to a scenario in which 100% of the demand is satisfied by EU manufacturing by 2030. Additional to this the report expects the demand for 68,000 additional workers for deployment. Meanwhile, in WindEurope and Rystad Energy's report Our wind, our value (March 2024), the forecasted manufacturing jobs in Europe needed are expected to increase from above 200,000 in 2024 to above 300,000 in 2030

286 See Germany's Country Factsheet.

287 Bundesverband WindEnergie, 2024, Windindustrie in Deutschland. 2024.

288 See here.

289 See here.

290 Germany is expected to lose seven million workers by 2035 unless mitigating measures are taken, according to the Nuremberg Institute for Employment Research (IAB). See Fuchs, Johann, Doris Söhnlein & Brigitte Weber (2021): Projection of the potential workforce until 2060: Demographic development is causing the labor supply to shrink sharply. (IAB Short Report 25/2021), Nuremberg, 12 p.

291 Nick Ferris, 20.05.2022, What the closure of Germany's only wind blade factory says about its energy transition, Energymonitor, available here.

292 Andrew Hayley, 10.04.2024, Explainer: China's dominance in wind turbine manufacturing, Reuters, available here

293 Ministry of Foreign Affairs of Denmark, 'Join our powerhouse for wind power technology', see here.

equivalents (FTEs) annually from 2023 to 2030 to meet climate targets.[294] Danish manufacturers, alongside their European counterparts, also face challenges with declining earnings, due to increasing material and logistics costs, combined with intense price competition from China.[295]

Spain is a major hub for wind energy industrial production operated by Vestas, Nordex, Siemens Gamesa and Enercon, particularly excelling in the export of offshore wind components such as gears and gearing. It holds nearly half of the EU's tower manufacturing capacity and has an untapped export potential exceeding EUR 900 million. The country's manufacturing industry is likely to benefit from a growing domestic market, which is expected to grow with additional investments planned for offshore wind. Spanish manufacturers, notably Siemens Gamesa and Nordex-Acciona, led in the number of installed capacity in Spain in 2023.[296] Spanish manufacturers can moreover benefit from comparatively lower labour costs than French, German and Danish manufacturers and lower energy costs are also attracting industries to Spain.[297] However, Spain remains heavily dependent on extra-EU imports, with a 55% import dependency.[298] Its wind industry could be affected by import dependencies for rare earths, metals like manganese and electronics, which may be additional costs.[299]

France contributes 9% of the EU's total wind power industrial production[300] and has introduced several supportive policies, including an investment tax credit for green investments and local content criteria in public procurement (see Sections 3.2 and 3.3). France's commitment to offshore wind development has attracted significant investments. An offshore sector deal between the French government and the wind industry targets 50% local content in projects by 2035, which is expected to boost local manufacturing further.[301] However, like Spain, France relies significantly on third-country imports, with China as its main supplier, notably for access to critical raw materials such as rare earths, alongside manganese or aluminium. Recycling wind turbines to recover materials through new chemical processes could constitute an opportunity to reduce this dependency.[302] France also faces challenges in securing skilled workers, notably engineers. To address this shortage, technical trainings has been deployed, including through industry initiatives.[303]

Poland has a smaller share of wind energy manufacturing capacity but excels in producing aluminium structures for wind turbines. The country has an untapped export potential of EUR 749 million for aluminium structures and Poland's comparative advantage outperforms both China and the USA according to our calculations.[304] However, at the same time, Poland is also highly dependent on extra-EU imports (69%) in its onshore wind and offshore energy sector.[305] Poland's sectoral agreement on offshore wind energy development[306] aims to maximise local content in the supply chain for offshore wind farms by at least 50% after 2030, which could help reduce its high extra-EU import dependency and constitute a growth opportunity.

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294 Green Power Denmark (2023) Mere arbejdskraft til den grønne omstilling. Available at the following link.

295 Green Power Denmark (2023), Havvind til Danmark og Europa. Available here.

296 Spanish Wind Energy Assocation, Installed wind power & generation, see here.

297 Montel News, 20.06.2024, Spain's lower power prices may attract EU industry relocation.

298 See Spain's Country Factsheet and section 2.2.

299 Lucía Salinas Conte (2022) The dependency on China of Spain's supply chains, available here.

300 See France's Country Factsheet and section 2.2.

301 WindEurope (2022), 'France commits to 40 GW offshore wind by 2050', available here.

302 Vestas introduced in 2023 a chemical process that allows epoxy resin to be chemically broken down into reusable material, which will enable recycling blades and recovering raw materials. See France Renouvelables (2023) Observatoire de l'éolien 2023, available here. See also La Dépêche (2023), 3 Ce nouveau procédé chimique va permettre de recycler l'intégralité d'une eolienne, available here.

303 France Renouvelables (2024) Observatoire de l'éolien 2024, available here.

304 See Poland's Country Factsheet and section 2.2.

305 Ibid.

306 Government of Poland, Morska Energetyla Wiatrowa. Czym jest Porozumienie sektorowe? Available here.

Italy and Portugal are known for their specialised industrial production. Italy produces mechanical components for gearboxes and bearings. With new manufacturing facilities planned for 2026-2028 and the designation of maritime areas for offshore wind infrastructure[307], Italy has significant growth potential in this sector. Portugal specialises and is a competitive exporter in manufacturing blades and steel structures for wind turbines. However, Italy strongly relies on extra-EU imports with 73% of non-EU imports, which is driven by a dependency on raw materials such as metals, minerals and other raw materials.[308] This situation echoes that of its European counterparts and poses a significant challenge to scaling up manufacturing.

Finally, Austria is involved in the industrial production of mechanical components for gearboxes and is an exporter of ball bearings and aluminium structures, with an untapped export potential of EUR 960 million.[309] Generally, Austrian firms show a positive future outlook and have a strong export focus, particularly in components, showcasing their integration into global value chains.[310] Austrian exports go primarily to China, Germany, the USA and Spain. Austria is also a leader in innovation in the fields of control systems, wind power generators, wind turbine design and high-tech materials. For example, start-ups invest in timber-based wind power towers that could help reduce C02 emissions and lower material dependencies as well as flexible couplings and torsional dampers reducing vibrations of turbines[311].

For more opportunities and bottlenecks, see the individual country fiches (Annex II) and Annex V.

Batteries and storage technologies[312]

The EU is witnessing a rapid expansion in battery and energy storage manufacturing capacities driven by the increasing demand for electric vehicles (EVs) and grid flexibility. Poland, Germany and Hungary are leading this expansion with massive investments in new manufacturing facilities for lithium-ion batteries. Investments are also taking place in France, Sweden, Czechia and Italy. In 2023, the European battery cell production capacities increased by 25% compared to 2022, however, expansions in the USA and China have been outpacing Europe with a 45% increase in both countries.[313]

This expansion is driven by the desire to overcome the current dependency on external sources for both finished battery products and components. The Net-Zero Industry Act refers to the objectives of the European Battery Alliance and the aim to meet almost 90% of the EU's annual battery demand through domestic industrial production by 2030, necessitating a manufacturing capacity of at least 550 GWh. The IEA estimates that the EU is on a promising path as domestic industrial production already met 75% of EV battery demand[314] with future battery manufacturing capacity potentially reaching 280 GWh in the coming years.[315] Additionally, sites currently under construction could add in the short to medium term another 190 GWh.[316] Considering this steady increase

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307 See Italy's Country Factsheet and section 2.2.

308 See Italy's Country Factsheet and section 2.2. See also G. Fiorindi et al. (2023) Le dipendenze critiche e strategiche dell'industria italiana, Confindustria, Numero 2/23, available here.

309 See Austria's Country Factsheet and section 2.2.

310 Biermayr, P., & Prem, E. (2023) Innovative Energietechnologien in Österreich Marktentwicklung, Technologiereport Bauteilaktivierung. Available here.

311 Ibid.

312 Due to the focus of the Net-Zero Industry Act and available data, we focus here mostly on battery technologies but provide where possible reflections on other energy storage technologies.

313 IEA (2024), Global EV Outlook 2024, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2024, Licence: CC BY 4.0.

314 Ibid.

315 According to our data the range is between 201 to 207 GWh.

316 Aiko Bünting and Sarah Vogl (2024) Market Update Q2 2024: Battery Cell Production in Europe Status Quo and Outlook

in manufacturing, the EU seems to be on a good path, however, recent announcements of project cancellations in Europe have raised some concerns.

We identified four key issues that could impact further industry scale-up.

- Critical raw material supply **import dependency** due to lack of mining, refining and recycling in the EU
- **Emerging technologies** offer promising alternatives but are not in industry focus
- Tough **price competition** with volatile prices but price differences are decreasing
- Lack of **harmonisation** and long permitting procedures

Import dependency is a major challenge as the EU remains heavily reliant on third countries for both battery cells and production equipment. Processed materials, components, and assemblies are primarily sourced from China, South Korea and Japan.[317] Critical raw materials such as cobalt, lithium, and natural graphite are imported mainly from China, Chile, Australia and Argentina. These dependencies can create supply chain vulnerabilities as import dependence can be a source of exposure to disruptions, shocks or foreign policies.[318] Reliance on imports was identified by our survey respondents as one of the main threats to EU battery manufacturers.

Emerging technologies are the second key issue as sodium-ion (Na-ion) and redox-flow batteries (RFB) offer promising alternatives for EV and stationary applications. These technologies are safer, potentially cheaper, and do not require critical raw materials. However, the EU has been slow to adopt these alternatives[319] focusing instead on Li-ion batteries, as confirmed by the literature[320] and participants at our roundtable discussion. The commercialisation of Na-ion batteries is being led by China and RFBs by the USA, Canada, Australia, and Asian countries. Similarly, lithium iron phosphate (LFP) battery cell chemistries have garnered increasing attention as they require less critical materials and are significantly cheaper than the more energy-dense lithium nickel manganese cobalt oxide (NMC) chemistries which are more widely spread in the EU.[321] These missed opportunities can create future dependencies and the Automotive Cells Company has recently paused its European projects considering switching to LFP cells.

EU producers also face intense price competition from Chinese and US manufacturers, who benefit from lower energy, material, equipment, land, and labour costs. Survey respondents highlighted this as a significant

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

318 Crowe, D. and Ł. Rawdanowicz (2023), "Risks and opportunities of reshaping global value chains", *OECD Economics Department Working Papers*, No. 1762, OECD Publishing, Paris, https://doi.org/10.1787/f758afe8-en

319 Currently, there are two significant projects on production of Na-ion in the EU (by Tiamat (FR) and Altris+Nothvolt (SE)), however third countries (mainly China) are faster and work at a higher scale.

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

321 IEA (2024), Global EV Outlook 2024, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2024, Licence: CC BY 4.0.

weakness. Although the price gap has narrowed,[322] materials such as lithium, nickel, and cobalt remain the primary cost drivers and EU-produced lithium-ion battery packs remain 20% more expensive than their Chinese counterparts.[323] This exposes EU manufacturers further to the aforementioned import dependencies.

Lengthy and complex permitting procedures in Member States can hinder the timely roll-out of battery manufacturing and energy storage projects. Despite available funding, these delays can impact the entire value chain, from mining to energy storage deployment. Permitting challenges are not limited to battery factories but extend across the entire value chain, including mining and the deployment of energy storage. The administrative burden and lengthy investment approval processes were identified as another key threat to EU manufacturers in our survey, which has already led to a slower rollout of projects.[324] The REPowerEU Plan and the Net-Zero Industry Act aim to address these issues by streamlining permitting processes.

While the EU has predominantly focused on mobile battery applications, stationary batteries and other energy storage solutions, such as pumped hydropower[325], are equally essential for enhancing the integration of renewable energy sources and ensuring grid flexibility. The stakeholders interviewed emphasised the need for clearer policies that differentiate between stationary and mobile energy storage applications.

Box 3 Opportunities and bottlenecks in Member States for batteries and storage technologies

Germany, Poland, and Hungary are the leaders in battery technology production in the EU, with significant investments in lithium-ion battery manufacturing facilities. Sweden and France are also important EU producers, while other Central and Eastern European countries like Slovakia, Czechia, as well as Greece, are emerging as significant industrial production hubs.

Germany is a key player in the EU's battery sector, with a strong focus on Li-ion battery industrial production. Opportunities for Germany lie in its advanced manufacturing capabilities and potential for innovation in next-generation battery technologies, such as Na-ion batteries. The closeness to key customers in the form of automotive manufacturers transitioning to EVs also provides an opportunity as many are looking to nearshore battery production or vertically integrate it for increased supply chain resilience. Streamlining permitting processes could further enhance Germany's ability to scale up industrial production. However, it faces significant bottlenecks due to high energy, labour, and industrial production costs, which make it challenging to compete with lower-cost producers in China and the USA. Another bottleneck is the limited access to critical raw materials, specifically rare earths, copper and lithium[326] which has contributed to Germany's relatively high import dependency with 54% of extra-EU imports[327]. Paired with the high energy price, this further increases cost disadvantages for German manufacturers.

[322] This is based on BloombergNEF data, which reports annually on battery pack prices in China, the USA and Europe. In 2021 the prices were cheapest in China, at $111/kWh, while in the USA and Europe costs were 40% and 60% higher. In 2022 this changed to $127/kWh in China with battery pack prices in the USA and Europe being 24% and 33% higher, respectively. Finally, in 2023 the price in China was $126/kWh compared to 11% and 20% higher prices in the USA and Europe. Please note, that the prices are averages across multiple battery end-uses, including different types of stationary storage projects and electric vehicles.

[323] These costs would directly impact mining and refining activities and could be passed along the value chain.

[324] Bloomberg, 20.06.2024, Europe's EV Battery Plans Fade on China Price War, US Aid. Available here.

[325] Although pumped-storage hydropower currently dominates energy storage in Europe with European companies commanding a 50% share of the global market, future investments are expected to shift towards stationary batteries and alternative technologies. See: IEA (2021), Hydropower Special Market Report, IEA, Paris https://www.iea.org/reports/hydropower-special-market-report, Licence: CC BY 4.0

[326] Köhler-Gebi, F. Levinger, H. and Ulrick, K., 2024, Set in stone? The German economy's dependency on copper, lithium and rare earths

[327] See Germany's Country Factsheets and section 2.2.

Poland and Hungary are two rising powerhouses in battery manufacturing. Both countries can benefit from somewhat lower labour costs even though they are not on par with China. Further investments into research and development, particularly in safety, utility, recycling, and reuse can provide opportunities to improve products and material availability, leading to a stronger positioning of these countries[328].

In Poland, various R&D initiatives are already underway, primarily pertaining to recycling and second-life applications.[329] Lithium-ion batteries already account for over 2.4% of all Polish exports with net exports exceeding EUR 8 billion in 2022. This strong position offers a foundation to further expand into other areas of energy storage technologies which is indicated by investments from companies such as Northvolt, Umicore, SK hi-tech battery materials, Capchem, Guotai Huarong, BMZ and more.[330] A potential bottleneck lies in the high extra-EU import dependency, with 80% for Poland[331] due to the strong integration of the Polish value chain with Asia as many investments come from South Korean and Chinese manufacturers. This dependency is prevalent for battery-active materials[332] and critical raw materials such as cobalt, lithium and nickel which are not mined in Poland except the Szklary nickel deposit. Investments in recycling and the industrial production of battery active materials for example through Umicore's battery materials gigafactory in Nysa[333] are going in the right direction to address this bottleneck.

Similar to Poland, Hungary benefits from its attractiveness to foreign direct investment for Asian firms as the country can serve as "a bridge between East Asian battery manufacturers and European automotive OEMs" while also providing cheaper labour costs, cheap land and natural resources and subsidies.[334] However, access to skilled labour can be a significant challenge.[335] In Hungary, the labour shortage is particularly an issue in the battery value chain where many jobs have been created with companies attracting workers from each other, other value chains and third countries. Current retraining and vocational training programmes in the country are struggling to provide the necessary skills for the battery industry.[336] To address labour shortages, third-country nationals are increasingly being attracted through temporary work agencies, which the government considers cheaper than training local workers[337].

France is also investing on a large scale. The France 2030 investment plan aims to accelerate the development of the country's battery industry, boost research[338], and support training and upskilling projects. France has also attracted investments to build gigafactories, including those by ACC and Verkor.[339] These investments will not only expand manufacturing capacity but also enhance the talent pool, supported by the network of specialised battery schools under the 'École de la Batterie' initiative. Currently, France faces a dependence on extra-EU imports with China as its main import partner. France has the potential to reduce this dependency thanks to its efforts to attract investments covering the entire battery value chain.[340] However, the increased manufacturing capacities could lead to supply chain vulnerabilities as they will increase the existing dependencies on raw and processed materials as

328 PSPA (2023). Europe runs on Polish lithium-ion batteries, available here.
329 PSPA (2023), Europe runs on Polish lithium-ion batteries. The potential of the battery sector in Poland and the CEE Region, available here.
330 Ibid.
331 See Poland's and Hungary's Country Factsheets and section 2.2.
332 See p.20, PSPA (2023), Europe runs on Polish lithium-ion batteries. The potential of the battery sector in Poland and the CEE Region.
333 Umicore, 21 March 2023, Umicore accelerates European E-Mobility with Nysa Gigafactory, available here.
334 Márton Czirfusz (2023). The battery boom in Hungary: Companies of the value chain, outlook for workers and trade unions. Available here.
335 Oxford Analytica (2024), "Hungary will ease immigration to meet labour shortage", *Expert Briefings*. https://doi.org/10.1108/OXAN-DB285183
336 Márton Czirfusz (2023). The battery boom in Hungary: Companies of the value chain, outlook for workers and trade unions. Available here.
337 Ibid.
338 Business France, The national "Batteries" strategy, a key priority for France on sustainable mobility, available here.
339 EIB, 30.05.2024, Giga-push for European batteries, available here.
340 Business France, 'The national "Batteries" strategy, a key priority for France on sustainable mobility', available here.

well as components which are currently primarily sourced from Asia. Material costs remain the primary cost drivers[341] and thereby negatively affect the price competitiveness of EU manufacturers, which has started a trend of automotive manufacturers such as Renault[342] switching to lower-cost and safer LFP cells.

Similarly, Sweden is investing on a large scale and hosts important industrial production facilities, including NorthVolt AB's Battery factory in Skellefteå, with an estimated capacity of 60 GWh, along with announced facilities that will further expand the country's manufacturing capacity.[343] Sweden also excels in R&D, with great potential in innovative Na-ion batteries.[344] Further opportunities for Sweden lie in its strong environmental legislation and a high share of fossil-free electricity, allowing the country to produce batteries in a highly sustainable manner.[345] Finally, the availability of critical raw materials such as rare earth metals deposits in Sweden (and Finland)[346] is another opportunity for reducing dependencies with China. However, one key issue is the slower-than-expected growth in EV demand in the short term, which is hindering expansion efforts. Northvolt, a leading Swedish company, has struggled to meet its targets and had to cancel plans for a cathode materials battery plant, leaving it reliant on imports. The company has also lost orders due to delays and announced layoffs in response to the challenges.[347]

Other Central and Eastern European (CEE) countries, including Slovakia and Czechia, are emerging as significant industrial production hubs. Czechia is home to one of the largest hardrock lithium deposits in Europe, where mining and production of lithium hydroxide are expected to commence in 2026. This strengthens the country's potential as a lithium battery production hub.[348] Opportunities arise also from Czechia's strong automotive sector and the transition to electric vehicles.[349] Moreover, Czechia could also benefit from regional cooperation with other Member States from Central and Eastern European countries.[350] However, Czechia's industry faces significant challenges in securing stable foreign investment, partly due to infrastructure limitations, regulatory and bureaucratic hurdles and available skilled workforce.[351]

Regarding Slovakia, several investments in battery manufacturing are already taking place. The country's large number of primary metal producers combined with the closeness to automotive manufacturers creates potential in battery manufacturing. Additionally, Slovakia's focus on STEM and engineering education, as well as the country's engagement in R&D activities supports the uptake of the industry.[352] However, Slovakia lacks significant mining capacity for battery materials.[353] Already, we see a high import dependency for batteries and energy storage technologies with 67% extra-EU imports. This dependency could be a future bottleneck for expanding the Slovak

341 BloombergNEF, 26 November 2023, Lithium-Ion Battery Pack Prices Hit Record Low of $139/kWh.

342 Renault will source LFP cells from CATL produced in Hungary and NMC and LFP cells from LG Energy Solutions produced in Poland, which will then be assembled into battery packs in France. However, France-based AESC and Verkor manufacturing plants will continue to supply NMC cells, see here: electrive, 02.07.2024, Renault embraces LFP batteries, available here.

343 See Sweden's Country Factsheet and section 2.2.

344 Northvolt, 21.11.2023, Northvolt develops state-of-the-art sodium-ion battery validated at 160 WH/kg, available here.

345 Swedish Energy Agency, The future of battery technology in Sweden looks promising, available here.

346 For an overview of opportunities in Sweden, Finland and Norway, see: Innovation Norway, Business Finland, Business Sweden, and the Swedish Energy Agency (2023) The Nordic Battery Value Chain, available here.

347 Rida Rambli (2024), Europe caught in the crosshairs between Chinese and US battery manufacturing & Northvolt, 23 September 2024, 'Northvolt outlines revised scope of operations in Sweden', available here.

348 Cyrani, Pavel (2022), Cinoves lithium extraction and processing project. Available here.

349 However, recent hopes of a battery gigafactory planned by Skoda's parent company Volkswagen have been suspended, see here: Central European Times, 03.11.2023, VW suspends plan for EV gigafactory in CEE, available here.

350 PSPA (2023), Europe runs on Polish lithium-ion batteries. The potential of the battery sector in Poland and the CEE Region.

351 Columby (2024), The Czech Gigafatory Shuffling, 2020-2024. Semantic Visions. Available here.

352 PSPA (2023), Europe runs on Polish lithium-ion batteries. The potential of the battery sector in Poland and the CEE Region.

353 Ibid.

battery industry. Establishing a long-term, strategic approach supported by a stable and reliable policy framework and boosting R&D investments could further strengthen the lithium-ion battery industry in the CEE region.[354]

Finally, Greece is another emerging player in the battery industry that could further boost its role in the battery value chain. The country holds a competitive position, particularly in lead-acid accumulators owing to the presence of Sunlight Group[355], with an estimated untapped export potential of EUR 353 million.[356] Financing from the EIB is expected to increase manufacturing capacity for lithium batteries and enhance research, development and innovation in the Greek battery industry, offering growth opportunities.[357]

For more opportunities and bottlenecks, see the individual country fiches (Annex II) and Annex V.

Heat pumps and geothermal energy technologies

The EU has strong manufacturing capabilities in the heat pump value chain, with Germany, and Denmark leading industrial production. In the geothermal sector, Italy is a frontrunner in both deployment and industrial production, alongside Germany and France. Several other Member States also contribute to the heat pumps and geothermal value chains.

According to the European Geothermal Energy Council[358], sales and installations of geothermal heat pumps grew by approximately 12% in 2023 while sales for air-source heat pumps slowed down by 5%. The heat pump and geothermal industries in the EU face less foreign competition than other Net-Zero technologies with the EU's industry delivering 60-70% of domestic demand for heat pumps and representing 20% of global manufacturing capacity in 2023. Nevertheless, several challenges could hinder their progress toward 2030 targets. Our assessment identified four key issues:

Unfavourable gas-to-electricity prices and volatile electricity costs have led to reduced demand and a sales drop for air-source heat pumps in 2023 causing sales and investment uncertainties for manufacturers. Heat pumps were the only Net-Zero technology that experienced a global slowdown in manufacturing capacity growth due to stagnation in global markets apart from the Chinese market.[359] This slowdown has caused some manufacturers to downsize and delay investments.[360] This was confirmed by an interviewee who noted that "the sales outlook is not that positive anymore for air-source heat pumps", which can also point to uncertain subsidy schemes, high

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354 Ibid.

355 The Sunlight Group has also invested in the recycling of lead-acid batteries through its recycling plant in Komotini. See here: Sunlight, 24 November 2021, 'Sunlight setting the standard for lead-acid battery recycling in the EU', available here.

356 See Greece's Country Factsheet and section 2.2.

357 EIB, 15 December 2023, 'Greece: EIB to support innovative battery production with €25 million loan to Sunlight', available here.

358 See EGEC Geothermal Market Report 2023. Accessible here.

359 IEA. 2024. Advancing Clean Technology Manufacturing: An Energy Technology Perspectives Special Report. Available at the following link.

360 European heat pump market development, EHPA press briefing 27.02.2024. See also Euractiv (2024) *First drop in sales: Honeymoon is over for Europe's heat pump industry,* available here.

interest rates, long permitting (for geothermal), market saturation, political debate or reduced ambition.[361] The geothermal sector continues to grow and has around 50 power plants in development[362], but its pace is uncertain and depends on political support, improved permitting processes, and financial risk management for larger projects.

The lack of skilled workers impacts both heat pumps and geothermal industries. Both face shortages of skilled workers for manufacturing and installation. An estimated 28,000 to 60,000 additional workers will be required by 2030 for heat pump production alone.[363] Specialised profiles are particularly needed as they are key in the drilling, permitting, installation and maintenance operations. This was confirmed by our survey results and during interviews. One stakeholder notably raised that "geothermal heat pump drillers tend to be hydro drillers. Both have an ageing demographic." Reskilling and upskilling programs are essential to address this challenge.

European companies hold technological leadership in heat pumps, particularly in air-to-water and water-to-water systems, as well as in geothermal technologies (geothermal heat pumps, district heating and cooling systems, seasonal storage and lithium extraction). This is confirmed by our survey results and during interviews. Despite the high share of EU manufacturers, the growing import of heat pump components from China is a concern. Heat pumps manufactured in Europe have twice the costs estimated for China, mainly driven by the costs of compressors and their materials[364]. As a result, the EU's trade balance turned to a deficit in 2020 followed by a steady increase of imports in 2021 and 2022, reaching an overall import value of EUR 898 million.[365] At the same time stakeholders noted that while foreign entrants to the market could pose a threat, they also bring potential benefits such as capital investment and innovation. In the geothermal sector, Europe maintains strong technological leadership in designing and operating district heating and cooling networks and geothermal heat pump production. Reliance on imported components, such as compressors and refrigerants particularly from China, is present. However, transitioning to natural refrigerants and continuing to innovate in geothermal lithium extraction could reduce this dependency and bolster Europe's leadership in these sectors.

Demand-side bottlenecks and public perception challenges persist especially for heat pumps. The high upfront capital cost of heat pumps deters homeowners, particularly in multi-family buildings and renovation projects, which tend to be more expensive and decision-making more complex. Additionally, older housing stock in some countries requires significant upgrades before heat pumps can be installed. For geothermal energy, a general lack of awareness slows its adoption. Generally, demand for heat pumps has been dropping across EU Member States (see also the Box hereunder) also due to between electricity and gas prices, which was favourable to heat pumps in 2022 but shifted in 2023 as gas prices dropped.[366]

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361 European heat pump market development, EHPA press briefing 27.02.2024.

362 These power plants are at different development stages (exploration, drilling, connection with the grid). See EGEC Geothermal Market Report 2023. Accessible here.

363 This refers to a scenario in which 100% of the demand is satisfied by EU manufacturing by 2030. See Employment and Social Developments in Europe 2023 report (European Commission, DG EMPL)

364 IEA. 2024. Advancing Clean Technology Manufacturing: An Energy Technology Perspectives Special Report. Available at the following link.

365 Lyons, L., Lecomte, E., Georgakaki, A., Letout, S. and Mountraki, A., 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, doi:10.2760/69478, JRC134991.

366 The Russian invasion of Ukraine led to high gas prices that decreased in 2022 and changed the relative advantage that electric heat pumps had gained. See European Heat Pump Association (April 2024), Pump it down: why heat pump sales dropped in 2023. Available here.

Box 4 Opportunities and bottlenecks in Member States for heat pumps and geothermal energy

Germany, France, Italy and Denmark are leaders in heat pump manufacturing, with Finland and Czechia also expanding their capacity. Germany, France, and Italy lead in geothermal energy manufacturing, while components for both technologies are produced across various Member States including Sweden.

As a leader in both heat pump and geothermal heat pump manufacturing, Sweden benefits from a strong domestic market and significant manufacturing capacity, particularly in heat pumps, heat exchange units, and centrifugal pumps. According to our assessment, Sweden outperforms China and the USA in exports, with a high comparative advantage in heat pumps. However, Sweden was also impacted by the slump in the heat pump market, experiencing in 2024 a slowdown in the domestic market caused by a decrease in construction activities.[367] Nonetheless, with growing domestic demand for renewable heating and nearly EUR 1.8 billion in untapped export potential[368], Sweden is well-positioned for further growth.

Germany is a competitive exporter of both heat pumps and geothermal technologies, with significant manufacturing capacity in both sectors. The country has strong growth potential, with an estimated export opportunity of over EUR 2 billion.[369] As heat pump demand slowed down in 2023, several companies including Vaillant and Stiebel Eltron had to reduce working time in several facilities for their employees.[370] In the meantime, high electricity costs and a lack of skilled workers remain the key challenges for the industry.

Denmark has at least five heat pump manufacturing facilities and a strong domestic market supporting the technology's development. The country has significant potential for growth in the renewable heating sector. However, as it has a large district heating coverage, the rollout of heat pumps can be slowed down by the priority given to district heating reducing the adoption of heat pumps by homeowners. The 2023 reduction in gas prices significantly affected the heat pump market as sales fell by 36% in a year.[371] Another potential bottleneck concerns refrigerants (hydrofluorocarbons) used in heat pumps and their high global warming potential. Denmark's experience with regulating these ahead of other countries pointed out the complexity of imposing taxes while relying on imports. The EU's F-gas regulations[372] constitutes an opportunity to harmonise approaches and ease imports.

Finland's role in heat pump manufacturing is growing and the country is a competitive exporter of heat pump components, heat exchange units, regulating instruments, and reversible heat pumps. Finland has seen a 130% increase in export competitiveness for reversible heat pumps between 2015 and 2022, with an export potential of over EUR 160 million.[373] In the meantime, like other Member States, Finland underwent a 42% fall in heat pump sales between 2022 and 2023, partly driven by a decline in the construction of new housing which affected mostly air-to-air heat pumps.[374] However, despite the setback, Finland's heat pump sector is

367 Svenska Kyl & Värmepumpföreningen, Heat pump sales. Available here.
368 See Sweden's Country Factsheet and section 2.2.
369 This includes an estimated untapped export potential for heat pumps of EUR 699 million. See Germany's Country Factsheet and section 2.2.
370 See European heat pump market development, EHPA press briefing 27.02.2024.
371 European Heat Pump Association (April 2024), Pump it down: why heat pump sales dropped in 2023. Available here.
372 See Ministry of Environment of Denmark. (2024. *Danish consumption and emission of F-gases in 2022*. The Danish Environmental Protection Agency. ISBN: 978-87-7038-582-4. See also F-gas Regulation (EU) 2024/573. Available here.
373 See Finland's Country Factsheet and section 2.2.
374 European Heat Pump Association (April 2024), Pump it down: why heat pump sales dropped in 2023. Available here.

expected to grow in the future, thanks to increasing profitability, electrification and large investments in heat pumps.[375]

France manufactures components for geothermal energy and has heat pump production facilities. The government has launched initiatives, including an investment tax credit and the French 2030 plan[376], to support manufacturers. Additionally, in 2023 the Ministry of Energy Transition launched a geothermal energy action plan[377] to expand geothermal energy use, improve drilling capacities, and raise awareness among stakeholders. However, France faces challenges with import dependency, particularly on China. Regarding the sales uncertainties, French sales of air-to-water heat pumps decreased by 14%, partly due to declining construction of new housing, lack of clarity on incentive schemes and volatile energy prices, which overall negatively affected demand.[378] In turn, several manufacturers, including Saunier Duval and Groupe Atlantic, implemented partial unemployment in the last quarter of 2023.[379] However, there are new planned investments, such as a new manufacturing plant by Groupe Atlantic in the Grand Chalon region[380] with expectations that demand will pick up again.

Italy is a key player in manufacturing gas turbines for geothermal energy and reversible heat pumps. According to the European Heat Pump Association, there are 50 manufacturing facilities in Italy. These include many family-run companies with a small number of employees, which however face a shortage of qualified workers and struggle to provide training to their employees.[381] Another bottleneck is a sharp decrease in domestic demand with heat pump sales dropping by 33% in 2023. The end of a tax credit, the Superbonus, has led to spending on the sector shrinking and halting the momentum of the market leading to the overcapacity of heat pumps.[382] A recovery of demand could come with the introduction of environmental criteria in public procurement to promote geothermal plants and heat pump systems as well as the renewal of subsidies for heat pumps expected for early 2025.[383]

Hungary is an internationally competitive exporter and producer of heat pump components, such as centrifugal pumps, heat exchange units and electric generating sets and has a combined untapped export potential of over EUR 1.1 billion.[384] The country's exports increased by 52% between 2015 and 2022 to reach EUR 290 million, boosting its Revealed Comparative Advantage index by over 130% over the same period.[385] Hungarian manufacturers specifically benefit from high foreign direct investments thanks to relatively low taxes, labour costs and good infrastructure. This provides Hungary with the opportunity to become a manufacturing hub for components such as compressors supplying their European neighbours and competing with lower-cost competition. This is a trend also observed across other Net-Zero technologies and is not limited to heat pumps.

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375 Ibid.

376 The French 2030 plan for 'Support for the industrialisation of solutions to decarbonise industry' supports projects addressing compressed air, ventilation and pumping, as detailed in section 3.3.1. For the French investment tax credit, see section 3.3.2.

377 Ministere de la Transition énergétique (2023) Géothermie : un plan d'action pour accélérer. Available here.

378 European Heat Pump Association (April 2024), Pump it down: why heat pump sales dropped in 2023. Available here.

379 See European heat pump market development, EHPA press briefing 27.02.2024.

380 Groupe Atlantic, GROUPE ATLANTIC investit 150 millions d'euros dans un nouveau site de fabrication de pompes à chaleur en Saône-et-Loire (71), France. Available here.

381 QualEnergiaI.It (2022) 'Gli ostacoli alla diffusione delle pompe di calore' Available here.

382 Financial Times (2024) 'European heat pump sales tumble as subsidies shrink', available here. See also: European Heat Pump Association (April 2024), Pump it down: why heat pump sales dropped in 2023. Available here.

383 European Heat Pump Association (April 2024), Pump it down: why heat pump sales dropped in 2023. Available here.

384 See Hungary's Country Factsheet and the RCA for Hungary as well as the section on "Data sources and methodological notes" at the end of the country factsheet for information on the underlying data used; calculations of indicators; and limitations.

385 See Hungary's Country Factsheet and section 2.2.

Moreover, the domestic market has also huge potential with the government aiming to install at least 100,000 systems or 400 MW of heat pumps by 2030. Similarly, Hungary has a huge potential for the deployment of geothermal energy especially for district heating according to the IEA.[386] However, Hungary faces some demand-side bottlenecks as a part of its building stock requires retrofitting, because of low insulation levels, before heat pump systems can be installed.[387] Another pervasive challenge for Hungary is labour shortages in industry leading the country to ease immigration rules to attract more foreign labour.

Czechia, Poland and Slovakia are emerging as key actors in heat pump manufacturing. They respectively produce turbine components, heat pumps, and heat exchange units. Both Czechia and Slovakia have strong competitive positions as they outperformed China and the USA for their respective components in 2022 and both have an untapped export potential of over EUR 250 million. Additionally, Czechia's exports rose by 215% between 2015 and 2022. Together, these Member States share an emerging 'heat pump valley'.[388] They can enhance cross-border collaboration and develop a local skilled workforce. However, domestic demand faces unfavourable electricity-to-gas ratios as Slovakia's gas is three times cheaper than electricity while Poland's gas is four times cheaper than electricity.[389] Additional challenges in Poland are the absence of visibility on electricity prices and a slowdown in new home or renovation projects.[390]

For more opportunities and bottlenecks, see the individual country fiches (Annex II) and Annex V.

Electrolysers and fuel cells

More than half of the EU's manufacturing capacity for electrolysers is concentrated in Germany, as outlined in Chapter 2. Besides Germany, manufacturing or assembly facilities for electrolysers have been established in France, Italy, Denmark, Portugal and Belgium. Europe is also a global leader in electrolyser technology and manufacturing is concentrated in China and Europe.[391] In comparison, industrial production for fuel cells is concentrated in Germany but is also found in Finland, France, Estonia, and Lithuania.

Despite ambitious EU decarbonisation targets, industrial production volumes for both technologies remain low due to an insufficiently large market for hydrogen. However, considering the political ambitions, the hydrogen market is expected to grow which will require manufacturing capacities for electrolysers. The 2022 Joint Declaration of the European Commission and industry[392] called therefore for a tenfold increase in electrolyser manufacturing capacities to 17.5 GW per year by 2025 and REPowerEU stipulates a target of 10 million tons of domestic production of renewable hydrogen by 2020. According to current estimates, the expected manufacturing capacity of electrolysers is unlikely to meet these targets[393] and achieving them is unlikely without addressing several key challenges:

386 IEA (2022), Hungary 2022, IEA, Paris https://www.iea.org/reports/hungary-2022, Licence: CC BY 4.0

387 T. Csoknyai (2024) Heat transition options for the least performing buildings of Hungary, FEANTSA Report, available here.

388 Euractiv (2023), *Europe's 'heat pump valley' takes root in the East*, available here.

389 European Heat Pump Association (April 2024), Pump it down: why heat pump sales dropped in 2023. Available here

390 Ibid.

391 European companies include thyssenkrupp nucera, Sunfire, Siemens Energy (Germany), Nel Hydrogen, Hydroge Pro (Norway), John Cockerill (Belgium), ITM Power (United Kingdom), McPhy (France) and Topsoe (Denmark). See: IEA, Energy Technology Perspectives, 2023

392 European Electrolyser Summit, Brussels, 5 May 2022, Joint Declaration.

393 Global nominal electrolyser manufacturing capacity accounted for 23 GW in 2023, 20% of which was accounted for from European manufacturers (60% Chinese and 16% US), see: IEA, Advancing Clean Technology Manufacturing - An Energy Technology Perspectives Special Report, 2024.

Lack of a **mature market** and demand for hydrogen

Lack of **standards** to qualify the performance of electrolysers and scale up production

High dependency on imports of **critical raw materials**

Strong **international competition** and interest combined with tough price competition

The priority issue is the low demand for hydrogen and the lack of market maturity. The industry is growing slowly but demand has not yet reached a level that helps sustain industrial production. This in turn creates uncertainty both for manufacturers and potential customers as the slow implementation of renewable hydrogen has led to delays in investment decisions translating into slower growth in demand for electrolysers.[394] This has been confirmed by our survey results and interviews, where respondents identified this as the main priority issue. While initiatives such as the Hydrogen Valleys are making progress[395], many projects fail to reach final investment decisions or operational status.[396] Moreover, large-scale investments, such as those under the Important Projects of Common European Interest (IPCEI), are slow to materialise.[397]

There are opportunities for growth via instruments such as the Hydrogen Bank, which guarantees hydrogen purchases and supports market development[398] and the Renewable Energy Directive (RED) III which mandates the use of renewable fuels of non-biological origin (RFNBO) in industry and transport with targets of 42% by 2030, and 60% by 2035. Both initiatives have the potential to drive market demand and industry scale-up. This has been confirmed by stakeholders in interviews and the survey. However, some stakeholders believe that the amount of financing provided by the Hydrogen Bank should be increased. Additionally, stakeholders noted that around 15% of the projects that submitted bids to the Hydrogen Bank plan to use Chinese electrolysers.[399]

The lack of standardisation was identified as the second priority issue. The absence of harmonised standards for testing and integration of electrolyser and fuel cell technologies weakens the EU's position in shaping global regulations. Standardisation is crucial for reducing costs, simplifying manufacturing processes, and scaling up industrial production.[400] Survey respondents identified this as the second most important priority issue. One stakeholder remarked that China has introduced national standards for these technologies and is actively promoting them internationally. Establishing EU-wide and international standards could strengthen the competitiveness of European manufacturers and facilitate the global adoption of European technologies.

Another challenge is the high reliance on critical raw materials and dependency on third-country suppliers. Electrolysers and fuel cells require critical raw materials, many of which are imported from non-EU countries such as China and the Democratic Republic of the Congo. This is particularly critical for PEM electrolysers which require iridium and platinum but less of an issue for other technologies such as Alkaline or Solid oxide

394 Ibid.

395 Hydrogen Valleys already include 15 European countries and represent an opportunity to create strong regional value chains

396 Oxford Institute for Energy Studies (2024) 2024 State of the European Hydrogen Market Report.

397 As pointed out by a stakeholder, while an important enabler in paving the way for the hydrogen economy, due to their size they are rather slow-moving as following their announcement in 2020, the first wave was only approved in 2022 (Hy2Tech), the second in 2023 (Hy2Use), and the third and fourth in 2024 (Hy2Infra and Hy2Move). Moreover, many projects notified in 2022 are still awaiting their financing. This delay is also reported by the Oxford Institute for Energy Studies in its 2024 State of the European Hydrogen Market Report.

398 The European Commission has announced a new mechanism to accelerate investments by providing a clearer picture of the market situation of both off-takers and suppliers and facilitating contacts between them (New pilot mechanism to boost the hydrogen market (europa.eu))

399 Oxford Institute for Energy Studies (2024) 2024 State of the European Hydrogen Market Report.

400 For a discussion on this, see: IRENA (2020), Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5ºC Climate Goals; TNO (2022) Projections of electrolyser investment cost reduction through learning curve analysis.

electrolysers. Currently, the EU produces less than 3% of the critical raw materials needed for fuel cells and only 1-4% for electrolysers.[401] The same applies for electrolysers, where the EU produces between 1% and 4% of the raw materials with key suppliers being China, South Africa and Australia. This dependency poses a significant risk to the EU's ability to scale up industrial production. In terms of processed materials, components, and assemblies, the EU is well-positioned for industrial production[402], which could be leveraged to reduce dependency on raw materials through innovation and circular economy practices. Nevertheless, with increasing electrolyser capacities, demand for components (e.g. membranes, cathodes, anodes, etc.) will rise. Considering these are also required for battery technologies, bottlenecks can be anticipated should the manufacturing of these components not be scaled up.[403]

European manufacturers face strong international competition from China and the USA, where companies benefit from greater financial support, such as subsidies and interest-free loans, as well as lower labour and energy costs. Specifically, if fully utilised, China could already today cover its own domestic needs with its electrolyser manufacturing capacity, which could lead to surpluses being exported to third countries. However, this will require Chinese manufacturers to modify their designs to adhere to European standards and address current operational challenges.[404] Despite these challenges, Europe leads in technological innovation, with strong positions in PEM electrolysers, accounting for 30% of global PEM manufacturing capacity, and Solid Oxide technology. European firms hold numerous international patents, positioning the EU as a leader in these emerging technologies.[405]

Box 5 Opportunities and bottlenecks in Member States for electrolysers and fuel cells

Industrial production levels for electrolysers and fuel cells are low compared to other Net-Zero technologies. However, industrial production has been increasing with Germany being the European leader for electrolysers and fuel cell manufacturing with half of the EU's industrial production. For electrolysers, the main producers next to Germany are Denmark, France, Spain, Italy, and Portugal. Belgium and Austria produce balance-of-plant components, which are however less critical. For fuel cell components, industrial production takes place to some extent also in Finland, Lithuania, Estonia and France.

Germany hosts more than half of Europe's manufacturing capacity for electrolysers with 2.8 - 3.5 GW/y.[406] It is home to firms such as Linde Engineering, thyssenkrupp nucera, Sunfire, Siemens Energy, Bosch, Daimler Truck and EKPO boasting an active industrial ecosystem for both electrolysers and fuel cells. The country could further strengthen its leadership position as it revised 2023 its National Hydrogen Strategy and introduced industrial leadership in hydrogen technologies (such as electrolysers) as a goal. Industrial research and innovation will be boosted by associated measures. Additionally, Germany's participation in the Hy2Tech IPCEI and national projects such as H2Giga support its ambition to produce hydrogen at scale. In scaling up, a bottleneck for the German

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

402 Ibid.

403 IEA, Advancing Clean Technology Manufacturing - An Energy Technology Perspectives Special Report, 2024.

404 Ibid.

405 Bolard, J., Dolci, F., Gryc, K., Eynard, U., Georgakaki, A., Letout, S., Kuokkanen, A., Mountraki, A., Ince, E. and Shtjefni, D., Clean Energy Technology Observatory: Water Electrolysis and Hydrogen in the European Union - 2023 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/133010, JRC135018.

406 See Germany's country factsheet and section 2.2.

industry will however be the reliance on importing critical raw materials as well as components that will simultaneously be needed also for battery manufacturers such as cathodes and anodes.

Denmark manufactures machinery and apparatus for electrolysis with companies such as Topsøe and provides 7-16% of the EU manufacturing capacity (0.4 – 0.9 GW/y). It is also a competitive producer and exporter of catalysts or reaction initiators for electrolysers. It has a significant role globally with a noteworthy RCA of 33 and an estimated export potential of EUR 219 million.[407] Additional growth potential lies in the announced electrolyser factories by Green Hydrogen Systems and Topsøe with expected outputs of 600 MW and 500 MW respectively. The low market demand challenges the fast development of the industry. To address this, Denmark implemented a EUR 170 million demand-side incentive scheme to support investment in hydrogen which has led to six new electrolyser projects.[408] While these are not guaranteed to procure their electrolysers from Danish manufacturers, it is nevertheless likely that Danish companies will benefit.

Spain's Green Hydrogen Roadmap is very ambitious and aims to make renewable hydrogen supply 25% of the total energy consumed by industry by 2030. Spain's access to renewable energy and existing infrastructure for energy transport, including the H2Med project to connect the Iberian Peninsula with France and the rest of Europe, offers opportunities to serve as a major clean energy hub for Europe. This growing green hydrogen industry presents a significant opportunity for Spain to lead also in hydrogen technology development. Already, Spain is contributing 9 – 11% to Europe's electrolyser and fuel cell manufacturing capacity[409] and recently Accelera opened a new electrolyser factory with a capacity of 0.5 GW/y.[410] Further momentum for Spanish manufacturers could come from the Commission's approval of EUR 1.2 billion of state aid to support the production of renewable hydrogen in Spain.[411]

Italy is home to 6% of the EU's electrolyser manufacturing capacity (0.3 GW/y)[412], with facilities that manufacture electrolyser machinery, compressors and storage. Italy is focusing on hydrogen development as a key decarbonisation pathway[413] and substantial funds from the NRRP are allocated to R&D for hydrogen technologies and industrial applications through EUR 450 million for the installation of gigafactories and supply chain components.[414] An additional EUR 100 million of funding was also made available under the Temporary Crisis and Transition Framework for electrolyser production.[415] Italy's strong manufacturing base combined with political ambition and public funding provides an opportunity to further develop electrolyser manufacturing.

Portugal produces compressors, storage systems, and electrical components contributing about 2-9% of the EU's manufacturing capacity for electrolysers and fuel cells. The country's industry is poised for further growth with the investment from Fusion-Fuel in new electrolyser facilities[416], which are expected to be operational by 2025. Portugal can capitalise on its favourable climate for renewable electricity production, which will allow it to generate a surplus

407 See Denmark's country factsheet and section 2.2.

408 Danish Energy Agency, 27 October 2023, The first PtX tender in Denmark has been determined: Six projects will establish electrolysis capacity on more than 280 MW.

409 See Spain's country factsheet and section 2.2.

410 Accelera, 03.10.2024, Accelera opens new electrolyzer factory in Spain, enabling Europe's energy transition.

411 European Commission, 26.07.2024, Commission approves €1.2 billion Spanish State aid scheme to support investments in the production of renewable hydrogen to foster the transition to a net-zero economy.

412 See Italy's country factsheet and section 2.2.

413 IEA (2023), Italy 2023, IEA, Paris https://www.iea.org/reports/italy-2023, License: CC BY 4.0.

414 M2 C2.5.2 Hydrogen (National Recovery and Resilience Plan)

415 European Commission, 09.10.1023, State aid: Commission approves €100 million Italian scheme to support the production of electrolysers to foster the transition to a net-zero economy.

416 Fusion Fuel, 16.02.2024, Fusion Fuel Receives Notification of IPCEI Approval from European Commission for 630 MW HEVO-Portugal Project.

of renewable energy to produce green hydrogen. This could also be beneficial for local manufacturers of electrolysers and relevant components to supply these hydrogen projects.

France currently has a small share in electrolyser manufacturing (60-160 MW/y), however, the country has announced a strong pipeline of projects with French companies such as McPhy, Genvia and Elogen.[417] France also recently made strong innovation and R&D efforts by launching a research program supporting new electrolytic technologies, backed by EUR 80 million in funding[418] and has a strong innovation ecosystem for hydrogen, electrolysers and fuel cells.[419]

In Belgium, companies such as Bekaert and AGFA manufacture and export less critical components such as tanks and containers (balance-of-plant components) but also membranes for alkaline technologies. For electrolysers, John Cockerill is already assembling stacks in its Seraing facility from cells produced in France and Belgium's capacity is growing with an expected output of 1 GW in electrolysers from the factories announced by Cummins through IPCEI support. Belgium is also emerging as a transportation hub for hydrogen and has signed a Memorandum of Understanding with Germany and the Netherlands highlighting a potential to further invest in cross-border collaboration[420].

For more opportunities and bottlenecks, see the individual country fiches (Annex II) and Annex V.

Sustainable biogas and biomethane technologies

The EU has a solid manufacturing base for biogas production equipment, such as anaerobic digesters and biogas upgrading systems with Germany and Italy leading in technology production. However, biogas technology production is unevenly distributed across Member States, and data on this sector remains limited. The evidence collected and input gathered from stakeholders suggest that challenges for biogas lie with deployment, rather than the supply and manufacturing of the equipment. Companies in the EU are generally well placed to produce the relevant components and technologies, which often are not reliant on input from third countries or are basic components such as tanks and containers.

Biogas and biomethane are key contributors to achieving the EU's 2030 clean energy objectives. The REPowerEU Plan[421] specifies a 35 billion cubic metres (bcm) annual biomethane production target by 2030[422] and estimates an investment need of around EUR 37 billion. The following challenges to reach these targets were identified:

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417 See information on investment here and here

418 Under France 2030 investment plan, the PEPR Hydrogène Décarboné programme has a budget of €83.1 million over 8 years. See H2 – Hydrogène décarboné available here.

419 Energynews, 19.19.2023, FC Lab Belfort revolutionizes Hydrogen in France,

420 The three countries notably jointly committed to develop the industry at the last Hydrogen Summit in May 2024 through a Memorandum of Understanding. Belgium also engaged in discussions with Denmark and Norway to support the overall CO_2 infrastructure. See L. Meillaud, 5 May 2024, 'Belgium, the Netherlands and Germany join forces to develop hydrogen', available here and Government.no, Strenghtened energy ties to Belgium, available here.

421 Available here.

422 From 3 bcm in 2021. See here.

Lengthy permitting leading to bottlenecks	High costs and market volatility	Varying feedstock availability constraints	Lack of standardisation limiting economies of scale

Lengthy permitting procedures are a key challenge. Permitting for biogas plants in Europe can take 2-3 years, with some cases extending to 5-7 years.[423] While this does not impact equipment manufacturers directly, it causes significant delays and increases investment uncertainties for manufacturers. Streamlining these processes is essential for accelerating biogas plant deployment and allowing the industry to further scale up. This bottleneck has also been confirmed by stakeholders in the interviews, the survey, and the roundtable discussion. An additional lengthy permitting procedure is linked to connecting biogas plants to the grid. A report by the GreenMeUP project[424], which analysed biogas/biomethane production and related policy frameworks in ten advanced European countries, identified permitting as "an area where no significant good practice was reported".

Another priority concerns high costs and market volatility. The cost of biomethane production remains high, particularly for smaller plants, which face capital costs 2-3 times higher per MW capacity compared to larger facilities. The Biomethane Industrial Partnership (BIP)[425] estimated the average cost of biomethane production and upgrading at EUR 84 MW/h for smaller plants (with a capacity of ~300-780 Nm3/h biomethane) and EUR 54 MW/h for large plants (with a capacity of >1200 Nm3/h biomethane)[426], indicating strong economies of scale. Market volatility, especially in natural gas prices, further complicates the business case for biogas and biomethane, impacting investment decisions. The lack of long-term predictability in natural gas prices increases the risks for project developers and affects the overall competitiveness of biomethane compared to natural gas. Lastly, changes in legislation and policy support strongly affect the market for biogas/biomethane.[427]

Constraints related to feedstock availability are an important challenge affecting the whole sector. Securing sufficient feedstock, such as animal manure, agricultural residues, and industrial wastewater[428], is a critical issue. It is particularly key for large-scale plants that need to secure a larger amount of feedstock than small-to-medium farm-based anaerobic digestion plants. Limited availability and competition from other uses restrict the scale and economic viability of biogas projects. Stakeholders also confirmed that feedstock availability and competition for feedstock are priority issues in producing biogas and biomethane. A study by the European Biogas Association (EBA) [429] indicates that enough sustainable feedstock could be available to meet the EU's 2030 target, with the potential for up to 40 bcm of biomethane production through novel feedstocks and technologies. This 2030 objective is based on Member State targets while current production is only at 20.2 bcm[430], indicating the need for adjusting national targets to accelerate the scale-up of biomethane production. Stakeholders also stressed

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423 BIP Europe (2023), Task Force 2, Accelerating biomethane permitting. Available here.

424 GreenMeUP Project (2024). Overview of production routes and end-uses of renewable gases and existing policy frameworks in advanced European and Mission Innovation countries. Available here.

425 BIP Europe (2023). Task Force 4. Insights into the current cost of biomethane production from real industry data. Available here.

426 These numbers are based on 2021 data, as 2022 was impacted by the energy price crisis and high inflation.

427 In Germany, the phasing out of feed-in tariffs threatens many biogas plants that were previously supported under the German Renewable Energy Act (REA). Terese E. Venus, Felix Strauss, Thomas J. Venus, Johannes Sauer, Understanding stakeholder preferences for future biogas development in Germany, Land Use Policy, Volume 109, 2021, 105704, ISSN 0264-8377, https://doi.org/10.1016/j.landusepol.2021.105704.

428 Gas for Climate (2022). Biomethane production potentials in the EU. Available here.

429 European Biogas Association (2024). Biogases towards 2040 and beyond. Available here.

430 European Biogas Association (2023). EBA Statistical Report 2023. Available here.

the need for policy drivers and recommendations to align with these feedstock opportunities to effectively support biogas production pathways.

Stakeholders noted the lack of standardisation, which limits economies of scale and increases costs. Unlike other sectors, such as photovoltaics, where standardisation has been achieved, biogas plants often need to adapt to locally available resources, resulting in unique designs for each plant. Stakeholder opinions varied regarding the scale of standardisation that could be achieved noting that biogas plants often need to utilise locally available resources, leading to inherent differences. However, there is room for increased standardisation which could enable equipment manufacturers to scale up and improve their production lines.

Box 6 Opportunities and bottlenecks in Member States for biogas and biomethane technologies

For sustainable biogas and biomethane technologies, manufacturing is led by Germany and Italy while Czechia, Poland, and Spain stand out in producing compressors, gas storage components, gas purifiers and liquefiers. Germany and Poland are particularly strong exporters of machinery for filtering or purifying gases, while Italy excels in gas turbines.

Germany excels in both the manufacturing and deployment of biogas and biomethane technologies. Based on available feedstock, it has the highest potential in the EU in 2040 for anaerobic digestion and the second highest potential for thermal gasification. Unlocking novel feedstocks and technologies, for instance, using seaweed harvested in the Baltic Sea[431], can further expand this potential. Regarding grid connection, Germany is among the countries that have implemented a cost-sharing mechanism, with substantial shares covered by grid operators.[432] This can significantly reduce the financial burden for new biomethane plants, especially for small to medium-sized project developers.[433] For Germany, challenges include the complexity of regulations, lack of an overall political strategy, and unclear priority of the pathways for biomethane.[434]

Italy is the second largest producer in the EU and among the countries with the highest biomethane production potential by 2040.[435] It also has legislation promoting and supporting biogas and biomethane production, including the Interministerial Decree of 2013 and the Ministerial Decree of 2018, which support the construction and conversion of plants for integration into gas networks, transport, and cogeneration. This decree was updated in 2022 establishing new incentive mechanisms and allocation of funding from the RRF.[436] Several projects are underway such as a 45Gwh biomethane plant which will be constructed in Grottole by a consortium of Italian companies and will rely on local feedstock available.[437] Regarding trade, Italy is a strong exporter of gas turbines but has otherwise a relatively high extra-EU import dependency.[438] However Italy, like many other countries, struggles with lengthy permitting procedures.

431 European Biogas Association (2024). Biogases towards 2040 and beyond. Available here.
432 This share amounts to 75% in Germany. See here.
433 GreenMeUP Project (2024). Overview of production routes and end-uses of renewable gases and existing policy frameworks in advanced European and Mission Innovation countries. Available here.
434 Ibid.
435 European Biogas Association (2024). Biogases towards 2040 and beyond. Available here
436 GreenMeUP Project (2024). Overview of production routes and end-uses of renewable gases and existing policy frameworks in advanced European and Mission Innovation countries. Available here.
437 Axpo (2024) ‘Axpo enters biomethane market in Italy, available here.
438 See Italy’s Country Factsheet and section 2.2.

While Czechia is not among the top EU producers, it has a large biomethane potential[439] and excels in compressor manufacturing. However, a potential bottleneck might arise from the country's agricultural and environmental policy framework. Current policy emphasises efficient management of energy crops and maximising the use of bio-waste. Bio-waste however, would not provide enough feedstock and has a lower conversion factor than energy crops, outlining the need for more bio-waste to be processed.[440]

Poland has emerged as a competitive exporter of machinery for filtering or purifying gases, with a 200 percent increase in this segment, reaching EUR 2.9 billion.[441] The country also has the second highest planned investments in the EU, with EUR 3.4 billion, translating to a foreseen capacity of 8.8 TWh/year.[442] Poland's Industrial Policy further supports biogas and biomethane technologies by maximising local content, enhancing market participation, and boosting employment and education initiatives.

Spain also has substantial potential for both anaerobic digestion and thermal gasification.[443] However, it faces challenges related to gas infrastructure and connection. Specifically, the complexity and delays in the permitting procedures hinder the potential growth in biomethane production[444], and stakeholders highlighted permitting challenges regarding the disposal of digestate. Unlike other countries that operate centralised systems with large plants (e.g. Denmark), Spain has a decentralised model based on small plants that use local residues over small distances. Spain's model limits scaling up manufacturing and would require upgrading infrastructure and technologies for biomethane injection in the grid.[445] Addressing this issue requires increased financial support and alignment with the preferences of major gas companies.

For more opportunities and bottlenecks, see the individual country fiches (Annex II) and Annex V.

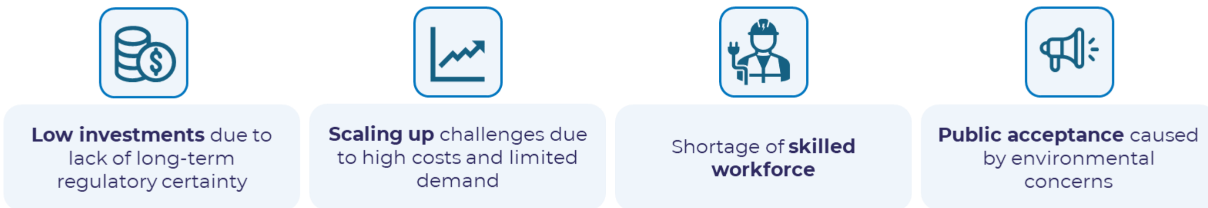
Carbon capture and storage technologies

Several EU countries maintain strong manufacturing capacities in carbon capture and storage (CCS) technologies by producing both chemicals and machinery. Leading manufacturing countries include Germany, the Netherlands, Sweden and Denmark. Globally, the United States has taken a leadership role in deployment accounting for more than half of all current and planned CCS capacity[446] and is also leading in technological development when considering patent applications (followed by the EU)[447].

While the technology has existed for over 20 years, relatively few plants have been built and operationalised and the main challenge for scaling up CCS (and CCUS) manufacturing lies in its deployment. Internationally, the largest operational and planned projects are located in the USA, Canada, and Brazil but there are also applications in Norway and Australia. In Europe, interest has recently surged following changes in the EU Emissions Trading Scheme, which stimulated initiatives introducing new technologies and enhancing manufacturing capabilities to reduce costs.

439 GreenMeUP Project (2024). Overview of production routes and end-uses of renewable gases and existing policy frameworks in the Target European countries. Available here.
440 Ibid.
441 See Poland's Country Factsheet and section 2.2.
442 2nd EBA Investment Outlook on Biomethane. Available here.
443 European Biogas Association (2024). Biogases towards 2040 and beyond. Available here
444 Sedigas (2023). A study of the capacity for biomethane production in Spain. Available here.
445 As opposed to countries that operate centralised systems, with large plants processing extensive volumes such as Denmark.
446 IEA, CCUS in Clean Energy Transitions, Regional opportunities, available here.
447 EIB and European Patent Office, 2024, Financing and commercialisation of cleantech innovation.

Alongside emissions reductions, ambitious targets have been set to remove CO_2 from the atmosphere. By 2050, the EU aims to capture, store or utilise 450 million tonnes of CO_2 per year.[448] To achieve this goal, The Net-Zero Industry Act stipulates a target of 50 million tonnes of annual operational CO_2 injection capacity by 2030. While it mostly focuses on CCS technologies, it also mentions carbon capture and utilisation technologies (CCU) which can help achieve 2030 climate targets. However, the CCS sector faces several challenges that could impede its growth and the achievement of EU climate targets. Our assessment identified the following issues that might challenge achieving these targets:



A low rate of investments caused by an absence of a long-term regulatory framework is a major challenge. CCS projects are capital-intensive and have long lead times (5-15 years), requiring stable policies to attract the necessary funding. This is particularly important for manufacturers and investors to be able to make long-term decisions such as identifying the locations for CCS or determining the appropriate means of CO_2 transportation. Current investment levels are insufficient, partly due to uncertainty around long-term carbon pricing and demand.

Despite its long history, the industry has not scaled up and is still in its early stages due to high costs and limited market demand. The lack of storage infrastructure further complicates this challenge, highlighting the need for more development in this area. During stakeholder discussions, one industry expert noted that since companies are technology licensors, they can only reach market maturity after having sold a large number of projects, while few units are sold with a significant base of engineering work. This implies significant investment costs for companies, including employment costs, and keeping such costs low remains a challenge.

Shortage of skilled workers, particularly in engineering and construction. As the sector grows, competition for these skilled workers is expected to increase,[449] potentially delaying project implementation. Engineers are particularly important as they are needed for feasibility assessment and front-end engineering design of projects that risk being delayed. Hence, the workforce bottleneck may apply at the very beginning of CCS projects. Leveraging skills from related industries, such as oil and gas, could help address this bottleneck. Their workforce possesses the skills and supply chain knowledge relevant to CCS activities.

Public acceptance of CCS projects echoes issues faced by the wind sector and the 'not in my backyard' sentiment. This was confirmed by the survey results. Public acceptance challenges impact both CCS and CCU although they affect projects to different degrees, covering both the required technical infrastructure and the use of CO_2-based products in the market.[450] Addressing these concerns through community engagement and incentives will be crucial for future projects.

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448 COM/2024/63 final

449 A high overlap between CCS skills and other sectors is highlighted in the findings and recommendations report by the Green Jobs Delivery group – CCS Task and Finish Group 2024. Accessible here

450 See Sapart, Célia Julia, Katrin Arning, André Bardow, Christian Breyer, Angela Dibenedetto, Suren Erkman, Colin D. Hills et al. "Climate Change Mitigation: The Contribution of Carbon Capture and Utilisation (CCU)." In *Proceedings of the 16th Greenhouse Gas Control Technologies Conference (GHGT-16)*, pp. 23-24. 2022.

Box 7 Opportunities and bottlenecks in Member States for CCS

Germany, the Netherlands, Sweden, and Denmark are leading countries in the EU's carbon capture and storage (CCS) sector, with strong manufacturing capacities, deployment initiatives, and substantial storage potential. Furthermore, opportunities for future scaling-up of CCS technology manufacturing exist in France and Poland.

Germany has strong manufacturing capabilities in CCS-related machinery, such as scrubbers and compressors contributing 30% of the total EU scrubber production. However, the industry faces bottlenecks such as high capital and operational costs, a lack of public acceptance[451] as well as the need for long-term regulatory stability to support investment. Regarding regulatory hurdles, an evaluation found several barriers within the Germany Carbon Dioxide Storage Act. Despite these challenges, Germany has an opportunity to leverage its technological expertise to scale up CCS manufacturing and contribute to the EU's decarbonisation goals. This is also reflected in Germany's recent shit to embrace CCS as a climate mitigation option showcased in the introduction of a Carbon Contract for Difference scheme, the upcoming Carbon Management Strategy and an amendment of the Carbon Dioxide Storage Act.[452] The key principles for the Carbon Management Strategy and a draft of the revision of the Carbon Storage Act were recently published by the German government aiming to accelerate the deployment of CCS. This could allow German manufacturers to scale up production, however, there are no provisions giving preference to local content[453].

The Netherlands leads in CCS deployment and storage capacity due to its geographic location and existing gas infrastructure. Projects such as the Aramis and Porthos projects in the Port of Rotterdam, which will be delivered by a consortium of Dutch, German and Greek companies can ensure the development of knowledge in setting up complex CCS projects. Building on these projects and the geographic location, opportunities exist for further developing storage sites and enhancing the country's role as a key player in the EU's CCS network. Nevertheless, environmental concerns and public acceptance have been issues and have led to delays and cost increases for the Porthos project[454] creating uncertainties for future projects.

Sweden is advancing in CCS deployment, particularly in the field of bioenergy with carbon capture and storage (BECCS) due to the presence of a large pulp and paper industry as a consumer of biomass.[455] Sweden's opportunities lie in leveraging its strong climate policies and commitment to sustainability to push forward CCS projects that align with its broader climate goals. A bottleneck for the Swedish CCS industry lies in the high costs associated with CCS projects and their economic viability. To unlock more investments, there is a need for cost reduction through improvements and learning or alternatively higher carbon prices.[456]

Denmark is also emerging as a leader in CCS, particularly in the North Sea, where it has significant potential for CO_2 storage. Denmark can capitalise on its existing offshore expertise and strong renewable energy sector to

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451 Patonia, A. (2022) Contrasting Public Acceptance of Carbon Capture and Storage in Norway and Germany.

452 Global CCS Institute (2024) CCS in Germany's Decarbinisation Pathway: State of Play and Way forward.

453 Federal Ministry for Economic Affairs and Climate Action, 29.05.2024, Cabinet clears path for CCS in Germany.

454 Carl Deconick, 8 March 2024, Groundbreaking Dutch CO_2 storage-project costs soar, Brussels Signal.

455 Karlsson, S., Eriksson, A., Normann, F. and Johnsson, F. (2021) Large-Scale Implementation of Bioenergy With Carbon Capture and Storage in the Swedish Pulp and Paper Industry Involving Biomass Supply at the Regional Level, Frontiers in Energy Research 9.

456 Beiron J., Johnsson, F., Progressing from first-of-a-kind to Nth-of-a-kind: Applying learning rates to carbon capture deployment in Sweden, International Journal of Greenhouse Gas Control, Volume 137, 2024, 104226, ISSN 1750-5836, https://doi.org/10.1016/j.ijggc.2024.104226.

advance CCS initiatives. The main bottlenecks are the same as for Sweden and include the high costs associated with CCS projects and the corresponding need for more investment in infrastructure and skilled labour. Reskilling and upskilling initiatives with 'outgoing' industries such as oil and gas provide an opportunity to address labour shortages.

France while not a major leader in CCS is beginning to explore the technology, driven by its strong climate policies. The country has recently launched a call for expression of interest for CCS to be built at various sites.[457] This initiative follows a recent agreement with Denmark which focused on jointly developing carbon transportation and storage options.[458]

Poland's heavy reliance on coal and heavy industries makes it a prime candidate for CCS to reduce emissions.[459] Poland is one of the EU countries with the highest number of jobs in the coal sector, specifically in regions such as Silesia, Lower Silesia and Wielkopolska.[460] The Polish government established a CCUS Working Group, which has conducted feasibility studies for five CCS facilities and established a public communication advisory group.[461] However, the country faces significant challenges, including a lack of supporting policy, investment, infrastructure, and public acceptance.[462] Poland's opportunity lies in transitioning its coal-based economy toward a low-carbon future by adopting CCS technologies, however, considering the lack of current CCS manufacturing capacities a supporting framework would be required to establish local industries.

Other Central and Eastern European such as Romania face similar opportunities and challenges.[463] Romania is also a competitive exporter of pumps and compressors for air or gas and machinery for filtering or purifying gases with exports having increased by 762% to nearly EUR 500 million between 2016 and 2022.

For more opportunities and bottlenecks, see the individual country fiches (Annex II) and Annex V.

Grid technologies

As discussed in Chapter 2, EU companies hold a strong position in grid technologies thanks to their leadership in cable manufacturing and innovation. However, there are bottlenecks in electrical grid components and EU manufacturers face competition from third countries. Top EU cable producers include Prysmian Group (Italy), Nexans (France), and NKT (Denmark), with important regional producers such as Tele-Fonika (Poland) and Hellenic Cables (Greece). Regarding smart grid technologies, manufacturing capacities are distributed across the EU, with countries such as Germany, Denmark, and Sweden hosting manufacturing facilities for smart meters, grid automation equipment, and energy management systems.

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457 Ministry of Economy, Finance and INdustrial and Digital Sovereignty, 30.04.2024, Roland Lescure launches a call for expressions of interest to develop France's carbon capture and storage capacities. Available here.

458 Letter of Intent between the Ministry of Climate, Energy and Utilities of Denmark and the Ministry of the Economy, Finance, and Industrial and Digital Sovereignty of the French Republic on cooperation of Carbon Capture and Storage (CCS), 2024. Available here.

459 Centre for Climate and Energy Analyses (2021) Poland Net-Zero 2050. The Roadmap toward achievement of the EU climate policy goals in Poland by 20250. Available here.

460 See also the interactive map and publications of the EU coal regions in transition platform, available here.

461 Paweł Pikus, 01.08.2023, Summary of the work conducted by the CCUS Working Group, Presentation. Available here.

462 J. Fabiszewska-Solares, K. Kobyłka, K. Laskowski, K. Marszał, A. Śniegocki (2021) Assessment of current state, past experiences and potential for CCS deployment in the CEE region – Poland. Available here.

463 CCS4CEE, 08.08.2023, Summary of CCS4CEE project – all documents. Available here.

The increasing deployment of grid technologies is driven by the growing demand for electricity and the integration of renewable energy sources, which require enhanced flexibility and efficiency. The EU Action Plan for Grids[464] identifies an investment need of EUR 584 billion for electricity grids, particularly for distribution. Specifically, ENTSO-E's Ten-Year Network Development Plan[465] identifies a need for 23 GW of capacity by 2025 and a further 64 GW for cross-border transmission infrastructure in Europe by 2030. A recent study by the IEA.[466] highlights the importance of meeting the necessary targets, as delays in grid investment and development would lead to increased GHG emissions, a slower energy transition and a higher reliance on natural gas. Being the backbone of today's electricity system, grids are essential for a successful energy transition. Our assessment identified the following issues that might challenge achieving these targets:

Lack of a qualified workforce can become a bottleneck for both deployment and manufacturing, especially for electrical engineers, but also project managers and electrical installers. Additionally, the digitalisation of grid infrastructure is expected to impact workforce requirements increasing the need for digital and technology-related skills in the electricity sector.[467] Industry actors stress the need to address this skills gap in the engineering workforce.[468] This has also been confirmed in interviews, the survey, and the roundtable discussion. Specifically, it was highlighted that the lack of a skilled workforce is not only an issue for the industry but also for customers. Stakeholders pointed out that manufacturers have to invest in warehousing for sold equipment as TSOs and DSOs cannot collect the equipment due to delays in projects caused by a lack of sufficient installation workforce. Qualified workers need to be attracted into the grid sector from both within and outside of Europe, which requires innovative approaches. The industry also needs to anticipate future workforce needs and attract young people into relevant education programmes.

The sector's reliance on critical raw materials with strong price variations, especially aluminium and copper used as electrical conductors, can pose another challenge to supply chain stability. Prices are expected to grow due to the increasing electrification in China and the USA, alongside a limited number of producers. As aluminium is in the scope of the Carbon Border Adjustment Mechanism (CBAM), the price of imported aluminium will likely increase. This, together with the phase-out of free allowances for European manufacturers, will increase overall industrial production costs, with potential additional costs as high as EUR 1,350 per tonne of cable after 2034.[469] On the other hand, power cables, which can contain up to 80% aluminium, are excluded from the scope of CBAM. This can cause distortions against EEA-based power cable manufacturers, disadvantaged compared to non-EEA

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464 Grids, the missing link - An EU Action Plan for Grids, available here.

465 ENTSO-E (2023 May). TYNDP 2022 System Needs Study, Final version. System needs study – Opportunities for a more efficient European power system in 2030 and 2040

466 IEA (2023), Electricity Grids and Secure Energy Transitions, IEA, Paris. Available here.

467 See: Spin360 (2017) Study On Skills Needs Developments, Vocational Education And Training Systems In The Changing Electricity Sector; and Eurelectric and Accenture (2024) Wired for tomorrow. Unleasing the power of digitalisation in grids.

468 ENTSO-E (2024 April), High-Level roundtable on electricity grids in Europe. Available here.

469 Europacable (2023), available here

manufacturers[470] unless downstream products are included in the CBAM scope. Another critical raw material with potential bottlenecks is silicon metals.[471] These are needed among others for the electronics in converters and China is the major global supplier (76% share of the global supply). However, the EU has diversified sources with Norway being its largest supplier (35% of EU imports) and 9% from Brazil. France, Spain and Slovakia are also responsible for processing and refining 5% of the global supply of silicon metals.[472]

Considering the growing global demand for grid technologies[473] material shortages are another concern. Aluminium and copper demand are expected to grow by 30% between 2023 and 2035.[474] For copper, the actual supply has not been keeping up with the projected supply shortages are anticipated.[475] This will increase lead times for grid technology manufacturers and might require reducing demand through more efficient use or substituting materials. For example, albeit having less electronic conductivity, aluminium is a primary substitute option for copper applications.[476] To reduce dependency on third countries, Europe needs to focus on keeping the processing of raw materials within the continent, increase the efficiency of resources and improve recycling and reuse.

Long and growing lead times were also reported by project promoters due to a limited supply of grid components.[477] Some European TSOs are reporting that the delivery of HVDC converters by European manufacturers ordered in 2023 is expected by 2031 – 2032.[478] A likely cause for these long lead times lies in the rapidly increasing global demand, including from larger non-EU countries placing bulk orders, outpacing supply. In our conversations with stakeholders, it was mentioned that manufacturers have been cautious in expanding operations due to past experiences when expected grid investments did not materialise punishing overly ambitious companies. Specifically, this has translated into a shortage of transformers doubling lead times as recently reported[479]. A challenge is the low number of manufacturers and limited investments amidst growing demand. Another bottleneck is the production of high-powered semiconductors, required for converter valves in the HVDC supply chain, which is concentrated in Taiwan.[480].

In addition, stakeholders also noted the importance of regulatory certainty and coherence when it comes to legislative frameworks. Changes to regulations require reengineering and recertification, which slows down the deployment process. Especially when operating across EU borders this can be a problem.

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470 Europacable (2023). Potential impacts of the EU Carbon Border Adjustment Mechanism on the European cable industry. Report (europacable.eu)

471 Trinomics and Artelys (2021) Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis.

472 European Commission, Study on the Critical Raw Materials for the EU 2023 – Final Report.

473 IEA, 2024, Global Critical Minerals Outlook 2024.

474 McKinsey & Company, 2024, Global Materials Perspective 2024.

475 See: McKinsey & Company, 2024, Global Materials Perspective 2024; Bloomberg Intelligence, 2023, Global Copper 2024 industry outlook: From near-term glut to long-term scarcity.

476 The lower electrical conductivity requires thicker cables for aluminium. Moreover, worse thermal and mechanical properties require greater maintenance making aluminium less suitable for high-voltage subsea and underground cables; see: IEA, 2024, Global Critical Minerals Outlook 2024.

477 Grids, the missing link - An EU Action Plan for Grids, available here.

478 De Paola, A., Andreadou, N., Kotsakis, E., Clean Energy Technology Observatory: Smart Grids in the European Union - 2023 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/237911, JRC134988

479 Transformer Technology, 07.05.2024, Europe Faces Transformer Shortage: Grid Expansion and Renewable Energy Projects at Risk, available here.

480 De Paola, A., Andreadou, N., Kotsakis, E., Clean Energy Technology Observatory: Smart Grids in the European Union - 2023 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/237911, JRC134988

European market position and technological leadership must be maintained. The EU holds technological and manufacturing leadership globally in producing HVAC as well as HVDC cable technology.[481] Specifically, in the competitive HVDC market, the completeness of the EU supply chain is a strength.[482] However, for HVDC cables EU companies show lower patenting volumes than their Chinese counterparts[483] while maintaining more diversity and geographical reach in their patents[484]. China also leads the development of multiterminal HVDC systems.[485] However, rising raw material prices, resistance to grid expansions within Europe, and increased competition from China pose significant risks, especially if a level playing field is not ensured. European manufacturers are subject to stringent sustainability requirements, while non-EU producers often face less rigorous regulations. To address this, stronger recognition of sustainability efforts by manufacturers is needed, with these efforts integrated into the tendering process. This approach would promote sustainable industrial production practices in Europe and help secure the continent's manufacturing base.

Box 8 Opportunities and bottlenecks in Member States for grid technologies

Italy is leading in cable manufacturing, followed by Germany, Sweden and France. Spain, Poland, Denmark, Greece and Czechia also have important manufacturing capacities for grid technologies. Regarding smart grid technologies, Germany, Denmark, and Sweden have a strong presence in manufacturing smart meters, grid automation equipment, and energy management systems, while Finland and Spain also have a strong presence in producing control-related components such as inverters, rectifiers, and capacitors.

Italy is a leading manufacturer of components for electricity grids, such as inverters, transformers, switchboards, grid balancing components, cables, meters and control software[486] contributing 13% to the EU's total grid technology production.[487] Based on this leadership position, Italy has the opportunity to grow its industry by relying on a strong and growing European market while expanding further into third-country markets. In terms of exports, Italy is a competitive exporter of insulated electric conductors and transformers, with an export potential of EUR 3,515 million and EUR 229 million, respectively. For both components, Italy's RCA index is higher than that of China or the USA.[488] Already, Prysmian, a major global industry player, has announced investments, targeted at capacity expansion and upskilling, which offer important growth opportunities for the Italian cable industry.[489] No country-specific challenges for grid technologies were identified in Italy, however similar to other Member States, the dependence on imported raw materials as well as the access to skilled labour are considered bottlenecks for Italian manufacturers. Regarding

481 With technologies such as 525KV DC technology for land and subsea cables.

482 U.S. Department of Energy, 2022, Electric Grid Supply Chain Review: Large Power Transformers and High Voltage Direct Current Systems.Supply Chain Deep Dive Assessment.

483 European companies such as ABB Group (now Hitachi Energy), Alstom and Siemens Energy seem to be performing well for HVDC Converters and DC Breakers (Switchgear), but generally Chinese patent applications have significantly increased since 2013, compared to European ones. See here: U.S. Department of Energy, 2022, Electric Grid Supply Chain Review: Large Power Transformers and High Voltage Direct Current Systems.Supply Chain Deep Dive Assessment.

484 De Paola, A., Andreadou, N., Kotsakis, E., Clean Energy Technology Observatory: Smart Grids in the European Union - 2023 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/237911, JRC134988

485 Trinomics and Artelys (2021) Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis.

486 Deloitte and Confindustria (2024), Le competitività nelle tecnologie verdi Una nuova politica industriale per le imprese italiane. Available here.

487 See Italy's Country Factsheet and section 2.2.

488 See Italy's Country Factsheet and section 2.2.

489 Prysmian has announced that it will invest €1.8 billion by 2027 in expanding capacity and upskilling. See here.

the former, Italy recently introduced an ambitious programme to speed up the reuse and mining of raw materials[490] and regarding the latter, the New Skills Fund supports companies in training their employees.[491]

Germany accounts for the largest share, notably 27%, of the EU's total grid technology production, excelling in both cable and smart grid technology manufacturing. Manufacturers include Südkabel and Siemens. The country is also a competitive exporter of electrical inductors and fuses, with an export potential of EUR 801 million and EUR 129 million, respectively. Similar to Italy, this leadership position puts the German industry in a position to further expand considering the growing global demand. However, despite Germany's general competitiveness, China has a higher RCA for electrical inductors and fuses.[492] Additionally, Germany faces challenges due to slow grid expansion, including issues with the supply chain of materials, such as steel, and a lack of skilled workers.[493] This limits domestic demand and increases the lead times of projects thereby negatively affecting manufacturers.

Sweden is another prominent player in both cable and smart grid technology manufacturing, with a strong global presence in exporting insulated electric conductors and devices for protecting electrical circuits. Moreover, the market saturation rate for these components remains favourable, offering Sweden an important opportunity to expand its global presence further.[494] Sweden is also an innovation leader, underscored by ABB's active role in patenting[495] and the Swedish Centre for Smart Grids and Energy Storage (SweGRIDS). SweGRIDS final funding phase ended however in 2022[496] and ABB's Power Grids division was taken over by Hitachi and now operates as Hitachi Energy, based in Switzerland. Hitachi Energy is nevertheless expanding its HVDC production in Sweden[497] which will enable Swedish-manufactured HVDC systems to contribute to addressing the growing demand in the EU and globally. Additional investments are planned into neighbouring Finland to establish a new transformer factory and Germany to expand an existing factory.[498]

France has a strong manufacturing presence in the EU, particularly in cable manufacturing, with Nexans as a leading EU producer. The country has also emerged as a strong competitor in exporting grid components, such as insulated electric conductors, outperforming both China and the USA in terms of growth rate and RCA.[499] However, stakeholders have raised concerns regarding potential capacity issues and shortages of components and workforce, particularly affecting TSOs and grid infrastructure projects thereby increasing lead times for manufacturers.

Denmark is another European leader in grid technologies, with a presence in both cable and smart grid technology manufacturing. Investments made by NKT[500], a top EU industry player, offers opportunities to meet the growing demand from customers and support the energy transition. The company also excels in offshore cable production,

490 The programme, set-up within the framework of the Critical Raw Materials Act, includes measures to simplify permitting procedures for mining concessions with an estimation that Italy can domestically source 16 of the 34 EU critical raw materials. See here: Reuters, 18.06.2024, Italy moves to boost procurement, reuse of critical raw materials.

491 The 'Fondo nuove competenze' was created counteract the economic effects of the Covid-19 epidemic and co-financed by the European Social Fund. For more information, see here.

492 See Germany's Country Factsheet and section 2.2.

493 Julian Wettengel, 21.06.2024, Europe must learn from Germany's power grid expansion mistakes – network operator. Available here.

494 See Sweden's Country Factsheet and section 2.2.

495 De Paola, A., Andreadou, N., Kotsakis, E., Clean Energy Technology Observatory: Smart Grids in the European Union - 2023 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/237911, JRC134988.

496 KTH, Swedish Centre for Smart Grids and Energy Storage. Available here.

497 Hitachi Energy, 15.11.2023, Hitachi Energy is expanding its production in Sweden.

498 Hitachi Energy, 23.04.2024, Hitachi Energy to invest additional $1.5 billion to ramp up global transformer production by 2027.

499 See France's Country Factsheet and section 2.2.

500 NKT (2024) NKT invests in medium-voltage power cable business to boost capacity for growing demand. Available here.

set to build the world's largest high-voltage offshore cable production site.[501] Additionally, Denmark has a strong export potential in grid components, such as insulated electric conductors and meters for electricity supply.[502] Similar to other EU Member States, the reliance on imported materials such as aluminium and copper can pose a risk to supply chains. Increased use of recycled materials could mitigate this risk.[503]

Poland's strong manufacturing sector benefits Net-Zero technologies such as grid technologies by providing easier access to basic components and skills. The country excels in cable manufacturing, being home to Tele-Fonika, another top European producer.

Greece while a smaller player, also contributes to cable manufacturing, driven by a major regional producer, Hellenic Cables. The company shows strong potential in submarine cable systems thanks to large investments in this segment and state-of-the-art industrial production equipment and storage facilities.[504] A challenge noted for Greece is water scarcity during dry periods which combined with the limited supply of raw or recycled materials could negatively affect production.[505]

For more opportunities and bottlenecks, see the individual country fiches (Annex II) and Annex V.

4.2 Summary of key cross-cutting challenges

While each of the eight technologies faces its unique challenges, our findings also identified some commonalities. Specifically, we identified four cross-cutting issues that affect most, if not all, technologies albeit to varying degrees.

Regarding the internal dimension, one pervasive issue for the manufacturing of Net-Zero technologies was delays in their deployment. This relates to both the slow rollout of manufacturing plants and the demand for Net-Zero manufacturing capacities, i.e. the deployment of the end products.[506] The latter leads to uncertainties regarding investment decisions for manufacturers and, in some cases, the need to invest in warehousing to store equipment. Permitting is also discussed in more detail in Section 3.2.2 with specific reference to Member State policies addressing the issue. Next to permitting, the slow rollout of financing (e.g. regarding IPCEIs), the general delays in projects, or the simple lack of demand (e.g. in the case of electrolysers, fuel cells and heat pumps)

501 NKT (2023) We are building the world's largest high voltage offshore cable production site. Available here.

502 See Denmark's Country Factsheet and section 2.2.

503 See for example this project by NKT and Prysmian: TenneT, 03.03.2023, TenneT selects NKT and Prysmian for world's largest offshore cable systems to connect increasing Dutch offshore wind volumes, available here.

504 Hellenic Cables. Submarine cable systems. Available here.

505 Hellenic Cables (2023), Sustainability Report 2023, available here.

506 On the deployment side, a 2023 study on renewable energy pointed to non-technical barriers, such as the lack of business cases, weak support schemes, market entry barriers, administrative obstacles and grid-related issues. They specified that increasingly administrative and grid connections and operation procedures have become an obstacle. For more information, see: European Commission, Directorate-General for Energy, Tallat-Kelpšaitė, J., Brückmann, R., Banasiak, J. et al., *Technical support for RES policy development and implementation – simplification of permission and administrative procedures for RES installations (RES Simplify) – Final report*, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2833/894296.

were highlighted as factors slowing down the rollout of Net-Zero manufacturing. Beyond these factors, the criticality of grid technologies was raised throughout our discussions with stakeholders across all technologies. Issues with grid connections, limited grid capacities and in general a need for grid expansion and modernisation have been raised across the technologies.

A second internal issue that came up across technologies is the lack of skilled workers both in manufacturing and deployment. Across technologies, there is a general worry that the labour shortage will increase considering factors such as ageing, changing skill requirements, and the general need to increase the speed of industrial production and deployment. Municipalities often lack the skills required for environmental and climate assessments in permitting procedures.[507] Overall, in Q3 of 2023, a fourth of European companies in clean technology manufacturing notably reported labour shortages.[508] Estimates on additional jobs in Net-Zero manufacturing are ranging from 198.000 (status quo) over 350.000 (NZIA proposal) to 468.000 (NZIA+ scenario[509]). The Net-Zero technologies will not only have to compete with each other for these workers but also with the wider demand on the job market, stemming from the green transition. There are different scenarios for the exact labour needs ranging from a net increase in jobs by 2030 of 880,000, 1 million, 1.2 million, and up to 2.5 million.[510] Next to the Net-Zero Industry Academies, various EU and national policies have been put in place to train the required workforce (see Section 3.4).

Concerning the external dimension, a key issue that came up across most technologies was the supply of (critical) raw materials and dependencies on imports for key components. This issue relates to the security of supply and to the costs of materials which are one of the key drivers of prices across Net-Zero technologies and are expected to increase with rising demand for Net-Zero technologies. While the extent of dependencies depends on the technologies, except solar thermal, CCS, ocean energy, and heat pumps, all the technologies under assessment face some issues in this regard. EU supply chains are particularly exposed in the case of graphite and lithium, where the EU imports up to 100% of its refined lithium.[511]

Linked to the previous issue, a concern across all technologies is also the international competition and price competition. This competition takes the form of strong political and financial support in countries such as China and the USA including direct subsidies which the EU cannot match. Moreover, competitive advantages in terms of labour costs, access to materials, and energy costs lead to lower prices in third countries affecting the competitiveness of European producers. Spiking prices of raw materials globally further reinforced the effect on European manufacturers.[512] These issues are most prevailing in sectors where economies of scale play a larger role, i.e. solar photovoltaic, batteries, heat pumps and wind power to some extent. High energy prices also

507 Mario Draghi, 2024, The future of European competitiveness. Part B | In-depth analysis and recommendations.

508 Ibid.

509 100% of demand satisfied by EU manufacturing. SWD(2023) 68 final. Investment needs assessment and funding availabilities to strengthen EU's Net-Zero technology manufacturing capacity.

510 These numbers refer to net employment gains related to the green transition and are a collection of different scenarios and modelling exercises. For more information, see: European Commission, Directorate-General for Employment, Social Affairs and Inclusion, *Employment and social developments in Europe 2023*, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2767/089698.

511 Mario Draghi, 2024, The future of European competitiveness. Part B | In-depth analysis and recommendations.
See also Carrara, S., Bobba, S., Blagoeva, D., Alves Dias, P., Cavalli, A., Georgitzikis, K., Grohol, M., Itul, A., Kuzov, T., Latunussa, C., Lyons, L., Malano, G., Maury, T., Prior Arce, A., Somers, J., Telsnig, T., Veeh, C., Wittmer, D., Black, C., Pennington, D., Christou, M., Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study, Publications Office of the European Union, 2023.

512 Mario Draghi, 2024, The future of European competitiveness. Part B | In-depth analysis and recommendations.

strongly affect the manufacturing of certain energy-intensive components, such as wafers and polysilicon for solar photovoltaics.[513]

Looking more broadly at the strengths of Net-Zero manufacturing in the EU, based on our survey (Annex IV) we identified the following five strengths for European manufacturers across all technologies.

- Established existing manufacturing base;
- Research & development (R&D) and capacity to innovate;
- Availability of renewable energy sources;
- Educational institutions and training programs;
- Established industry clusters.

513 Ibid.

5 Policy recommendations

The EU's support for the manufacturing of Net-Zero technologies is driven by three main policy goals:

1. Empowering a competitive industry that provides job opportunities and growth perspectives to European economies. This goal is reflected in the EU's industrial policy particularly the 2021 update to the EU Industrial Strategy and the 2023 Green Deal Industrial Plan.
2. Ensuring the security and resilience of EU economies through access to strategic materials, components, and technologies. This goal is reflected in the concept of open strategic autonomy and EU policies such as the REPowerEU plan, the Critical Raw Materials Act and the Strategic Technologies for Europe Platform.
3. Enabling the clean energy transition and the EU's journey to net zero by having access to technologies and equipment need to decarbonise the energy, industry and transport sectors. This goal is reflected in the European Green Deal, the Fit for 55 Package and associated policies such as the Renewable Energy Directive, the Energy Efficiency Directive and more.

The NZIA takes these three policy goals into account and puts much-needed attention on the key technologies that are needed to enable these goals. The introduction of the NZIA has been welcomed by European industries as a way to bolster European manufacturing. Specifically, it supports the deployment of manufacturing for Net-Zero technologies through:

- simplifying the permit-granting process for strategic projects;
- facilitating market access for strategic technology products (in particular through non-price criteria in public procurement or the auctioning of renewable energies);
- enhancing the skills of the European workforce in these sectors (i.e. with Net-Zero Industry Academies and high-concentration industrial areas or 'valleys');
- creating a platform to coordinate EU action in this area.

During our consultation, the support for NZIA was raised, but also the necessity for the EU and its Member States to follow up in its implementation through Delegated Acts and supporting instruments at the national level. For many of the Net-Zero technologies under assessment, we see worrying signals of manufacturing capacity moving abroad and the inability to scale up industrial production in Europe. This is despite the EU's strength in innovation and the EU being one of the largest global markets for Net-Zero technologies.

The fact is, the EU faces a competitive disadvantage due to subsidies in third countries it cannot match, higher labour and energy costs in Europe, dependency on critical raw materials, administrative burdens such as longer permitting times and a lack of skills. The situation is exacerbated by a lack of stability and predictability of demand as these technologies require high upfront investments. Yet, the EU was still the world's second most attractive destination for Net-Zero investments in 2023.[514] As pointed out by Mr Draghi, there is an opportunity for the EU to build on its innovation leadership and retain autonomy by providing the conditions to develop and scale

[514] In 2023, the European Union attracted $334 billion in investments, behind China with $654 billion — equivalent to one-third of the world's investments. Zero Carbon Analytics analysis (2024). BNEF Energy Transition Investment in Europe. See also Strategic Perspectives. 2024. A wake-up call for a powerful Clean Industrial Deal. Brussels.

competitive EU industries[515]. This will require bold approaches and paying a premium to enable industries to simultaneously innovate and scale up.

5.1 Overview of identified policies per technology

In this section, we build on the issues identified in Chapter 4 by giving an assessment of the status of each technology and discussing technology-specific policies identified from our desk research and stakeholder consultations. In Section 5.2 we then describe our proposed cross-cutting policy recommendations.

Solar photovoltaic and solar thermal technologies

Our research reveals that solar PV and, to a lesser extent, solar thermal technologies are at a critical juncture. While deployment has been fuelled by various incentives, in line with the broader push to accelerate the energy transition, support for domestic manufacturing has lagged. The emphasis in Member States and the EU had been on creating the conditions for the rollout of renewable energy and stimulating demand for solar panels. Despite attempts by the EU to introduce anti-dumping measures[516], this favoured large imports of cheaper solar panels on the European market, predominantly from China. This influx has left EU manufacturers—of which few remain—struggling to stay afloat.

It is questionable whether the EU could match foreign subsidies. Moreover, even with high European subsidies supporting capital expenditures in new factories, it is doubtful that EU manufacturers would be able to compete on scale with Chinese or Indian competitors due to the higher production costs in the EU. We might just create an industry dependent on subsidies. Security of supply is also a less pressing issue for products like PVs as existing PVs can be used for decades allowing time to ramp up industrial production again or find alternative suppliers. Therefore, a diversified approach that addresses unfair practices in third countries while focusing on high-value activities for solar PV equipment, machinery and innovative areas such as perovskite-silicon tandem solar panels might be more prudent than trying to outspend other countries to re-establish large-scale manufacturing in Europe.

Several policy frameworks are in place to support solar technologies within the EU. However, considering the challenges faced, a more robust and assertive approach may be necessary to ensure the sector's future.

Policy framework
REPowerEU is crucial for the EU solar manufacturing industry as it aims to rapidly reduce dependence on fossil fuel imports and accelerate the transition to renewable energy, with a significant focus on scaling up solar power. Other policy frameworks include: • The EU Solar Energy Strategy**:** It is part of the REPowerEU plan and aims to deliver over 320 GW of solar photovoltaic by 2025 and almost 600 GW by 2030. Sets out measures to increase the capacity of solar energy, support research and innovation, and strengthen the EU's solar manufacturing industry. It includes initiatives to streamline permitting processes, enhance market access, and provide financial support for solar projects. The strategy comprises the European Solar Rooftops Initiative, the EU Solar PV Alliance and the EU large-scale skills partnership.

515 Mario Draghi, 2024, The future of European competitiveness. Part B | In-depth analysis and recommendations.

516 In 2013, the EU imposed anti-dumping tariffs on Chinese solar panels following an investigation. However, the tariffs started a trade dispute with China which led ultimately to a settlement on a minimum price and a limitation of the export volume. This agreement was however violated by some Chinese manufacturers. For more information, see: Yu-Chen (2015) EU-China Solar Panels Trade Dispute: Settlement and challenges to the EU, European Institute for Asian Studies. Available here.

Policy framework

- The European Solar Charter**:** it sets out voluntary actions to support the development of the solar photovoltaic industry. Its goal is to create a cohesive framework for enhancing solar manufacturing capabilities, supporting innovation, and ensuring a competitive market for solar energy within the EU. It sets out actions by Member States, the EU and industry, including the inclusion of non-price criteria as introduced in the Net-Zero Industry Act (e.g. resilience, sustainability, responsible business conduct, ‘ability to deliver”, innovation and cybersecurity) in renewable energy auctions. SolarPower Europe recently surveyed solar developers on their commitments finding that 17 respondents have incorporated non-price criteria in their procurement strategies and five respondents reported an increased demand for ‘Made in the EU’ products[517].
- Horizon Europe**:** Provides funding for R&D in renewable energy technologies, including solar PV. It supports collaborative projects that aim to improve solar panel efficiency, reduce costs, and develop new materials and manufacturing processes.

Beyond the above policy framework, the EU launched the European Solar Academy which supports the development of a skilled workforce for the industry.

Beyond these existing policies, stakeholders raised also various policy measures when discussing the priority issues presented in Section 4.1.

The EU faces a negative trade balance**,** primarily due to the influx of cheaper solar panels from China. Chinese manufacturers benefit from state subsidies, an integrated supply chain and economies of scale among others enabling them to undercut European prices significantly. To counteract this competitive disadvantage, it has been urged by consulted stakeholders that the EU should adopt a more aggressive trade policy stance**.** This could involve implementing higher tariffs on imported solar panels and exploring the possibility of establishing trade quotas to limit the quantity of imports. However, there are also concerns by stakeholders that tariffs would increase costs[518] as many manufacturers focus on the assembly of imported components. Specifically, duties on glass imports have been identified as a driver of costs[519].

Instead of tariffs or quotas, local content requirements for procurement as introduced through the voluntary French Solar Pact Initiative could incentivise investments in European manufacturing. These come however with concerns about compliance with WTO rules and have also been found a barrier to international investments[520]. Alternatively, a stronger focus on environmental, climate, resilience and other aspects through non-price criteria[521] as introduced in the NZIA, and proposed in the European Solar Charter, could help level the playing field. Similarly, stakeholders raised the idea of a carbon tax on imported solar products.

For the EU's reliance on imported raw materials**,** such as germanium and gallium, an integrated approach to becoming less vulnerable to supply chain constraints is essential. Solely supporting the manufacturing of final products and components is insufficient if dependency on a few critical raw material suppliers persists. The approach to mitigating this vulnerability should mirror strategies proposed for battery and energy storage technologies, discussed in this section below. A focus could be placed on expanding

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517 SolarPower Europe (2024) Support for European Solar Manufacturing, A State of Play Report.

518 SolarPower Europe, Statement opposing trade defence measures. Available here

519 Mario Draghi, 2024, The future of European competitiveness. Part B | In-depth analysis and recommendations.

520 OECD (2015), "Local-content requirements in the solar- and wind-energy global value chains", in *Overcoming Barriers to International Investment in Clean Energy*, OECD Publishing, Paris, https://doi.org/10.1787/9789264227064-6-en.

521 In a survey by SolarPower Europe, five offtaker companies proposed the introduction of a resilience bonus with mandatory criteria such as ‘Made in the EU’ by offtakers to promote research and innovation, long-term contracts and foster collaboration between EU manufacturers and large-scale solar projects. See: SolarPower Europe (2024) Support for European Solar Manufacturing, A State of Play Report.

mining within Europe, securing and diversifying supply through trade policies, enhancing material recycling and reuse, and innovating to reduce or replace critical materials with more abundant alternatives.

There is a need to build upon the CRM Act**.** Despite its ambitious objectives, stakeholders argue that the Act falls short of delivering tangible outcomes. While the CRM Act aims to reduce the EU's dependency on external sources by setting targets for domestic supply—10 percent from mining, 40 percent from refining, and 15 percent from recycling—actions have primarily focused on import substitution**.** This approach does not fully address the broader issue of the EU's vulnerability to CRM supply chain disruptions, which are driven by global dependencies that domestic industrial production alone cannot resolve, given the limited availability of viable resources within the EU. Moreover, focusing on technologies such as perovskite solar cells and thin silicon wafers could reduce material demand.

The fragmented regulatory environment within the EU presents a significant challenge for the solar PV sector**.** Variations in policies and incentive schemes between Member States create an uneven support landscape, which undermines the ability of European manufacturers to compete effectively. To address this issue, the EU must lead efforts to harmonise regulatory frameworks across the EU, among others to ensure a level playing field across European solar PV manufacturers. This includes:

- Streamlining permitting processes: The permitting process for solar PV installations and manufacturing facilities varies widely across the EU, leading to inefficiencies and delays. To address this, the European Solar Charter calls for the removal of permitting barriers and establishing a streamlined permitting framework that simplifies the approval process for solar projects. Designating national contact points as outlined in the NZIA or 'one-stop-shop' permitting systems that consolidate all necessary approvals and regulatory requirements into a single application process could be beneficial as developed in several Member States (Member State initiatives on one-stop-shop permitting systems are discussed in Section 3.2.2).
- Ensuring consistent implementation of state-aid rules**:** The European Solar Charter calls for using all available EU funding opportunities as well as flexibilities under the state-aid Temporary Crisis and Transition Framework (TCTF). Nevertheless, the implementation of state-aid rules is crucial for maintaining fair competition and preventing market distortions. The EU should enforce a uniform application of state aid regulations to ensure that national support schemes do not inadvertently favour domestic companies over their European counterparts. This includes rigorously monitoring and assessing national schemes to ensure compliance with EU rules and preventing any form of unfair advantage. For instance, the Commission could implement regular evaluations of state-aid measures in Member States, as well as provide guidance and support to ensure that national policies align with EU-wide objectives.

The EU should work closely with Member States to ensure that national policies align with EU-wide objectives and effectively support the growth of the solar PV sector. A coherent regulatory framework will provide a more predictable and supportive environment for investors and manufacturers.

Cost competitiveness is a critical challenge for the EU solar PV industry, driven by higher industrial production costs and slower technological advancements compared to international competitors. To enhance competitiveness, the EU should implement a range of supportive measures. This includes:

- Expanding financial support for solar PV manufacturers, with a focus on scaling up industrial production capabilities in innovative and high-value-added areas. Financial support could come from the Innovation Fund, EU ETS revenues, the IPCEI instrument and state aid under the TCTF framework. Stakeholders stressed that while capital costs (CAPEX) are supported already in various ways, support for operational costs (OPEX) is rarely addressed[522]. However, such support would contradict State aid principles, which is why stakeholders call to adjust State Aid Rules to allow Member States to better support the scaling up of the industry. The Draghi Report similarly calls for more flexibility in providing OPEX support for limited periods of time while production is ramped up[523].

- Targeted incentives, such as subsidies for research and development and financial support for scaling industrial production, are essential to address the cost disparities. This can include, in line with ongoing efforts, the creation of IPCEI for PV manufacturing and innovation. Furthermore, the EU should facilitate such projects by providing targeted funding, setting clear milestones, and ensuring robust stakeholder engagement.
- Support initiatives to reduce labour costs and decrease labour shortages in the sector.

Onshore wind and offshore renewable technologies

Based on our assessment, we find that while maintaining a strong position, Europe's position is weakening in onshore wind and offshore renewable technologies (except for ocean energy). Europe is losing its leadership in the international market, where China has been gaining market shares and is leading in capacity installation worldwide with cheaper but also high-quality turbines. This is confirmed by stakeholders who also see the increasing turbine size as a main challenge to unlock economies of scale in the supply chain. Setting a standardised size at the European level can be an opportunity to boost cost competitiveness for European manufacturers by enabling economies of scale.

The overarching policy challenge for Europe in onshore wind and offshore renewable technologies is to maintain and grow its leadership position in the sector. Several policy frameworks are in place already supporting onshore wind and offshore renewable technologies within the EU.

Policy framework

Onshore wind and offshore renewable technologies are supported since October 2023 by the EU Wind Power Package[524], which includes the European Wind Power Action Plan and a dedicated communication on EU offshore wind ambitions (COM/2023/668). In parallel, offshore renewable technologies have as an overall policy framework the EU strategy on offshore renewable energy. Detailed below is an overview of these policies that support the growth of wind technologies.

- The EU strategy on offshore renewable energy (COM/2020/741): Published in 2020, this strategy aims to support Europe's offshore wind capacity. It sets targets of 60 GW of offshore wind and 1 GW of ocean energy installed capacity by 2020. The strategy provides a roadmap for the growth of offshore wind energy and notably outlines actions to support grid infrastructure development and boost investments in offshore wind projects.
- The European Wind Power Action Plan (COM/2023/669): It is based on six pillars, (i) accelerating deployment through faster permitting and increased predictability, (ii) improved auction design, (iii) access to finance, (iv) creating a fair and competitive international environment, (v) skills, (vi) industry engagement and EU country's commitments. From these pillars, the plan sets out 15 concrete actions targeted to public and private actors that aim to provide immediate support to the wind industry.
- The European Wind Charter: As part of the actions recommended in the above European Wind Power Action Plan, this charter was signed on 19 December 2023 by 300 companies and 26 EU Member States[525]. This charter outlines voluntary commitments to support the development of the wind sector in the EU and endorses the Wind Power Package.

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[522] For an overview of OPEX and CAPEX support to the solar manufacturing industry, see: SolarPower Europe (2024) Support for European Solar Manufacturing, A State of Play Report.

[523] Mario Draghi, 2024, The future of European competitiveness. Part B | In-depth analysis and recommendations.

[524] See EU wind energy, available here.

[525] See European Wind Charter, 19 December 2023, available here.

- The Renewable Energy Directive overall supports renewable energy by setting an EU-wide target of at least 32% in the total energy mix by 2030. It notably encourages the integration of renewable energy sources into the electricity market and aims to simplify and streamline administrative processes, which directly impacts the deployment rate of wind projects.

Beyond the above policies, the Net-Zero Industry Act and the Critical Raw Materials Act are relevant to the development of the wind industry. The Net-Zero Industry Act notably includes pre-qualification criteria and refers to a target of 36 GW per year for the EU manufacturing capacity in wind by 2030.

Beyond these existing policies, stakeholders raised also various policy measures when discussing the priority issues presented in Section 4.1.

Regarding administrative barriers and permitting bottlenecks, as discussed in Section 4.1, the high number of authorities involved in administrative processes is an obstacle. Project delays are slowing down the development of the sector creating uncertainties for investments. This is also recognised in the European Windpower Action Plan which puts attention to the Accele-RES initiative and its support in digitalisation of permitting processes through technical assistance to Member States. The acceleration of permitting requires centralisation of processes through a unique authority that would constitute a unique contact point for companies in a Member State, as per the national single points of contact provided for in the NZIA. To lift this barrier, a policy option is to consolidate all processes into a single application procedure (such as through a one-stop-shop). As permitting bottlenecks is a cross-cutting policy challenge for several Net-Zero technologies, a more detailed policy recommendation is included in Section 5.2.

Regarding economies of scale and supply chain challenges, we found that European industrial players are disadvantaged by the changes in manufacturing equipment due to the trend of increasing size of turbines. The constant race for larger turbine sizes makes it difficult for companies to keep up as facilities need to be upgraded. To address this issue, experts and stakeholders called for the adoption of a European standard for turbine size**.** We found that there is currently no way of standardising industrial production for the manufacturing of large components. Hence, adopting a European standard on turbine size would unlock economies of scale and provide manufacturers with the stability to invest in new capacities with greater certainty. It could also benefit circularity as increased standardisation would facilitate the replacement of parts. Nevertheless, this would only provide a common size for European manufacturers and would not address issues coming from Chinese competition. Additionally, ensuring the stability of demand (e.g. through faster permitting) and access to finance through for example the Innovation Fund, state aid under the TCTF or guarantees by the EIB will support manufacturers in scaling up.

Regarding the tough competition with third countries and unpredictable markets, the main policy challenge is to maintain European leadership and hold a strong position for wind energy. Specifically, China has made significant investments in wind energy, increasing its market share while European manufacturers face higher prices and potential bottlenecks for materials such as steel and rare earths. Stakeholders raised that in particular the auction systems have created market volatility and do not provide the same financial stability as feed-in tariffs or Contracts for Difference. Additionally, a relatively slow process of electrification in Europe has led to lower levels of investment by manufacturers than would be required. We found that demand-side support, alongside policies that reinforce renewable energy deployment, are potential levers to increase competitiveness for wind technologies. From our discussions with stakeholders, the following measures were identified:

- Encouraging electrification and addressing grid congestion to increase the demand for renewable energy. Europe is experiencing a decrease in electricity demand, which further reduces the need for new wind turbines. Electrification would be necessary to support renewable energy growth through higher electricity consumption. However, this involves ensuring that the grid infrastructure can support the greater integration of renewable energy sources. Efforts should focus on addressing grid congestion[526] and balancing the grid needs and connections, in addition to improving grid infrastructure so that all renewable energy sources can be integrated. Accelerating the pace of electrification is an important policy priority for all EU Member States under analysis.
- Integrating local content or other non-price criteria in public procurement could further help support the sector and ensure increased demand for turbines and components that are produced within the EU. This was done in France with the Offshore Wind Industry Pact which sets a target of 50% of local content in wind farms CAPEX by 2035[527]. Local content requirement rules would need to be designed—as in the case of the French scheme—in a way that is non-discriminatory towards operators based in any EU country. Design should also pay attention to the provisions of the General Agreement on Tariffs and Trade (GATT) (particularly Article III:8(a)), and the Government Procurement Agreement (GPA).[528] Similarly, integrating objective non-price criteria and improving the auction design as proposed in the European Wind Power Action Plan can help alleviate the tough price competition.

A lack of skilled workers both for manufacturing and installation was identified (see Section 4.1). Beyond the implementation of Net-Zero Industry Academies, no specific measures were raised by stakeholders for the onshore wind and offshore renewables industry. Section 5.2 addresses this challenge and presents cross-cutting policy recommendations on skills and supporting the workforce, while Section 3.4 provides an overview of existing relevant Member State policies.

Additional policy recommendations emerged from discussions with stakeholders:

- Establishing clear timelines and targets to provide market predictability.
- Supporting small and medium-sized investors with stable long-term agreements.

Batteries and storage technologies

Based on our assessment, we find that in batteries and storage technologies, developments are promising with an increase in investments and manufacturing capacities in the EU. This is confirmed by stakeholders who see a positive outlook with a strong momentum thanks to the demand from EU automotive manufacturers. Specifically, major investments are taking place in Germany, France, Italy and Sweden. Moreover, Czechia, Poland and Hungary are major players in the European battery value chain with in particular the latter two attracting FDI from Asian manufacturers. Nevertheless, a slowdown in the uptake of electric vehicles and recent news of cancelled projects and layoffs have raised some concerns[529].

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526 According to the Grid Access report by WindEurope, more than 500 gigawatts of total wind capacity are waiting for their grid connection assessment (in Croatia, France, Ireland, Italy, Norway, Romania, Spain and the UK). Wind Europe (2024) Grid access challenges for wind farms in Europe. Accessible here.

527 See Offshore wind in France, ADEME / DBER / SEV, 07/07 2022. Accessible here.

528 On the legality of different types of LCRs under the WTO, and on the difficulties of enforcement, please see Kuntze, J. and Moerenhout, T. 2013. Local Content Requirements And The Renewable Energy Industry - A Good Match? ICTSD (International Centre on Trade and Sustainable Development); and Hufbauer et al. 2013. LCRs: A global problem. Peterson Institute for International Economics. Available, respectively, here and here.

529 For example, plans have been cancelled by Northvolt in Sweden and by the Automotive Cells Co. in Germany and Italy.

Despite all these investments, it will be difficult to achieve the scale of China. More attention should be drawn to research and different technologies[530]. Many projects are just starting and currently, much of the expertise is still in Asian countries with many of the tier-1 suppliers being located in South Korea, Japan and China. Recent announcements of project suspensions in Europe due to the higher costs of NMC batteries have raised some concerns.

Moreover, as outlined in Section 4.1, there is a strong dependency on the supply of critical raw materials from third countries. In light of this, the European Court of Auditors issued a warning that despite the massive amounts of grants and loan guarantees (EUR 1.7 billion between 2014 and 2020 alone), the EU is still at risk of ending up in a dependent position. Specifically, they point to the risk of battery manufacturing abandoning the EU in favour of other regions such as the USA which offer massive incentives as well as the issue of price competitiveness in light of volatile material and energy prices.[531]

Policy framework

The European Commission has been aware of these issues and there are several policies in place that aim to address them:

- The Battery Regulation: It entered into force in 2023 intending to create harmonised rules for the sustainability and safety of batteries. As such it defines battery categories, introduces requirements for CE marking, a battery passport, provisions for carbon footprint and recycled content, recycling and material recovery targets, removability and replaceability requirements of batteries, safety testing requirements, and more. Stakeholders have been positive about the regulation as they see the standards it sets as a good way to level the playing field.
- The Critical Raw Materials Act: It identifies the main battery raw materials (cobalt, graphite, lithium, manganese and nickel) as strategic and sets benchmarks to ensure that the EU can extract 10% and process 40% of its consumption of strategic raw materials by 2030. Moreover, 15% of the EU's annual consumption should originate from the EU's recycling capacities. The Act also includes provisions on streamlining permitting applications for strategic projects and developing a demand aggregation and joint purchasing mechanism for CRMs.
- The European Battery Alliance: It aims to build up battery technology and industrial production capacity by bringing together stakeholders, EU, national and regional authorities.
- Various funding opportunities: EU public finance is available through the Innovation Fund, the EIC Accelerator, the EIB and the EBRD.[532] Next to these research funding from Horizon Europe is coordinated through the BATT4EU public-private partnership. Most of the funding however comes from the two IPCEI on batteries, combining state aid and private finance.[533]

Other relevant policies include the Circular Economy Action Plan, the Net-Zero Industry Act, and the REPowerEU Plan which aims to boost energy storage deployment by for example faster permitting.

Beyond these existing policies, stakeholders raised also various policy measures when discussing the priority issues presented in Section 4.1.

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530 For example, lithium iron phosphate batteries (LFP), sodium-ion (Na-ion) and redox-flow batteries (RFB) offer promising alternatives for EV and stationary applications. These technologies are safer, potentially cheaper, and do not require critical raw materials.

531 European Court of Auditors (2023) Special report 15/2023: The EU's industrial policy on batteries – New strategic impetus needed.

532 As a good practice, EIT InnoEnergy, under the framework of the European Battery Alliance, has set up a One-Stop-Shop service to EU public finance: https://www.eba250.com/one-stop-shop/.

533 Two IPCEIs in the battery ecosystem have been launched, involving 59 companies across 12 Member States, with up to €6.1 billion in state aid expected to trigger more than €13.8 billion in private investment. See: https://competition-policy.ec.europa.eu/state-aid/ipcei/approved-ipceis/batteries-value-chain_en.

Regarding the current dependencies on critical raw materials and battery components, there are generally four angles to approach this issue: 1) Expanding mining in Europe; 2) Diversifying and securing supply through trade policy and demand aggregation and joint purchasing; 3) Expanding recycling of materials and reuse of batteries; and 4) innovation to reduce the number of materials required or replace them completely with more abundant materials. All four angles are currently being pursued in the EU. Mining is explored more actively in the EU, specifically lithium mining in Portugal, Czechia and Spain and cobalt and nickel in Finland. However, many of these projects are plagued by local resistance.[534]

Requirements for recycled content as well as recycling and material recovery targets have been included in the Battery Regulation. In our discussions with stakeholders, developing a recycling industry was stressed as a policy priority.[535] Research finds that “integrating recycling facilities, even at low utilization levels, into Gigafactories allows to hedge against volatility in raw material prices”[536] providing also an economic reason for expanding recycling. However, currently, key materials are being lost to China as there are no sufficient battery recycling facilities across the EU to process the black mass after the first step of recycling which is then exported to China for extracting the final materials. Just under half of the recycling sites in Europe can recover battery raw materials from black mass. However, research by Fraunhofer ISI shows general progress in expanding recycling in Europe.[537] Nevertheless, a 2024 study found that “China will be the first to realise a circular battery value chain, doing so more than ten years earlier than Europe and the US for lithium and nickel and seven years earlier for cobalt” in 2059, 2046 and 2045 respectively.[538] Finally, regarding innovation, as stressed in Section 4.1, more attention should be drawn to battery technologies that require fewer or no critical raw materials such as RFB, LFP and Na-ion batteries. The Innovation Fund could be used to support small-scale projects in these technologies allowing companies to set up projects.

Regarding the tough price competition, as noted in Section 4.1, there have been improvements with the price gap of batteries between China and the EU closing. However, in light of the decreasing battery prices and the overall volatility of energy and material prices, this remains a major concern for European manufacturers. Battery costs are driven mainly by materials. Addressing this will require reducing dependencies (see above). Next to ensuring access to raw materials, there is a need to ensure secure access to cheap renewable energy sources[539] to keep costs for manufacturers low. Promoting the swift deployment of renewable energy and insulating energy costs from price fluctuations through Power Purchase Agreements (PPAs) by improving financial conditions, standardisation and improving PPA markets would benefit manufacturers by giving them access to lower and more stable energy prices. Specifically, Member States with a high potential for renewable energy such as Sweden, Spain or Portugal and therefore lower energy prices could have a competitive advantage. Similar EU countries with lower labour costs could be more cost-

[534] Central European Times, 17.04.2023, EU plan to source local raw materials will boost mining, battery industries in CEE – CET analysis.

[535] See also a Joint Letter by Eurometaux, RECHARGE, Transport & Environment, and the WWF: https://www.transportenvironment.org/uploads/files/2023_09_Joint_letter_on_black_mass_final.pdf.

[536] Moritz Gutsch, Jens Leker, Costs, carbon footprint, and environmental impacts of lithium-ion batteries – From cathode active material synthesis to cell manufacturing and recycling, Applied Energy, Volume 353, Part B, 2024.

[537] The majority of recycling currently takes place in Central Europe, particularly in Germany and Poland but also other countries such as Finland, Sweden, Hungary, the Netherlands and Spain. Capacity is also being built in France. For more information, see: Fraunhofer ISI (2023) Europe expands recycling of lithium-ion batteries: Focus on capacity development, demand analysis and market players.

[538] Jannis Wesselkämper, Laureen Dahrendorf, Lukas Mauler, Simon Lux, Stephan von Delft, A battery value chain independent of primary raw materials: Towards circularity in China, Europe and the US,Resources, Conservation and Recycling, Volume 201, 2024.

[539] Following the energy crisis, the EU experienced a sharp increase in energy prices. The ensuing competitiveness gap vis-à-vis the EU’s trade partners is however not only related to high prices but also to the unpredictability and volatility of prices. high level of volatility and the unpredictability of prices in EU compared to other world regions. These high and unpredictable prices have started impacting overall investments in the European economy. See; Mario Draghi, 2024, The future of European competitiveness. Part B | In-depth analysis and recommendations.

competitive. Already Hungary and Poland have been able to attract FDI and become key producers of batteries and battery components in the EU.

Regarding this issue, stakeholders raised several policies relating to sustainability requirements:

- Strengthening the Carbon Footprint Declaration would help support the competitiveness of European manufacturers as could provide transparency and a basis for comparability. If more renewable energy sources are integrated into the system, it could also constitute a key advantage for EU manufacturing.
- Batteries should be added to the ETS compensation list. This would bring down the costs of manufacturing in Europe.

Regarding emerging technologies, this is a broader issue for the whole technology group as it should encompass both battery and other storage technologies but the focus is mainly on battery technologies specifically battery technologies for mobile applications. While electric vehicles are certainly the main source of demand, technology neutrality is important and political attention should also be drawn to other technologies within this group. Moreover, within the field of chemical batteries, there are many different chemistries where EU manufacturers have been focusing on high-performing but more expensive NMC batteries. However, currently, the industry is experiencing a shift to lower-cost and safer LFP battery cells. Next to technology neutrality, this mainly calls for additional support to innovation and research into batteries by defining Net-Zero technologies as a strategic priority area of the 10th EU Framework Programme for research and innovation[540]. Moreover, reinforcing EU-level coordination in close collaboration with industry and research organisations will be key to ensuring emerging technologies are identified and supported[541].

On the topic of harmonisation and permitting, stakeholders noted that permitting times remain lengthy and permitting processes continue to pose a challenge. This issue relates to mining, manufacturing plants and the deployment of energy storage. Overall this reduces Europe's attractiveness for investments. The delay in energy storage deployment impacts demand, negatively affecting energy storage manufacturers, specifically those focusing on stationary energy storage applications. To provide certainty for planning and future expansions of manufacturers, there is a need to streamline permitting processes for building energy storage grid connections. Member States now need to follow up on the Net-Zero Industry Act and the Critical Raw Materials Act by setting up single points of contact for permitting, ensuring a timely resolution of disputes, or setting time limits for permit granting processes.[542] Additionally, Member States should set a priority on energy storage in energy system integration and grid planning to help facilitate approval procedures..

Heat pumps and geothermal energy technologies

In our assessment, the EU has strong manufacturing capacities for both heat pumps and geothermal energy technologies. These technologies face mainly challenges in their deployment in the EU Member States, due to a slowdown in demand for heat pumps and a shortage of skilled workers both for installation and manufacturing. Specifically, the slowdown in the construction of housing and the gas-to-electricity ratio being favourable to gas boilers have reduced demand in many Member States for heat pumps. In contrast, the deployment of geothermal energy technologies depends on political attention and can be enhanced if an EU geothermal strategy, with associated targets and tools, is published.

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540 See also, p. 136, Mario Draghi, 2024, The future of European competitiveness. Part B | In-depth analysis and recommendations.

541 Ibid, p. 138.

542 Recommendations on permitting are further discussed in cross-cutting policy recommendations (Section 5.2).

Policy framework

The EU Heating and Cooling Strategy (COM/2016/051) constitutes an overall policy framework for heat pumps and geothermal energy technologies. It supports the development of both technologies as renewable heat sources that help achieve targets for the heating and cooling sector. Additionally, the supportive policy framework for heat pumps and geothermal energy technologies comprises the EU Heat Pump Action Plan, the Renewable Energy Directive, the Energy Efficiency Directive, the Energy Performance of Buildings Directive and the Critical Raw Materials Act. These policies are detailed below:

- The EU Heat Pump Action Plan**:** It comprises 4 building blocks which aim to accelerate heat pump deployment. The four pillars are (i) the Heat pump accelerator, (ii) Communication and skills with a dedicated heat pump skills partnership (iii) Legislative work (iv) Financing opportunities.
- The Renewable Energy Directive: Revised in November 2023, it sets a binding target of at least 42.5% renewable energy at the EU level by 2030 and notably supports heat pumps and geothermal technologies as renewable heating and cooling sources.
- The Energy Efficiency Directive: Revised in September 2023, it aims to reduce overall energy consumption by 11.7% by 2030 at the EU level and notably requires Member States to draft National Energy and Climate Plans (NECPs). The Directive supports renewable energy sources specifically geothermal energy technologies and heat pumps for heating and cooling.
- The Energy Performance of Buildings Directive (EPBD): This directive aims to improve energy efficiency in EU buildings by requiring zero-emissions new buildings by 2030 and all buildings by 2050. It notably plans to phase out fossil-fuel boilers by 2040 and favours the adoption of heat pumps and clean heating technologies.
- The Critical Raw Materials Act**:** This act aims to strengthen the EU's critical raw materials capacities across the value chain and focuses on reducing dependencies. Geothermal lithium is a major driver for investment in countries such as Germany, France and Italy due to this.

In addition to these policies, heat pumps are also supported through REPowerEU, which aims to increase the rate of deployment for both heat pumps in buildings and large district heating and cooling network heat. Geothermal energy is supported through funding schemes such as Horizon, the European structural and investment funds. Both technologies are also supported by the Net-Zero Industry Act and financing instruments from the Social Climate Fund that provide incentives for the installation of heat pumps and the decarbonisation of heating and cooling in buildings.

Beyond these existing policies, stakeholders raised also various policy measures when discussing the priority issues presented in Section 4.1.

To address the sales and investment uncertainties**,** providing a stable policy framework and a better gas-to-electricity ratio is key to helping the transition to heat pumps. The realisation of the Heat Pump Action Plan will be key in providing a stable regulatory framework for manufacturers and supporting long-term investments in installations We identified several policy measures based on stakeholders' inputs that could help address this challenge:

- Low tax rate on electricity: apply a lower tax rate for electricity when used for geothermal heat pumps to support adoption. A noteworthy example is Finland, where the tax on electricity is only 5% if used in a high-efficiency (geothermal) heat pump[543].
- European Geothermal strategy: to ensure regulatory stability and encourage investments, a European Geothermal strategy is needed alongside national roadmaps in all Member States.

[543] See State aid: Commission approves €1 billion Finnish scheme to support companies in the context of Russia's war against Ukraine (europa.ec)

To address the lack of skilled workers, upskilling and reskilling of the workforce is needed. A focus on specialised profiles was raised as stakeholders as a priority to enable the manufacturing and deployment of heat pumps and geothermal technologies. Training of professionals will also help address the lack of awareness of practitioners. Several measures were raised by stakeholders:

- Opening more training facilities: training facilities are lacking for both deep and shallow geothermal.
- Focus on reskilling and upskilling initiatives: specialised profiles need to be trained (such as plumbers, electricians, engineers, and architects) for installation and maintenance. The absence of skilled workers for the installation needs to be addressed as it is a key bottleneck for the technology deployment.
- Facilitating skill transfers between industries**:** there is an overlap between the geothermal value chain and other industries such as oil and gas, where skill transfers can happen if they are supported by an overall strategy.

To retain European leadership, technological advancements are key especially to address the dependence on Chinese imports for refrigerants. Regulatory alignment and standardisation can support the development of natural refrigerants in Europe by harmonising the legislation. The refrigerant legislation is complex and harmonising EU and national regulations can support the growth of the industry to compete with the Chinese leadership.

Demand bottlenecks and a lack of public acceptance present challenges to deploying heat pumps and geothermal energy technologies, particularly due to the existing old building stock and the high upfront costs for homeowners. The lack of stability of subsidy schemes also hinders visibility for market actors and consumers. We identified the following policy measures to address these points:

- Incentives for building renovations: Renovations need to take heat pumps into account and incentives can help address the high costs associated with it, especially for multi-family housing and old housing stock. Several Member States such as Belgium, France and Poland implemented subsidies to support the adoption of residential heat pumps.[544]
- Building renovations**:** Accelerating the renovation of the housing stock can help increase the market for heat pumps integrated into renovation projects.
- Enhancing public awareness through collaborations with local organisations: Initiatives with local organisations can help increase community engagement and improve consumer knowledge about technologies. In turn, it will foster acceptance of heat pumps and geothermal energy technologies. Providing information to consumers about technologies can help stabilise the market and strengthen demand.

Electrolysers and fuel cells

In our assessment, the EU is well-placed in the developing field of electrolysers and fuel cells, with European companies leading in manufacturing and technology. However, industry experts note a slowdown in the rollout of the hydrogen economy, making ambitious targets seem unachievable at the current pace. This is mainly due to demand-side challenges, with producers waiting for demand to materialise, while potential customers in industry and transport hesitate to invest without more industrial production and infrastructure. EU initiatives such as the Hydrogen Bank and mandates for renewable hydrogen are positive but insufficient.

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[544] EHPA (2023) Subsidies for residential heat pumps in Europe. Available at the following link.

Policy framework

The EU Hydrogen Strategy (COM/2020/301) provides an overall policy framework for hydrogen. It outlines 20 actions across four areas: 1) an investment agenda for the EU; 2) boosting demand for and scaling up industrial production; 3) designing an enabling and supportive framework; and 4) the international dimension. It also specifies a target of 6 GW of renewable hydrogen electrolysers installed by 2024 and 40 GW by 2030, while noting that the total European production capacity for electrolysers is below 1 GW per year.[545] Beyond the EU Hydrogen Strategy, the following policies impact the manufacturing of electrolysers and fuel cells:

- Renewable Energy Directive: Increases demand for hydrogen through sector-specific targets for industry and transport. Specifically, Art. 22 requires an average annual increase of 1.6 percentage points in the use of renewable energy sources in industry. Moreover, it mandates that 42% of the hydrogen used in the industry should come from RFNBOs by 2030 increasing to 60 per cent by 2035. Art. 25 requires hydrogen and e-fuels to amount to at least 1% of all fuels used in transport by 2030.
- Emission Trading System (ETS) and the Carbon Border Adjustment Mechanism (CBAM): While not directly dealing with hydrogen, they increase costs for GHG-emitting economic activities thereby making renewable hydrogen a more cost-competitive alternative.
- Hydrogen and decarbonised gas market package[546]: The package revises the ‘Gas Directive’ and ‘Gas Regulation’ and has the ambition to adopt a comprehensive governance system for hydrogen and decarbonised gases. It establishes a European Network of Network Operators for Hydrogen (ENNOH), supports hydrogen infrastructure development, encourages the use of renewable and low-carbon gases (e.g. through blending with natural gas), proposes a certification system for renewable and low-carbon gases, and empowers the Commission to develop a mechanism to support the market development of hydrogen.
- FuelEU maritime and RefuelEU aviation: Supporting the adoption of RFNBOs in both the maritime and aviation sectors.

Other relevant policies include the Net-Zero Industry Act, Critical Raw Materials Act and various EU financing mechanisms (e.g. Innovation Fund, Hydrogen Bank, IPCEI, the Recovery and Resilience Facility, the Modernisation Fund, etc.)[547].

Beyond these existing policies, stakeholders raised also various policy measures when discussing the priority issues presented in Section 4.1.

A low demand for hydrogen and its applications has so far barred the electrolyser and fuel cell industry from scaling up. Based on stakeholder discussions, we identified additional policy measures beyond the Hydrogen Bank and the ETS to address the lack of a mature market for hydrogen:

- Enabling market uptake by addressing carbon leakage: Renewable hydrogen is currently not cost-competitive however the EU ETS has successfully introduced a price signal for carbon content covering sectors where hydrogen can act as a clean energy carrier substitute**.** Properly pricing GHG emissions through ETS (and CBAM), and reducing fossil fuel subsidies, will narrow the price gap between fossil and green alternatives, boosting demand for renewable hydrogen. Follow-up by EU and national policymakers and close monitoring of the impacts are encouraged to identify whether additional actions such as more offtaker incentives are needed. In parallel, research funding supporting the efficiency of electrolysers and fuel cells as well as scaling up production can help reduce hydrogen costs.

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545 According to our calculations presented in Chapter 2, by the end of 2024, Europe is projected to reach an annual water electrolyser manufacturing capacity of 8.8 GW. As of May 2024, 5.4 GW of this capacity is already operational, with an additional 3.4 GW planned to come online.

546 For a discussion on the ‘Hydrogen and decarbonised gas market package’ see: Heidecke, L., Kustova, I., Flickenschild, M., Dijkhof, Y., Larmi, I., Van Til, H., Van Benthem, M., Nguyen, N., 2022, The Revision of the Third Energy Package for Gas, Publication for the committee on Industry, Research and Energy (ITRE), Policy Department for Economic, Scientific and Quality of Life Policies, European Parliament, Luxembourg.

547 For a detailed overview, see: Oxford Institute for Energy Studies (2024) 2024 State of the European Hydrogen Market Report and European Hydrogen Observatory (2024) The European hydrogen policy landscape.

- Renewable Energy Directive and RNFBO targets: ensure Member States comply with RNFBO targets and create enabling conditions, including funding, certification, product labelling for low-carbon products, and carbon leakage protection.[548]
- Adopting non-price criteria: Include non-price criteria related to resilience, environmental impact, safety, social impacts and energy performance in public funding mechanisms and the Hydrogen Bank. This will support EU electrolyser sourcing, industry scale up and cost reduction.[549]

Addressing the lack of standardisation and harmonisation can reduce electrolyser and fuel cell costs through economies of scale reducing the costs of first-generation electrolysers. Experts and stakeholders highlighted the need to develop standards to qualify electrolyser performance and establish an EU R&D infrastructure for testing and validation. Such an infrastructure would give European industries access to a broad basis of support for benchmarking and make large investments for demonstrator facilities more viable.[550]

Regarding the reliance on critical raw material imports, enhanced focus on research and innovation specifically addressing the development of alternative materials and innovative manufacturing processes that use less or different raw materials could directly benefit EU manufacturers. For example, Alkaline or Solid oxide electrolysers require less critical raw materials than PEM electrolysers. Furthermore, circular designs could facilitate re-use and repair and enable take-back business models in line with the extended producer responsibility outlined in the Waste Framework Directive. Finally, European recycling and recovery technologies for precious metals may constitute an opportunity, however, the recycling potential of electrolysers will only be realised after 2030 once electrolysers are deployed more widely. In the meantime, the identification of alternative sources for (recycled) materials such as platinum and iridium could provide support for EU industries.

International competition and price competitiveness pose a threat, particularly from the USA and China. The high OPEX and CAPEX[551] costs of renewable hydrogen, driven by high EU electricity prices, hinder price competitiveness and increase concerns about the potential relocation of manufacturing facilities. While the EU is currently a leader in terms of innovation and manufacturing, the slowdown in the rollout of the hydrogen economy creates uncertainty among manufacturers delaying investment decisions. One of the barriers is the lack of price competitiveness of renewable hydrogen versus fossil alternatives (see also above). Stakeholders recommended the following measures:

- Increased budget for the Hydrogen Bank to further incentivise hydrogen production and compete with third-country measures in combination with resilience criteria (see above).
- An EU-wide next-generation electrolyser program through which industry and researchers can work together towards shared industry milestones to accelerate the development and deployment of next-generation

548 Additional policy opportunities in this regard were identified by Hydrogen Europe in their Position Paper on “Recommendations to the EU and its Member States on the transposition of the RED III industry target for RFNBO consumption”.

549 See also Hydrogen Europe Position Paper - Resilience criteria in European public funding instruments.

550 This could be linked to an EU wide next-generation electrolyser program dedicated to the accelerated development, implementation and scale-up of second- and third-generation technologies as suggested in this report: VOLTACHEM (2023) Electrolysers: opportunities for the high-tech manufacturing industry.

551 The Danish Energy Agency estimated that the whole electrolyser system (incl. stacks) represents 66% of total CAPEX for a 100 MW alkaline green hydrogen plant. As previously mentioned, both standardisation and scaling up as well as innovation could play an important role in decreasing electrolyser costs. See: Danish Energy Agency, January 2024, Technology Brief Update of hydrogen production via electrolysis in the Technology Catalogue (Jan 24).

electrolysers[552]. This programme could be linked with the above-mentioned EU infrastructure for testing and validation of electrolyser systems.

- Enforcing European green market regulations to apply sustainability standards to third countries via extended supply chains, levelling the playing field.

Sustainable biogas and biomethane technologies

Based on our assessment, the main challenges for biogas and biomethane lie with the deployment rather than the manufacturing of the technology and its components. Therefore, focusing on policies boosting demand for biogas and biomethane is more important than incentives for producing specific components. To meet the ambitious targets, broadening the feedstock base is essential, as are clear framework conditions and cost distribution schemes for the gas grid connection of biomethane production facilities. Scalability is also critical: standardisation efforts could help achieve economies of scale. Additionally, biogas and biomethane technology development need to be seen and addressed in the wider context of energy, climate, agriculture and environmental policies and regulations.

Policy framework

The regulatory framework supporting the scale-up of sustainable biogas and biomethane technologies includes the REPowerEU Plan, the accompanying Staff Working Document, the Waste Framework Directive, the revised Renewable Energy Directive, and the Gas Package. We shortly introduce these below:

- The REPowerEU Plan (COM/2022/230): Recognises the need to scale up sustainable biomethane production to 35 bcm by 2030 to reduce imports of natural gas from Russia. It also specifies an estimated investment need of EUR 37 billion over the period to increase the capacity of biogas production in the EU and promote its conversion into biomethane.
- The Commission Staff Working Document[553]**:** Accompanying the REPowerEU Plan, it outlines a number of actions which could be taken to achieve the 2030 target. It specifies five areas of action: 1) promoting the sustainable production and use of biogas and biomethane and the injection of biomethane into the gas grid; 2) providing incentives for biogas upgrading into biomethane; 3) promoting the adaptation and adjustment of existing and the deployment of new infrastructure for the transport of more biomethane through the EU gas grid; 4) addressing gaps in research, development and innovation; and 5) facilitating access to finance.
- Under the Waste Framework Directive (2008/98/EC), EU countries have to separate organic waste from commercial waste as of 2024. This supports the scale-up of sustainable biogas production and offers farmers and foresters additional income opportunities.
- The revised Renewable Energy Directive: Extends the scope of the fuel supply obligation to all uses of biomethane[554].
- The hydrogen and decarbonised gas package: Grants renewable and low-carbon gases, including biomethane, better access to markets and infrastructure, facilitating the increasing replacement of fossil gasses and thus supporting the targets of the REPowerEU Plan[555].

In addition to these, the Biomethane Industrial Partnership (BIP) was launched in 2022 to further support the achievement of the EU's 2030 target. This biogas and biomethane industrial partnership promotes active engagement between the Commission, EU countries, industry representatives, feedstock producers, academics and NGOs. It aims to increase the production and use of sustainable biomethane and unlock further potential by 2050.

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552 VOLTACHEM. 2023. Electrolysers: opportunities for the high-tech manufacturing industry.
553 Available here.
554 Biomethane - European Commission (europa.eu)
555 https://energy.ec.europa.eu/topics/markets-and-consumers/hydrogen-and-decarbonised-gas-market_en

Beyond these existing policies, stakeholders raised also various policy measures when discussing the priority issues presented in Section 4.1.

Lengthy permitting processes constitute a main issue which poses a risk to achieving the 2030 target. Stakeholders emphasised the need for simplified processes and resolving the problems causing long permitting times. The Biomethane Industrial Partnership (BIP) also identified best practices, including a zoning approach and the introduction of a 'one-stop-shop', and set out an ideal permitting procedure[556]. Several Member States have launched initiatives including one-stop-shops to reduce permitting times as discussed in Section 3.2.2.

Regarding the issue of high costs and market volatility, easing financial burdens, incentivising biogas over fossil fuels, and considering all benefits of biogas are essential. Specifically, we identified the following measures:

- Implement a cost-sharing mechanism for grid connection CAPEX and improve market access. For small-to-medium-scale projects, the CAPEX for the grid connection is a burden. Market access also hinges on the availability and terms of grid access. It is crucial to ensure that biomethane producers can connect to nearby gas grids under clear and equitable conditions. This includes defining responsibilities for costs related to biogas production, purification, direct connection, and infrastructure development, such as compressors and grid expansions. These costs should be shared among gas infrastructure providers, gas consumers, and Member States or the EU to ensure affordability and encourage development.
- Implement tax incentives to promote biomethane over fossil fuels. This will enhance its competitiveness in the energy market.
- Take a holistic approach to biogas and its benefits. Biogas has many benefits, including economic, environmental, and social externalities, which should be considered. Often, biomethane is neglected or forgotten about because it seems expensive. But it is not just about energy – it is also about waste treatment and also about the production of fertiliser, among others.
- Utilise market pools. Shifting financial burdens from governments to market forces can spur innovation and reduce costs associated with energy transition efforts. For example, Germany's CO_2 reduction obligations incentivise decarbonization efforts among market players. Market pools such as Germany's CO_2 reduction obligations could also be relevant for other technologies such as hydrogen.
- Establish national long-term biogas strategies. Long-term commitment is essential to keep investors in the EU. National policies are also critical due to country-specific circumstances, including different feedstock availabilities and different infrastructure (e.g. gas grids).

Another priority issue constitutes feedstock availability constraints**.** Broadening the feedstock base, possibly beyond the current focus on residues and wastes, is essential to achieve the ambitious policy targets. Specifically, we identified the following recommendations:

- Put the targets of biogas and biomethane production on the EU level in line with feedstock opportunities. This includes:
    - Allowing the use of energy crops. Stakeholders noted that the energy crop policy in Europe is complex because of the reluctance towards energy crops, despite their necessity to achieve biogas targets. Energy crops are discouraged due to their use of agricultural land, yet similar concerns can

[556] For more information, see here.

be applied to the land use of PV panels, for example. Addressing public perception is therefore crucial to navigating this issue effectively.

- Allowing the use of intermediate crops. Another stakeholder pointed out that focusing on intermediate crops presents a different avenue with significant benefits, such as retaining nutrients within the agricultural sector and reducing nitrate leaching into aquatic environments. They emphasised the need to develop the agricultural sector in a way that optimises biogas production across Europe, ensuring robust food security and high-quality food while generating a surplus for the energy sector. This approach aligns closely with climate and environmental targets.

- Enforcing a local separate collection of bio-waste could unlock more feedstock for biomethane production. This includes waste from households, restaurants, and international catering, potentially boosting bio-waste volumes.

There is a need for more standardisation, unlike other Net-Zero technologies, biogas plants often need to adapt to local needs, resulting in unique designs for each plant, which prevents equipment manufacturers from scaling up and improving their production lines. Stakeholders highlighted that there is a high potential for reducing costs by scaling up production. This relates both to biogas plants, whereas larger plants can save capital and operational costs for biogas production[557], and to the equipment manufacturers. Similarly, for the gas infrastructure and the availability of grid connection, there are significant differences between EU countries with some having large-scale plants handling substantial feedstock volumes, while others have predominantly farm-based plants. Challenges remain in countries like Spain, where both the gas grid infrastructure and upgrading technologies for injecting biomethane into the grid are underdeveloped. Addressing this issue requires increased financial support and alignment with the preferences of major gas companies. Policies must also consider the different production models and country-specific circumstances within the EU.

Carbon capture and storage technologies

We find that Europe has strong manufacturing capacities and holds a good position for upscaling CCS. However, its deployment is hindered by lacking storage infrastructure and services that would support the scaling up. Qualified workers are also missing in the picture as skill sets overlap with other industries which results in competition for skilled workers. We also find the need for a stable regulatory framework with a long-term view, is a condition for investments whose current rates are too low to meet the targets. Lastly, stakeholders confirmed that the lack of public acceptance is hindering the development of CCS activities.

Policy framework

Carbon capture and storage activities in the EU are developed under a policy framework which includes the Directive on the Geological Storage of Carbon dioxide[558], also referred to as the CCS directive, the Industrial Carbon Management Strategy, the EU Emissions Trading System (ETS) and the Carbon Removals and Carbon Farming Regulation. These policies are detailed below:

- The EU's Industrial Carbon Management strategy (ICM): is a comprehensive approach to the development of Carbon capture and storage activities (COM/2024/62). The strategy aims to establish a homogeneous deployment of CCS, CCU and carbon removal technologies. CCS is one of the key pillars of the ICM which also brings stakeholders together to support the deployment of industrial carbon management technologies in the Industrial Carbon Management Forum[559].

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557 BIP Europe, 2023, Insights into the current costs of biomethane production from real industry data, available here.

558 European Commission, The role of Industrial Carbon Management in climate policies, available here.

559 This forum was initially established under the name of CCUS Forum in 2021. It brings together companies, NGOs, academia, EU and third countries as well as EU institutions representatives. See ICM Forum and Working Groups.

- The European Emissions Trading System: explicitly mentions CCS and supports its deployment as the cap on emissions progressively diminishes and pushes industries to bring down their emission levels. ETS prices are directly linked to companies' business models, as discussed in Section 4.1.
- The Directive on the Geological Storage of carbon dioxide or "CCS directive": provides the overall legal framework for the geological storage of CO_2 across the EU and over the entire lifetime of storage sites. It complements the existing Environmental Impact Assessment Directive which covers activities of capture and transportation of CO_2.
- The Carbon Removals and Carbon Farming (CFCF) Regulation: establishes a framework for certifying carbon removals, farming and storage products across EU Member States.

The policy framework for CCS also obviously includes the Net-Zero Industry Act which sets a target of 50 million tonnes of CO_2 injection capacity available by 2030. The Hydrocarbon Directive (Directive 94/22/EC) [560] also supports CCS activities by requiring oil and gas producers to contribute to storage objectives through the development of CO_2 storage sites or financial contributions. The Renewable Energy Directive also encourages the replacement of fossil fuels by CCU-based fuels which specifically supports the utilisation of carbon in addition to storage technologies. Additional policies are also supportive of carbon capture and utilisation, notably the ReFuelEU Aviation and FuelEU Maritime Regulation. Both support the use of CCU-based fuels and consider them as RFNBOs. This policy framework also includes some EU financing mechanisms (Innovation Fund, Horizon EU, and State aid)[561].

Beyond these existing policies, stakeholders raised also various policy measures when discussing the priority issues presented in Section 4.1.

To address the lack of long-term regulatory certainty and low investments, we identified the following measures:

- Setting a strong ETS price: it is key for CCS manufacturers to be able to deploy their technology without relying on subsidies. A strong ETS price would provide a strong incentive for CCS as it encourages companies to use carbon storage rather than trading allowances. This policy recommendation is discussed under the cross-cutting policy recommendations in Section 5.2.
- Adopting a holistic approach: an approach that considers the entire value chain would be important as storage sites and cross-border CO_2 networks are key elements in the planning and overall development strategy for carbon management.
- Adopting recycling incentives, similar to the waste management industry, could be applied to CO_2 management. Incentives that have proved to be successful in recycling and waste management could be adopted in CCS. An example could be the introduction of a collection fee for CO_2 which could incentivise businesses to capture and store carbon.

Regarding scaling up challenges, support for storage infrastructure development would be needed alongside measures that help achieve lower prices. We identified the following measures:

- Encouraging the development of CCS facilities based on site suitability: infrastructure development should consider the availability of CO_2, the price of electricity, but also factors such as wind and temperature ranges or existing infrastructure like pipelines and export facilities. Such factors, and especially weather conditions, significantly affect the level of efficiency of wells.

560 ELI: http://data.europa.eu/eli/dir/1994/22/oj
561 Industrial Carbon Management (europa.eu)

- Standardising and creating further homogeneity for the transport infrastructure, storage site management and CO_2 export between countries would help ease the transport of CO_2 between Member States.

Taxation policy options could also be considered to address the high costs and notably the cost of energy. Stakeholders suggested easing taxation by considering tax incentives to support off-grid energy use to tackle the high cost of energy for carbon capture projects.

Regarding the lack of a skilled workforce**,** the industry will need to attract more workers and harness existing skill sets that are relevant to its activities. Stakeholders raised the following measures:

- Repurposing skillsets in existing sectors and industries**:** This could enable the transfer of a skilled workforce with engineering or logistics skill sets and ensure a strong base of competencies to address the emerging demand. Supply chains and skill sets from coal regions, such as in the Western Balkans and Ukraine, may be particularly relevant for CCS activities. This could constitute an opportunity to follow up on EC's initiative to support the just transition of coal-based energy production[562].
- Creating CCUS chairs in universities and academia could be a dedicated initiative to help attract more master's and PhD students into the CCUS value chain. Eventually, an overarching program would be needed to make the connection between students and the industrial ecosystem, relying on internships or industrial advisors to strengthen this connection. This could be further supported by Horizon programs channelled for CO_2 projects that provide incentives for academicians to attract more students in the CCUS domain.

Regarding low public acceptance and environmental concerns**,** stakeholders raised revenue-sharing with the population as a policy option which was implemented in the USA and Denmark. Sharing part of the electricity revenues with the population affected by the deployment of infrastructure could help tackle public acceptance and 'not in my backyard' attitudes, alongside a strong public education effort about the risks.

Grid technologies

Our assessment shows that the EU holds a strong position regarding grid technologies specifically for transmission and distribution cables[563], with companies operating in various Member States. The challenge for the grid industry lies with implementing the policy targets, which require massive grid expansion and modernisation. To achieve this, long-term planning and clear commitments are essential to secure investments, and more skilled labour is needed for both manufacturing and deployment. In addition to uncertainties in planning, long lead times for projects due to permitting issues also slow down deployment, creating uncertainties for manufacturers. Moreover, the grid industry lacks visibility and its importance in the political agenda for the energy transition is not always recognised making it a potential bottleneck for the rollout of other industries such as energy storage and renewable energy.[564]

Policy framework
The EU's legal framework supporting the rollout of grids includes the revised Trans-European Networks for Energy (TEN-E) Regulation, the revised Renewable Energy Directive, the Net-Zero Industry Act, and the revised Electricity Market Design (EMD).[565]

562 Initiative for coal regions in transition in the Western Balkans and Ukraine (europa.eu)

563 Italy leads in cable production with EUR 1.2 billion, followed by Sweden at EUR 0.8 billion, and Germany at EUR 0.6 billion. Combined, these three countries already account for slightly less than 50% of the total EU market, valued at EUR 5.8 billion in 2022 (see Chapter 2).

564 EMBER (2024) Putting the mission in transmission: Grids for Europe's energy transition. Available here.

565 European Commission, 'Actions to accelerate the roll-out of electricity grids', European Commission website, 28 November 2023, https://ec.europa.eu/commission/presscorner/detail/en/ip_23_6044

Policy framework

In addition to these, the Commission launched an Action Plan for grid technologies to further accelerate and expand the rollout of electricity grids. These policies are detailed below:

- The revised TEN-E Regulation: Focuses on connecting the energy infrastructure within the EU. It identifies eleven priority corridors, categorised into electricity, offshore grid, and hydrogen corridors. Additionally, it specifies three priority thematic areas, including smart electricity grid deployment, smart gas grids, and a cross-border carbon dioxide network[566]. It also contributes to improving permitting and improving access to funding.[567] It also introduces a national priority status to accelerate permitting.
- The revised Renewable Energy Directive**:** Introduces stronger measures to further support the development and uptake of renewable energy and sets a new target for 2030. In the context of grid technologies, it recognises lengthy and complex grid-connection procedures as an important bottleneck and identifies the need for further simplification and shortening of such procedures in the context of Renewable Energy Sources acceleration areas.
- The revised Electricity Market Design**:** Promotes the clean energy transition and aims to ensure energy security and affordability in the EU, while also contributing to the competitiveness of the European industry. It recognises the need for investments in grids to integrate renewable energy and to deliver the EU's climate targets. It stresses the importance of anticipatory investments for grids, promotes transparency and monitoring and requires countries to publish national Development Plans consistent with the EU-wide Network Development Plan.
- The EU Action Plan for Grids (COM/2023/757): It aims to address the main challenges in expanding and digitalising the EU electricity transmission and distribution grids. It outlines 14 actions through 7 horizontal challenges: 1) accelerating the implementation of existing PCIs and developing new projects; 2) enhancing long-term network planning; 3) introducing a supportive, future-proof regulatory framework; 4) making better use of existing grids and smartening them; 5) improving access to financing; 6) ensuring faster and leaner permitting processes; and 7) strengthening supply chains. It also recognises the need for EUR 584 billion in investments by 2030, and an increase in capacity of 23 GW by 2025 and a further 64 GW by 2030[568].

In addition to these, the grid industry, notably power cable manufacturers, will also be affected by the CBAM**.** As detailed in Section 4.1, aluminium, which is a key component of power cables, is in the scope of the regulation, which will increase the price of imported aluminium.

Meeting current ambitions for grid expansion and modernisation might be difficult considering the issues identified in Section 4.1. To further enable the industry and the rollout of grid technologies, we identified various policy measures in our research and discussions with stakeholders.

To address the issue of the lack of skilled workforce, stakeholders highlighted the need for innovative approaches to attract workers into the sector**.** Experts from outside the usual energy policy stakeholders should be involved in developing creative campaigns and strategies. Additionally, the industry increasingly requires digital skills as the number and complexity of digital devices grow. Therefore, it is essential to work with educational institutions to add the necessary digital skills to the curriculum and with authorities to introduce new requirements into existing certifications where needed[569]. In Section 5.2, we also

566 Regulation (EU) 2022/869

567 Investments in grid technologies are supported by the CEF-E envelope (Connecting Europe Facility). European Commission, 'Connecting Europe Facility – Energy', European Commission website, available here.

568 COM/2023/757 final

569 International Energy Agency (IEA) (2023). Electricity Grids and Secure Energy Transitions. Available here.

present cross-cutting recommendations aimed at expanding and upskilling the workforce of the Net-Zero industries, while Section 3.4 covers skill policies in Member States.

Regarding the bottlenecks of (critical) raw materials, EU and national-level support for the recycling and recovery of materials would be beneficial as most grid materials can be recycled, including around three-quarters of a transformer's materials, materials used for overhead lines, the cable conductor, and the polyethylene used as insulation material. Reusing and recycling materials can also reduce the need for additional mining capacity, which requires significant investments[570]. Embracing circularity can extend the useful life of grid components, reintroducing them within the same or in other supply chains to create new products[571]. Stakeholders therefore suggested complementing the Critical Raw Materials Act by measures to identify and promote technologies with lower environmental impacts and raw material use in line with the energy efficiency first principle. For instance, superconducting cables require 150 times less raw material than conventional, copper-based power cables to carry one kA one metre, significantly reducing the materials used for energy transmission[572].

Regarding the challenging environment linked to the global grid transformation and expansion**,** long-term commitments and digitalisation as outlined in the European Grid Action Plan are key to ensuring predictability for manufacturers. The proposed Electrification Action Plan and the Clean Energy Investment Strategy should further highlight the importance of the energy grid as a key enabler for the energy transition. Nevertheless, stakeholders voiced concerns that the focus is often on "more visible" technologies, such as renewable energy technologies.

Beyond this overarching recommendation, stakeholders also raised the following measures:

- Clear and long-term planning and commitment are needed from transmission system operators (TSOs), distribution system operators (DSOs), and Member States to ensure that manufacturers have a clear view of the demand for grid technology. This would enable them to increase capacity, organise their supply chain, recruit, and develop the necessary skills. While there are ambitious outlooks for the future, planning must be backed up by reliable commitments of governments, regulators, and customers. Stakeholders also emphasised that network development plans should be better integrated into National Energy and Climate Plans and be accompanied by industrial plans, specifying the demand from network operators.
- Digitalisation and cybersecurity are a priority. Stakeholders emphasised the need for both grid expansion and digitalisation, highlighting that these go hand in hand, and one does not replace the other. To achieve fast digitalisation, EU legislation should consistently promote increased investments in digital electricity infrastructure. Additionally, cybersecurity and cyber resilience must remain in focus to prevent cyberattacks. With increased interconnectivity between countries, cyberattacks can quickly spread and affect multiple electricity systems. Moreover, the cyberattack surface for malicious actors to exploit is expanding, due to, for example, the proliferation of Internet of Things devices and the digitalisation of business models.[573]
- The need for new technologies should be recognised**.** One stakeholder also stressed the importance of recognising that current technologies are insufficient to achieve the necessary targets and that new and more

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570 IEA (2023), Electricity Grids and Secure Energy Transitions, IEA, Paris. Available here.

571 For example, Enel's Open Meter is a second-generation smart meter device, produced by reusing materials (e.g. plastic) from first-generation smart meters and other field devices. See International Energy Agency (IEA) (2023). Electricity Grids and Secure Energy Transitions. Available here.

572 CurrENT (2023) Efficient electricity grids are key for a Net-Zero Industry and managing demand for Critical Raw Materials. Available here.

573 See also T&D Europe Grids Action Plan Position Paper (2024), available here.

efficient technologies are needed. For instance, superconductors could enable high-capacity cables that would not take more space.

To maintain the European leadership in the cable industry and strengthen the EU's position for other grid components, ensuring fair competition with non-EU manufacturers and sustaining innovation is essential. The European Grid Action Plan and its proposed investments send a good signal for future grid expansion and modernisation giving manufacturers some certainty. This signal will be further underlined by the proposed Clean Energy Investment Strategy for Europe[574] and its ambition to prioritise investments in clean energy infrastructure including grids. Specifically, for transformers where more manufacturing capacity is needed, clear signals and grid expansion plans, including by Member States, are needed to unlock investments. Additionally, regulatory consistency and coherence are needed to support the industry and keep investors in the EU. Specifically, the following measures were identified:

- Sustainability needs to be recognised. European manufacturers are following the EU's lead in driving sustainability. This needs to be recognised to ensure a level playing field with non-EU producers who face less stringent sustainability regulations. Sustainability criteria could be integrated into the tendering processes, and rules should incentivise or even prescribe sustainable practices to secure European manufacturing. Similarly, other criteria such as resilience criteria (e.g. cybersecurity) could be considered[575].
- Expand the scope of CBAM to downstream products. Notably, power cables containing aluminium and steel should be included in the scope of CBAM to prevent the unfair competitive advantage of non-EU power cable manufacturers.
- Regulatory consistency and coherence in technical requirements**.** Regulatory certainty on the specifications and requirements of products and solutions is essential to avoid the need for re-engineering and recertification, which would slow down the processes and the delivery of equipment[576]. This links to the European grid connection network codes, which have among their objectives "to increase competition among equipment providers by harmonising the requirements they need to comply with in different markets"[577]. These are regularly updated and guidelines are prepared to ensure harmonisation also in their implementation. Stakeholders raise however the need for complying with recognised standards and for Member States to avoid any amendments or additional requirements[578]. Moving towards common technical requirements, standardisation, and tenders limited to functional specifications is essential to achieve economies of scale and drive both innovation and competitiveness. The many special design requests faced by manufacturers limit economies of scale.

5.2 Cross-cutting policy recommendations

Building on the insights gained from previous tasks and recent EU policy developments, in this chapter we present our policy recommendations designed to overcome key challenges and facilitate the scaling up and advancement of the Net-Zero technologies in Member States. While the main recommendations apply to all Net-Zero technologies and across Member States, some may have a more pronounced impact on specific

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574 European Commission, 17.09.2024, Mission Letter to Dan Jørgensen, Commissioner-designate for Energy and Housing.

575 This is under consideration as part of the Clean Transition Dialogues, see here: European Commission, 10.04.2024, Commission takes stock of the Clean Transition Dialogues with EU industry and social partners, Press release.

576 For instance, the position paper by T&D Europe notes that the revision of the Ecodesign regulation on transformers should not change the current efficiency requirements or add criteria that would reduce Europe's production capacity.

577 Florence School of Regulation, 2020, The EU Electricity Network Codes. 2020 edition.

578 See also T&D Europe Grids Action Plan Position Paper (2024), available here.

technologies, products, or countries. Technology-specific policy actions identified through our consultations are presented in Section 5.1 while a long list of identified actions is presented in Annex VII.

Recommendation 1: Following up on the Net-Zero Industry Act

The NZIA framework has demonstrated significant political commitment, creating an encouraging environment for investors. During our consultations, stakeholders expressed strong support for the NZIA. However, the effective implementation of this framework across Member States is crucial for translating commitment into tangible outcomes. The Net-Zero Europe Platform established by NZIA provides a framework for collaboration between Member States, sharing good practices and monitoring progress towards NZIA's objectives.

One of the primary challenges currently faced is the variation in permitting processes across Member States. These discrepancies result in inefficiencies, as each country operates with different requirements, involves different actors and lacks standardised timelines or capacity to follow up on requests. This variability not only increases costs but also places European manufacturers at a competitive disadvantage In particular, following up on the NZIA, Member States are required to set up national contact points for permitting and ensure that they can enable shorter permit procedures for Net-Zero technology manufacturing projects and Net-Zero strategic projects in line with the requirements from the NZIA. Regulatory sandboxes are currently not used in many Member States as identified in our research. Their use could also be spread more widely across ￼, in line with the provisions of NZIA on ￼.

Single points of contact within each Member State should be supported by skilled staff and provide relevant support to investment decisions. This approach, similar to the system used in the United States, could streamline applications and enhance efficiency by providing a centralised resource for navigating regulatory requirements. Member States should reinforce their administrative capacity to implement the NZIA, focusing more specifically on permitting.[579]

Recommendation 2: Leveraging EU and national strengths in providing targeted support

Only a few Member States have the fiscal capacity to support several Net-Zero industries simultaneously. Identifying and monitoring the changes in comparative advantages at the EU and national level (vis-à-vis international partners) is essential for creating impactful policies and supporting instruments. Our report showcases leading Member States across the eight technologies and we find that the EU possesses a comparative advantage in certain industries where economies of scale are less critical and product differentiation is more important. For instance, rather than competing directly with China's large-scale industrial production capabilities, the EU can focus on strengthening its capacity in machine building for producing photovoltaic (PV) panels, as highlighted by the German PV industry's success in this area. Additionally, Denmark's leadership in wind turbine manufacturing and the Netherlands' expertise in offshore wind technology exemplify the EU's comparative advantage in high-tech, differentiated products. These countries can further leverage their strengths through standardisation and innovation. Meanwhile, other EU countries, with lower labour and energy costs, might also be able to compete in scale as long as access to skilled labour, investments and raw materials is ensured. For example, Poland, Hungary and other Central and Eastern European countries have been successful in attracting FDI for battery manufacturing.

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[579] Mario Draghi, 2024, The future of European competitiveness. Part B | In-depth analysis and recommendations.

The Smart Specialisation Platform and its observatory or the Net-Zero Europe Platform could be used as a central node to guide Member States in focusing their efforts on technologies where they have a comparative advantage. However, this will require more complete, accurate and timely data on the entire value chains of Net-Zero technologies. A central issue is that current product and custom codes do not reflect Net-Zero technologies very well, which also complicated our analysis specifically for technologies that are difficult to separate from other equipment[580]. Updating EU statistics, reinforcing research by the JRC and strengthening data exchange with the IEA would be beneficial in this regard[581]. This also requires alignment from national statistical services in Member States to ensure consistency of data. Similarly, in cooperation with the WTO, there could be opportunities to improve understanding of trade flows of environmental goods and services[582].

Based on better data, Member States can focus on specific technologies where they see the most opportunities. By doing so, they can bundle national and EU funding effectively to maximise impact. For example, through targeted R&D support for R&D funding through initiatives like Horizon Europe or the Innovation Fund. This could target for example machine building for PV production in Germany. Similarly, Spain and Portugal can capitalise on their abundant solar and wind energy resources and strong domestic markets to support local manufacturing and innovation while also developing leading positions in the hydrogen economy and investing in electrolyser and fuel cell developments. Sweden, with its existing battery production, could focus on sustainable battery production using its high share of fossil-free electricity while expanding recycling and leveraging innovative Na-ion batteries, which can be produced from locally sourced materials. Our country factsheets provide additional details on the comparative advantages of Member States. To effectively bundle national and EU-level funding streams as well as provide more accessible information to companies, the EU with the support of Member States should consider building consolidated overviews of available funding streams. The collection of such information in full would require either a political commitment by the Council or the introduction of EU regulatory requirements towards Member States.[583]

Regions transitioning away from coal and other traditional industries require particular attention. These can benefit from funding aimed at both enabling Net-Zero manufacturing and ensuring a just transition for affected workers and communities. For instance, policies should facilitate infrastructure development (incl. grid development and energy storage) and investment in renewable energy projects, enabling these regions through good infrastructure and available renewable energy sources to become potential clusters for Net-Zero technologies. Consideration could also be drawn to designate promising regions as Net-Zero Acceleration Valleys. For example, Central and Eastern European countries such as Poland, Hungary, Romania, Czechia and Slovakia, looking to modernise, can benefit from targeted investments. Potential coal regions with existing wind component manufacturing facilities have been found in Spain and Germany, for solar PV manufacturing in Germany, Poland and Spain, and for batteries in Germany and Poland[584]. Specifically, Member States can make use of the Just Transition Fund but also instruments such as the Modernisation Fund to support these regions and promote economic diversification.

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580 Our research specifically identified data issues for the following technologies: heat pumps (codes are available but also contain AC units diluting the picture), electrolysers (no code for electrolyser stacks), biogas (no code on digestors and generally difficult to disentangle from other products), solar PV (codes are available but not yet used by all countries, wind power (missing codes for foundations and blades), grid technologies (smart grid technologies are difficult to distinguish from other electronic equipment).

581 Mario Draghi, 2024, The future of European competitiveness. Part B | In-depth analysis and recommendations.

582 Ecorys (2023) Trade in Environmental Goods and Services, Final Report. Available here.

583 European Court of Auditors (2023) Special report 15/2023: The EU's industrial policy on batteries – New strategic impetus needed; and Replies of the European Commission to the European Court of Auditors' Special Report.

584 Kapetaki, Z., Ruiz, P. et al., Clean energy technologies in coal regions: Opportunities for jobs and growth: Deployment potential and impacts, EUR 29895 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-12330-9, doi:10.2760/063496, JRC117938.

Furthermore, research and innovation support should prioritise technological leaps that can bypass specific bottlenecks that currently prevent scale-up. For example, in the case of the solar sector, this could include research into new types of solar cells (e.g. perovskite solar cells) that require fewer materials and materials that are more abundant and less dependent on third-country suppliers or advanced recycling techniques that maximise recovery and reuse of critical raw materials. Similar research should focus on new battery technologies (e.g. Na-ion, LFP batteries) less dependent on import and into sectors where the EU is a current global frontrunner such as wind energy and electrolyser. Supporting continuous investments can help maintain a leadership position in a dynamic global market.

Recommendation 3: Stimulating private investment in Net-Zero technologies

To achieve the EU's ambitious climate goals, an estimated EUR 92 billion is required alone for five of the key technologies covered in the SWD[585]. While the NZIA promotes manufacturing capacity, it relies on various existing funding tools such as the TCTF, RRF, InvestEU, Horizon Europe, the Innovation Fund, and the Modernisation Fund. State aid provided through IPCEIs has already managed to pull in private investments, specifically EUR 38 billion across the six IPCEIs relevant to Net-Zero technologies.[586] However, funding from IPCEIs is mainly addressed to countries with sufficient budgets available to attract private finance and, so far, IPCEIs are only available for battery and hydrogen technologies. This could distort competition within the EU.

The challenge lies in creating conditions that make investment in manufacturing capacities viable amidst budget constraints that limit the EU's ability to compete with China or the USA. Current funds are insufficient and risk depletion, potentially creating a funding gap for green technologies. Additionally, the temporary nature of programs such as the RRF could raise concerns about the continuity of financial support for green technologies across many countries when these programs end. Therefore, an efficient use of the EU's and national budgets is crucial to draw in private investments. The Strategic Technologies for Europe Platform (STEP) was set up to boost and steer investment in strategic technologies and provide a centralised gateway to EU funding opportunities. Member States in coordination with the existing sources provided by the EU, need to further facilitate access to funding sources through centralised portals that aggregate available resources and connect EU and Member State funding streams.[587] Furthermore, combining EU funds with Member State funds in areas of high potential (see Recommendation 2) can create synergies, maximising the impact of investments. Timely response to dynamically changing market conditions requires flexible financing mechanisms. Utilising current Multiannual Financial Framework flexibilities can help allocate funding for projects immediately. This approach allows for a more responsive approach that can adapt to emerging needs and opportunities.

One significant barrier to private investment is the lack of guarantees from banks. Manufacturers often avoid contracts and investments, since they have to provide bank guarantees to mitigate the buyer's risks in purchasing their equipment[588]. To overcome this, there is a need for state-backed guarantees to de-risk investments. At the

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[585] European Commission, 23.03.2023, Investment needs assessment and funding availabilities to strengthen EU's Net-Zero technology manufacturing capacity, SWD(2023) 68 final.

[586] Two IPCEI on batteries, and four IPCEI on hydrogen. See here.

[587] A good practice from a Member State is the German Funding database which provides centralsied information on EU, national and regional funding opportunities, (see here). Similarly, the 'One-Stop-Shop to EU Finance' program set up by EIT InnoEnergy under the framework of the European Battery Alliance provides services to start-ups and scale-ups to support them in accessing funding.

[588] Cleantech for Europe, 18.05.2024, The EIB's Strategic Roadmap 2024-2027 should stimulate more public guarantees to unlock the EU's cleantech competitiveness.

EU level, already EIB programmes such as the EIB's counter-guarantee facility[589], the European Tech Champions Initiative (ETCI), the Scale-up Initiative and the Cleantech EIB-EIF Co-Investment Programme provide guarantees and equity that support the expansion of Europe's cleantech sector by crowding in risk capital. Further to this, the implementation of the foreseen Strategic Tech-EU programme will be key to increasing investments into the value chain of Net-Zero technologies including critical raw materials[590]. Similarly, guarantees and other measures could be set up by national promotional banks such as done with the equity finance provided by Germany's KfW[591]. The EU and Member States must work together to encourage the private sector to invest, as public funding alone is unlikely to be sufficient.

There are a number of EU instruments already in place that could be adjusted to further facilitate Net-Zero manufacturing scale-up. IPCEIs are crucial for fostering innovation and large-scale, strategic industrial projects. However, they need modernisation and faster implementation to remain effective and relevant. Streamlining the approval and funding processes for IPCEIs can help accelerate technological advancements and industrial growth. In response to a recommendation from the European Court of Auditors, the Commission indicated its willingness to request Member States "to provide more systematically planned timeframes for the actual disbursements of the aid".[592] Investments are also essential for bringing innovations to market. Investments usually fall short in this risky phase, known as a funding "valley of death".[593] Findings from a report by the EIB and the European Patent Office confirm that innovative firms in the EU face a financing gap regarding their US counterparts, specifically regarding equity finance[594]. The Capital Markets Union Action Plan[595] acknowledges the need for greater involvement of private investors in this phase. Enhancing flexibility and reducing barriers in capital markets can help attract more private investment. Currently, the EU is not leveraging its full potential in capital markets, and addressing this can significantly boost funding for Net-Zero technologies.

Recommendation 4: Leveraging the EU's sustainability leadership

The EU has a history of implementing regulations that set high environmental standards for products sold in the internal market, ensuring that only products meeting these standards can enter the market. A risk here is that stricter rules if not enforced also in imported products might disproportionally affect EU manufacturers as they might restrict access to required inputs thereby increasing costs[596]. Instead, the EU's leadership in sustainability can be turned into a significant advantage for the Net-Zero industry. By promoting the reduced carbon emissions and environmental footprint of European products, the EU and Member States can help its manufacturers remain competitive despite potentially higher industrial production costs. In parallel, it can level the playing field by imposing equivalent sustainability costs on third-country competitors entering the EU market. An EU Green Market Communication, which consolidates various policies to ensure both domestic and imported products meet sustainability requirements, could reinforce this message effectively. Such a communication need not introduce new policy proposals but could build on existing measures, as outlined in the following paragraphs.

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[589] Under this facility, the EIB provides guarantees to commercial banks to enable them to set up banking guarantees for Net-Zero technology investments. See for example, EIB, 31.07.2024, Germany: EIB and Deutsche Bank to boost Europe's wind energy manufacturers. Available here.

[590] European Investment Bank (2024) EIB Group 2024-2027 Strategic Roadmap.

[591] KfW provides equity finance to high-tech startups including in the area of clean technology, see here.

[592] Replies of the European Commission to the European Court of Auditors' Special Report: The EU's industrial policy on batteries – New strategic impetus needed.

[593] Institute for Climate Economics (I4CE). 2023. The sharpest tool in the box: how to strengthen the EU Innovation Fund for climate, competitiveness and security. Available here.

[594] EIB and European Patent Office, Financing and commercialisation of cleantech innovation, 2024.

[595] European Commission (2020): Capital markets union 2020 action plan - European Commission (europa.eu)

[596] Stakeholders from battery, grid technology and electrolyser manufacturing sectors pointed to restrictions to the use of PFAS as an example where manufacturers would need to find substitutes.

Building on previous revisions of the Public Procurement Directive and the green procurement guidelines[597], Member States can put stronger regulatory provisions in place to ensure demand for renewable technologies and products. The Public Procurement Directive in most cases already requires the use of the "economically advantageous" criteria to select winning bids using security of supply, environmental investments, and long-term sustainability considerations in addition to the lowest price. This approach, however, could be further strengthened through sustainability and resilience criteria that explicitly refer to the preferred use of renewable technologies, recycled content and environmentally and socially sustainable products and services. For instance, France is exploring the integration of resilience and sustainability criteria into public procurement processes, where products are awarded higher scores based on the number of industrial processes conducted within the EU. Similarly, Austria has passed legislation to introduce a "Made-in-Europe" bonus in the form of a top-up for investment support for new photovoltaic projects.

Mandatory carbon footprint declarations for products can promote transparency and allow consumers and supply chain partners to make informed choices. The European Commission has recently undertaken a public consultation related to the format of the Carbon Footprint Declaration of batteries. Battery manufacturing countries such as Poland, Hungary, Italy, Germany and Sweden could be affected as well as electric vehicle manufacturers in Germany, Sweden, Czechia, Slovakia and Belgium. Paired with the use of tools such as digital product passports to track CO_2 footprints, sourcing, and origins of components, this increases transparency and accountability across value chains. Such digital passports can be introduced across all Net-Zero industries and will allow consumers and businesses to make informed choices. The harmonisation of ecological content and industrial production requirements can strengthen the level playing field.

Finally, companies can utilise the EU sustainability and safety standards as a marketing tool, emphasising the superior quality and safety of European products. An example is highlighting the absence of harmful substances such as antimony in EU-produced glass versus imported glass from regions with lower safety standards. Technologies impacted could include wind energy (safety standards for turbines), solar energy (absence of hazardous substances in panels) and primary producers in Germany (solar), and Denmark (wind energy). In terms of a wider impact, such initiatives can differentiate EU products in the global market, allowing manufacturers to compete on quality and sustainability rather than just price.

Recommendation 5: Talent and skills development

The transition to a net-zero economy requires a substantial increase in skilled workers. By 2025, over a million skilled workers are needed to meet ambitions alone in the battery, solar PV, and hydrogen industries (see Section 3.4). Additionally, there is a growing need for specialised workers in deployment and installation. To address these shortages, industries must enhance their education and skills programs to attract and retain talent effectively. They also need to ensure that skill sets are updated to match evolving needs and technologies.

To tackle these challenges, the establishment of European Net-Zero Industry Academies, as foreseen also in NZIA, will be beneficial. These academies can be set up in sectors where skills shortages are most acute and anticipated. Their role will be to coordinate and implement cross-sectoral training initiatives tailored to the specific requirements of emerging Net-Zero technologies. For instance, the European Battery Academy and the European Solar Academy, launched in 2022 and June 2024 respectively, represent significant steps forward,

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[597] European Commission: Green Public Procurement Criteria and Requirements https://green-business.ec.europa.eu/green-public-procurement/gpp-criteria-and-requirements_en#gpp-requirements-in-sectoral-legislation

welcomed by industry stakeholders. There is also a pressing need to establish similar initiatives for the raw materials sector and the wind industry (as detailed in Chapter 4). The deployment of European Net-Zero Academies relies on networks of local partners across Member States such as vocational and education training providers, businesses, universities, and other education and training providers. This generates platforms for collaboration and exchanges of good practices to support the development of initiatives in countries with a lower-skilled workforce.

Academies should leverage existing skills programs established in Member States to develop the most needed skill sets, such as the Danish Green Skills Development Programme which focuses on adapting existing vocational education and training to emerging jobs (see Section 3.4). Another key element to the success of Net-Zero Academies' training programmes is ensuring companies use them. As suggested in Mr. Draghi's report, project promoters should be mobilised and contribute to the academies, especially in the context of Strategic Projects and Net-Zero Acceleration Valleys. In this regard, strengthening collaborations between academia and industry is another critical measure. Public-private partnerships can facilitate continuous education and on-the-job training. This can be achieved by creating dedicated academic positions and programs designed to attract students and professionals into the Net-Zero sector. Noteworthy examples include Ireland's Centre of Excellence[598], which promotes collaboration between industry and research institutions, and France's French Battery School[599] (École de la Batterie). This school, comprising a network of 16 organisations including educational institutions and companies, provides training directly aligned with industry needs and aims to attract students and professionals. Strong public-private partnerships should also support the rapid operationalisation of Net-Zero Academies.[600]

Repurposing existing skill sets is also vital. Collaboration with the Just Transition Fund to target the retraining of workers in coal regions and carbon-intensive industries into emerging Net-Zero sectors should be considered. Across the EU, the distribution of jobs should notably ensure a fair allocation to regions with declining industries or in need of restructuring, such as carbon-intensive activities or automotive industries.[601] This approach not only preserves valuable expertise but also enhances overall competitiveness. Spain's smart specialisation strategy is a model in this regard, focusing on adapting skill sets to meet the demands of the net-zero economy.

Finally, supporting the development and use of EU skills passports is imperative. While Mr Draghi's report stresses mutual recognition of skills across the EU as a priority to bridge the skills gap[602], these passports would serve to recognise and validate skills across borders, thereby enhancing workforce mobility. By ensuring that skills are properly documented and transferable within the EU, these passports will support the seamless integration of skilled workers into the Net-Zero manufacturing sector. Alongside the skills passports, further harmonisation of EU certification schemes would also support the recognition of valuable expertise across borders.

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[598] Education in Ireland, Centres of excellence, Ireland's research centres of excellence - Education in Ireland

[599] https://ecoledelabatterie.fr/

[600] Mario Draghi, 2024, The future of European competitiveness. Part B | In-depth analysis and recommendations.

[601] Strategic Perspectives. 2024. A wake-up call for a powerful Clean Industrial Deal. Brussels. Available here.

[602] Mario Draghi, 2024, The future of European competitiveness. Part B | In-depth analysis and recommendations.

Annex I: List of product codes

Final product codes in PRODCOM and Harmonised System

Table A 1 PRODCOM codes summary

Net zero technology	Subcategory	Number of codes
Batteries	Battery components	3
	Final battery products, battery packs, battery cells	16
	Li-ion battery products	3
Biogas	Biogas compressors	11
	Biogas gas storage and transport	1
	Biogas purifier and liquefier	5
	Biogas turbine	1
CCS	CCS compressors	11
	CCS machinery	6
	CCS scrubbers	3
Electrolysers	Electrolyser catalysts	2
	Electrolyser electrical component	1
	Electrolyser machinery	1
	Fuel cell	1
	Hydrogen (gas)	1
	Hydrogen compressors	12
	Hydrogen gas storage and transport	1
Grid	Distribution cables	1
	Electronic control boards	6
	Grid electronical components	6
	Grid insulators	5
	Grid switchgears	9
	Grid transformers	6
	Transmission cables	1
Heatpumps and geothermal	Geothermal electricity generator	5
	Geothermal heat exchanger	1
	Geothermal pumps	2
	Geothermal steam turbine	3
	Heat pump	2
	Heat pump compressor	1
	Heat pump heat exchanger	1
	Heat pump pumps	1
	Thermostats and regulators	2
Solar energy	Solar PV components	10
	Solar PV electrical components	11

Net zero technology	Subcategory	Number of codes
	Solar PV manufacturing	3
	Solar PV panels	3
	Solar PV panels, modules and cells	1
	Solar thermal electric components	2
	Solar thermal electric generator	5
	Solar thermal electric structure	5
	Solar thermal heaters	1
Wind	Components of wind turbine gearboxes	8
	Components of wind turbine generators	3
	Components of wind turbine structure	7
	Wind turbine	1
Batteries	Battery components	3

Table A 2 Harmonised system codes summary

Net zero technology	Subcategory	Number of codes
Batteries	Battery components	2
	Final battery products, battery packs, battery cells	10
	Li-ion battery products	1
Biogas	Biogas compressors	2
	Biogas gas storage and transport	1
	Biogas purifier and liquifier	2
	Biogas turbine	2
CCS	CCS compressors	2
	CCS machinery	3
	CCS scrubbers	3
Electrolyzers	Electrolyzer catalysts	2
	Electrolyzer electrical component	1
	Electrolyzer machinery	1
	Hydrogen (gas)	1
	Hydrogen compressors	2
	Hydrogren gas storage and transport	1
	Hydrogren purifier and liquifier	1
Grid	Distribution cables	1
	Electronic control boards	3
	Grid electronical components	5
	Grid insulators	4
	Grid switchgears	9
	Grid transformers	6
	Transmission cables	1
Heatpumps & geothermal	Geothermal electricity generator	5
	Geothermal Heat exchanger	1
	Geothermal Pumps	1

Net zero technology	Subcategory	Number of codes
	Geothermal steam turbine	3
	Geothermal Turbine	1
	Heat pump	2
	Heat pump compressor	1
	Heat pump heat exchanger	1
	Heat pump pumps	1
	Thermostats and regulators	2
Solar energy	Solar PV components	4
	Solar PV electrical components	3
	Solar PV manufacturing	3
	Solar PV panels	3
	Solar PV panels, modules and cells	1
	Solar thermal electric components	2
	Solar thermal electric generator	6
	Solar thermal electric structure	5
	Solar thermal heaters	1
Wind	Components of wind turbine gearboxes	2
	Components of wind turbine generators	3
	Components of wind turbine structure	5
	Wind turbine	1

Table A 3 PRODCOM codes and description

Net zero technology	Subcategory	PRODCOME code	PRODCOM description
Batteries	Battery components	27.20.12.00	Parts of primary cells and primary batteries (excluding battery carbons, for rechargeable batteries)
		27.20.24.10	Parts of electric accumulators. Separators.
		27.20.24.20	Parts of electric accumulators. Other than separators.
	Final battery products, battery packs, battery cells	27.20.11.10	Manganese dioxide cells and batteries, alkaline, in the form of cylindrical cells
		27.20.11.15	Other manganese dioxide cells and batteries, alkaline (excl. cylindrical cells)
		27.20.11.20	Manganese dioxide cells and batteries, non-alkaline, in the form of cylindrical cells
		27.20.11.25	Other manganese dioxide cells and batteries, non-alkaline (excl. cylindrical cells)
		27.20.11.30	Mercuric oxide primary cells and primary batteries
		27.20.11.40	Silver oxide primary cells and primary batteries
		27.20.11.70	Air-zinc primary cells and primary batteries
		27.20.11.75	Dry zinc-carbon primary batteries of a voltage of >= 5,5 V but <= 6,5 V
		27.20.11.90	Other primary cells and primary batteries, electric (excl. dry zinc-carbon batteries of a voltage of >= 5,5 V but <= 6,5 V, and those of manganese dioxide, mercuric oxide, silver oxide, lithium and air-zinc)
		27.20.22.30	Lead-acid accumulators working with liquid electrolyte, other than of a kind used for starting piston engine
		27.20.22.40	Lead-acid accumulators other than working with liquid electrolyte and other than of a kind used for starting piston engine
		27.20.23.10	Hermetically sealed nickel-cadmium accumulators
		27.20.23.20	Not hermetically sealed nickel-cadmium accumulators
		27.20.23.40	Nickel-metal hydride accumulators
		27.20.23.50	Lithium-ion accumulators
		27.20.23.96	Other electric accumulators (including nickel-iron accumulators)
	Li-ion battery products	27.20.11.50	Lithium primary cells and primary batteries, in the form of cylindrical cells
		27.20.11.55	Lithium primary cells and primary batteries, in the form of button cells
		27.20.11.60	Lithium primary cells and primary batteries (excl. in the form of cylindrical or button cells)
Biogas	Biogas compressors	28.13.25.30	Turbo-compressors, single stage
		28.13.25.50	Turbo-compressors, multistage
		28.13.26.30	Reciprocating displacement compressors having a gauge pressure capacity ≤ 15 bar, giving a flow ≤ 60 m³/hour
		28.13.26.50	Reciprocating displacement compressors having a gauge pressure capacity ≤ 15 bar, giving a flow per hour > 60 m³
		28.13.26.70	Reciprocating displacement compressors having a gauge pressure capacity > 15 bar, giving a flow per hour ≤ 120 m³

Net zero technology	Subcategory	PRODCOME code	PRODCOM description
		28.13.26.90	Reciprocating displacement compressors having a gauge pressure capacity > 15 bar, giving a flow per hour > 120 m³
		28.13.27.30	Rotary displacement compressors, single-shaft
		28.13.27.53	Multi-shaft screw compressors
		28.13.27.55	Multi-shaft compressors (excluding screw compressors)
		28.13.28.11	Air pumps and ventilating or recycling hoods incorporating a fan, whether or not fitted with filters, with a maximum horizontal side > 120 cm (excl. vacuum pumps, hand- or foot- operated air pumps and compressors)
		28.13.32.10	Parts of air and vacuum pumps, of air and gas compressors, of fans, and of hoods
	Biogas gas storage and transport	25.29.12.00	Containers for compressed or liquefied gas, of metal
	Biogas purifier and liquifier	28.25.11.50	Machinery for liquefying air or other gases
		28.25.14.10	Machinery and apparatus for filtering or purifying air (excluding intake filters for internal combustion engines)
		28.25.14.31	Machinery and apparatus for filtering and purifying gases (other than air and excluding those which operate using a catalytic process, and isotope separators)
		28.25.14.41	Machinery and apparatus for filtering or purifying gases by catalytic process (excluding intake air filters for internal combustion engines, machinery and apparatus for filtering or purifying air, catalytic converters)
		28.25.14.50	Machinery and apparatus for filtering and purifying gases with stainless steel housing, and with inlet and outlet tube bores with inside diameters not exceeding 1,3 cm (excluding intake filters for internal combustion engines)
	Biogas turbine	28.11.23.00	Gas turbines (excluding turbojets and turboprops)
CCS	CCS compressors	28.13.25.30	Turbo-compressors, single stage
		28.13.25.50	Turbo-compressors, multistage
		28.13.26.30	Reciprocating displacement compressors having a gauge pressure capacity ≤ 15 bar, giving a flow ≤ 60 m³/hour
		28.13.26.50	Reciprocating displacement compressors having a gauge pressure capacity ≤ 15 bar, giving a flow per hour > 60 m³
		28.13.26.70	Reciprocating displacement compressors having a gauge pressure capacity > 15 bar, giving a flow per hour ≤ 120 m³
		28.13.26.90	Reciprocating displacement compressors having a gauge pressure capacity > 15 bar, giving a flow per hour > 120 m³
		28.13.27.30	Rotary displacement compressors, single-shaft
		28.13.27.53	Multi-shaft screw compressors
		28.13.27.55	Multi-shaft compressors (excluding screw compressors)
		28.13.28.11	Air pumps and ventilating or recycling hoods incorporating a fan, whether or not fitted with filters, with a maximum horizontal side > 120 cm (excl. vacuum pumps, hand- or foot- operated air pumps and compressors)
		28.13.32.10	Parts of air and vacuum pumps, of air and gas compressors, of fans, and of hoods

Net zero technology	Subcategory	PRODCOME code	PRODCOM description
	CCS machinery	25.93.13.15	Woven cloth, including endless bands, of iron or steel wire (excluding endless bands for machinery of stainless steel)
		28.25.11.50	Machinery for liquefying air or other gases
		28.25.14.10	Machinery and apparatus for filtering or purifying air (excluding intake filters for internal combustion engines)
		28.25.14.31	Machinery and apparatus for filtering and purifying gases (other than air and excluding those which operate using a catalytic process, and isotope separators)
		28.25.14.41	Machinery and apparatus for filtering or purifying gases by catalytic process (excluding intake air filters for internal combustion engines, machinery and apparatus for filtering or purifying air, catalytic converters)
		28.25.14.50	Machinery and apparatus for filtering and purifying gases with stainless steel housing, and with inlet and outlet tube bores with inside diameters not exceeding 1,3 cm (excluding intake filters for internal combustion engines)
	CCS scrubbers	20.14.42.33	Monoethanolamine and its salts
		20.14.42.35	Diethanolamine and its salts
		20.14.42.38	Amino-alcohols, their ethers and esters with only 1 oxygen function and their salts (excluding monoethanolamine and its salts, diethanolamine and its salts)
Electrolyzers	Electrolyzer catalysts	20.59.56.62	Supported catalysts with nickel or a nickel compound as the active substance, n.e.s.
		20.59.56.64	Supported catalysts with precious metal or a precious-metal compound as the active substance, n.e.s.
	Electrolyzer electrical component	27.90.41.30	Rectifiers (excluding of a kind used with telecommunication apparatus, automatic data-processing machines and units thereof)
	Electrolyzer machinery	28.49.12.83	Machines and apparatus for electroplating, electrolysis or electrophoresis
	Fuel cell	27.90.42.00	Fuel cell
	Hydrogen (gas)	20.11.11.50	Hydrogen
	Hydrogen compressors	28.13.25.30	Turbo-compressors, single stage
		28.13.25.50	Turbo-compressors, multistage
		28.13.26.30	Reciprocating displacement compressors having a gauge pressure capacity ≤ 15 bar, giving a flow ≤ 60 m^3/hour
		28.13.26.50	Reciprocating displacement compressors having a gauge pressure capacity ≤ 15 bar, giving a flow per hour > 60 m^3
		28.13.26.70	Reciprocating displacement compressors having a gauge pressure capacity > 15 bar, giving a flow per hour ≤ 120 m^3
		28.13.26.90	Reciprocating displacement compressors having a gauge pressure capacity > 15 bar, giving a flow per hour > 120 m^3
		28.13.27.30	Rotary displacement compressors, single-shaft
		28.13.27.53	Multi-shaft screw compressors
		28.13.27.55	Multi-shaft compressors (excluding screw compressors)
		28.13.28.11	Air pumps and ventilating or recycling hoods incorporating a fan, whether or not fitted with filters, with a maximum horizontal side > 120 cm (excl. vacuum pumps, hand- or foot- operated air pumps and compressors)
		28.13.32.10	Parts of air and vacuum pumps, of air and gas compressors, of fans, and of hoods

Net zero technology	Subcategory	PRODCOME code	PRODCOM description
		28.25.11.50	Machinery for liquefying air or other gases
	Hydrogren gas storage and transport	25.29.12.00	Containers for compressed or liquefied gas, of metal
Grid	Distribution cables	27.32.13.80	Other electric conductors, for a voltage ≤ 1 000 V, not fitted with connectors
	Electronic control boards	27.12.31.30	Numerical control panels with built-in automatic data-processing machine for a voltage ≤ 1 kV
		27.12.31.50	Programmable memory controllers for a voltage ≤ 1 kV
		27.12.31.70	Other bases for electric control, distribution of electricity, voltage ≤ 1 000 V
		27.12.32.03	Boards, cabinets and similar combinations of apparatus for electric control or the distribution of electricity, for a voltage > 1.000 V but ≤ 72,5 kV
		27.12.32.05	Boards, cabinets and similar combinations of apparatus for electric control or the distribution of electricity, for a voltage > 72,5 kV
		27.12.40.30	Boards, panels, consoles, desks, cabinets and other bases for apparatus for electric control or the distribution of electricity (excluding those equipped with their apparatus)
	Grid electronical components	26.51.63.70	Electricity supply or production meters (including calibrated) (excluding voltmeters, ammeters, wattmeters and the like)
		27.11.50.80	Inductors (excluding induction coils, deflection coils for cathode-ray tubes, for discharge lamps and tubes)
		27.90.41.30	Rectifiers (excluding of a kind used with telecommunication apparatus, automatic data-processing machines and units thereof)
		27.90.41.55	Inverters having a power handling capacity > 7,5 kVA
		27.90.51.00	Fixed capacitors for 50/60 Hz circuits having a reactive power handling capacity ≥ 0,5 kvar
		27.90.52.20	Fixed electrical capacitors, tantalum or aluminium electrolytic (excluding power capacitors)
	Grid insulators	23.19.25.00	Glass electrical insulators (excluding insulating fittings (other than insulators) for electrical machinery, appliances or equipment)
		23.43.10.30	Electrical insulators of ceramics (excluding insulating fittings)
		27.11.62.03	Ferrite cores of transformers and inductors
		27.11.62.05	Parts of transformers and inductors (excluding ferrite cores)
		27.90.12.30	Electrical insulators (excluding of glass or ceramics)
	Grid switchgears	27.12.10.10	Fuses for a voltage > 1 kV
		27.12.10.20	Automatic circuit breakers >1kV
		27.12.10.30	Isolating switches and make-and-break switches >1kV
		27.12.10.41	Lightning arresters and voltage limiters for a voltage > 1 kV
		27.12.10.90	Other apparatus for switching... electrical circuits > 1 000 V
		27.12.21.70	Fuses for a voltage ≤ 1 kV and for a current > 63 A
		27.12.22.50	Automatic circuit breakers for a voltage ≤ 1 kV and for a current > 63 A

Net zero technology	Subcategory	PRODCOME code	PRODCOM description
		27.12.23.70	Electrical apparatus for protecting electrical circuits for a voltage ≤ 1 kV and for a current > 125 A (excluding fuses, automatic circuit breakers)
		27.12.24.50	Relays for a voltage > 60 V but ≤ 1 kV
	Grid transformers	27.11.41.20	Liquid dielectric transformers having a power handling capacity ≤ 650 kVA
		27.11.41.50	Liquid dielectric transformers having a power handling capacity > 650 kVA but ≤ 10 000 kVA
		27.11.41.80	Liquid dielectric transformers having a power handling capacity > 10 000 kVA
		27.11.42.60	Other transformers, having a power handling capacity > 1 kVA but ≤ 16 kVA
		27.11.43.30	Transformers, n.e.c., having a power handling capacity > 16 kVA but ≤ 500 kVA
		27.11.43.80	Transformers, n.e.c., having a power handling capacity > 500 kVA
	Transmission cables	27.32.14.00	Insulated electric conductors for voltage >1 000 V (excluding winding wire, coaxial cable and other coaxial electric conductors, ignition and other wiring sets used in vehicles, aircraft, ships)
Heatpumps and geothermal	Geothermal electricity generator	27.11.26.11	Alternators of an output ≤ 75 kVA (excluding photovoltaic AC generators)
		27.11.26.31	Alternators of an output > 75 kVA but ≤ 375 kVA (excluding photovoltaic AC generators)
		27.11.26.51	Alternators > 375 kVA but ≤ 750 kVA (excluding photovoltaic AC generators)
		27.11.26.71	Alternators of an output > 750 kVA (excluding photovoltaic AC generators)
		27.11.32.50	Generating sets (excluding wind-powered and powered by spark-ignition internal combustion piston engine)
	Geothermal heat exchanger	28.25.11.30	Heat exchange units
	Geothermal pumps	28.13.14.13	Submersible motor, single-stage rotodynamic drainage and sewage pumps
		28.13.14.15	Submersible motor, multi-stage rotodynamic pumps
	Geothermal steam turbine	25.30.12.50	Condensers for steam or other vapour power units
		28.11.21.60	Steam turbines and other vapour turbines
		28.11.31.00	Parts for steam turbines and other vapour turbines
	Heat pump	28.25.12.50	Air conditioning machines with refrigeration unit (excluding those used in motor vehicles, self-contained or split-systems machines)
		28.25.13.80	Heat pumps other than air conditioning machines of HS 8415
	Heat pump compressor	28.13.23.00	Compressors for refrigeration equipment
	Heat pump heat exchanger	28.25.11.30	Heat exchange units
	Heat pump pumps	28.13.14.17	Glandless impeller pumps for heating systems and warm water supply
	Thermostats and regulators	26.51.70.15	Electronic thermostats

Net zero technology	Subcategory	PRODCOME code	PRODCOM description
		26.51.70.90	Instruments and apparatus, regulating or controlling, n.e.c.
Solar energy	Solar PV components	20.59.53.00	Chemical elements doped for use in electronics, in the form of discs, wafers or similar forms; chemical compounds doped for use in electronics
		22.21.42.30	Non-cellular plates, sheets, film, foil, strip of condensation or rearrangement polymerisation products, polyesters, reinforced, laminated, supported/similarly comb. with other materials)
		22.21.42.50	Non-cellular plates, strips..., of phenolic resins
		22.21.42.75	Non-cellular plates, sheets, film, foil, strip of condensation or rearrangement polymerisation products, amino-resins (high pressure laminates, decorative surface one/both sides)
		22.21.42.79	Other plates, sheets, films, foil and strip, of polymerisation products
		22.21.42.80	Other plates..., non-cellular of plastics other than made by polymerisation
		23.11.12.12	Non-wired sheets, of float, surface ground or polished glass, having a non-reflecting layer
		23.11.12.14	Non-wired sheets, of float, surface ground or polished glass, having an absorbent or reflective layer, of a thickness ≤ 3,5 mm
		23.11.12.17	Non-wired sheets, of float, surface ground or polished glass, having an absorbent or reflecting layer, not otherwise worked, of a thickness > 3,5 mm
		23.12.12.30	Toughened (tempered) safety glass, n.e.c.
	Solar PV electrical components	26.11.30.03	Multichip integrated circuits: processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock and timing circuits, or other circuits
		26.11.30.06	Electronic integrated circuits (excluding multichip circuits): processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock and timing circuits, or other circuits
		26.11.40.70	Parts of diodes, transistors and similar semiconductor devices,photosensitive semiconductor devices and photovoltaic cells, light emitting diodes and mounted piezo-electric crystals
		27.11.62.03	Ferrite cores of transformers and inductors
		27.11.62.05	Parts of transformers and inductors (excluding ferrite cores)
		27.90.41.30	Rectifiers (excluding of a kind used with telecommunication apparatus, automatic data-processing machines and units thereof)
		27.90.41.53	Inverters having a power handling capacity ≤ 7,5 kVA
		27.90.41.55	Inverters having a power handling capacity > 7,5 kVA
		27.90.41.70	Static converters (excluding polycrystalline semiconductors, converters specially designed for welding, without welding equipment, accumulator chargers, rectifiers, inverters)
		27.90.41.80	Accumulator chargers
		27.90.41.90	Parts of static converters, n.e.c. (excl. electronic assemblies of a kind used with telecommunication apparatus, automatic data-processing machines and units thereof)
	Solar PV manufacturing	28.99.20.20	Machines and apparatus used solely or principally for the manufacture of semiconductor boules or wafers
		28.99.20.40	Machines and apparatus for the manufacture of semiconductor devices or of electronic integrated circuits

Net zero technology	Subcategory	PRODCOME code	PRODCOM description
		28.99.51.00	Parts and accessories of machines and apparatus used solely or principally for (a) the manufacture of semiconductor boules or wafers, semiconductor devices, electronic integrated circuits or flat panel displays, (b) the manufacture or repair of masks and
	Solar PV panels	27.11.10.95	Photovoltaic DC generators of an output not exceeding 50 W
		27.11.10.96	Photovoltaic DC generators of an output exceeding 50 W
		27.11.26.80	Photovoltaic AC generators
	Solar PV panels, modules and cells	26.11.22.40	Photosensitive semiconductor devices, including photovoltaic cells whether or not assembled in modules or made up into panels
	Solar thermal electric components	26.70.21.53	Prisms, mirrors and other optical elements, n.e.c.
		26.70.21.55	Mounted lenses, prisms, mirrors, etc., of any material, n.e.c.
	Solar thermal electric generator	27.11.26.11	Alternators of an output ≤ 75 kVA (excluding photovoltaic AC generators)
		27.11.26.31	Alternators of an output > 75 kVA but ≤ 375 kVA (excluding photovoltaic AC generators)
		27.11.26.51	Alternators > 375 kVA but ≤ 750 kVA (excluding photovoltaic AC generators)
		27.11.26.71	Alternators of an output > 750 kVA (excluding photovoltaic AC generators)
		28.11.21.60	Steam turbines and other vapour turbines
	Solar thermal electric structure	22.29.29.96	Other articles of plastic n.e.c. (excluding protective face shields/visors and appliances identifiable for ostomy use)
		23.12.13.90	Other glass mirrors, whether or not framed
		25.99.24.00	Statuettes, frames, mirrors and other ornaments of base metal
		26.70.22.50	Instruments (excluding binoculars) such as optical telescopes
		32.12.14.00	Other articles of precious metal; articles of natural or cultured pearls, precious or semi-precious stones
	Solar thermal heaters	27.52.14.00	Non-electric instantaneous or storage water heaters
Wind	Components of wind turbine gearboxes	28.15.24.32	Gear boxes for stationary equipment, spur and helical gear boxes
		28.15.24.33	Gear boxes ..., bevel and bevel/spur and helical gear boxes
		28.15.24.34	Gear boxes ..., worm gear boxes
		28.15.24.40	Other gear boxes
		28.15.24.50	Gearboxes and other speed changers for machinery and land/sea vehicles excluding gears and gearing
		28.15.24.73	Ball or roller screws
		28.15.24.75	Other transmission elements (excluding gears and gearing, ball or roller screws, gearboxes and other speed changers)
		28.15.26.00	Clutches and shaft couplings (including universal joints)

Net zero technology	Subcategory	PRODCOME code	PRODCOM description
	Components of wind turbine generators	27.11.26.51	Alternators > 375 kVA but ≤ 750 kVA (excluding photovoltaic AC generators)
		27.11.26.71	Alternators of an output > 750 kVA (excluding photovoltaic AC generators)
		27.11.61.10	Parts suitable for use solely or principally with electric motors and generators, electric generating sets and rotary converters, n.e.c. (excluding fuel cells)
	Components of wind turbine structure	25.11.22.00	Iron or steel towers and lattice masts
		25.11.23.50	Other structures principally of sheet: other
		25.11.23.55	Weirs, sluices, lock-gates, landing stages, fixed docks and other maritime and waterway structures, of iron or steel, Structures and parts of structures of iron or steel, n.e.s. (excluding bridges and bridge-sections; towers; lattice masts; gates; doors,
		25.11.23.70	Aluminium structure and parts of structures..., n.e.c.
		25.99.29.95	Permanent magnets and articles intended to become permanent magnets, of metal
		28.15.10.30	Ball bearings
		28.15.10.55	Spherical roller bearings
	Wind turbine	28.11.24.00	Generating sets, wind-powered

Table A 4 Harmonised system codes and descriptions

Net-zero Tech-nology	Subcategory	HS code	HS Description 2012	HS Description 2022
Batteries	Battery components	850690	Cells and batteries; primary, parts thereof	Cells and batteries; primary, parts thereof
		850790	Electric accumulators; parts n.e.c. in heading no. 8507	Electric accumulators; parts n.e.c. in heading no. 8507
	Final battery products, battery packs, battery cells	850610	Cells and batteries; primary, manganese dioxide	Cells and batteries; primary, manganese dioxide
		850630	Cells and batteries; primary, mercuric oxide	Cells and batteries; primary, mercuric oxide
		850640	Cells and batteries; primary, silver oxide	Cells and batteries; primary, silver oxide
		850660	Cells and batteries; primary, air-zinc	Cells and batteries; primary, air-zinc
		850680	Cells and batteries; primary, (other than manganese dioxide, mercuric oxide, silver oxide, lithium or air-zinc)	Cells and batteries; primary, (other than manganese dioxide, mercuric oxide, silver oxide, lithium or air-zinc)

Net-zero Tech-nology	Subcategory	HS code	HS Description 2012	HS Description 2022
		850720	Electric accumulators; lead-acid, (other than for starting piston engines), including separators, whether or not rectangular (including square)	Electric accumulators; lead-acid, (other than for starting piston engines), including separators, whether or not rectangular (including square)
		850730	Electric accumulators; nickel-cadmium, including separators, whether or not rectangular (including square)	Electric accumulators; nickel-cadmium, including separators, whether or not rectangular (including square)
		850750	Electric accumulators; nickel-metal hydride, including separators, whether or not rectangular (including square)	Electric accumulators; nickel-metal hydride, including separators, whether or not rectangular (including square)
		850760	Electric accumulators; lithium-ion, including separators, whether or not rectangular (including square)	Electric accumulators; lithium-ion, including separators, whether or not rectangular (including square)
		850780	Electric accumulators; other than lead-acid, nickel-cadmium, nickel-iron, nickel-metal hydride and lithium-ion, including separators, whether or not rectangular (including square)	Electric accumulators; other than lead-acid, nickel-cadmium, nickel-metal hydride and lithium-ion, including separators, whether or not rectangular (including square)
	Li-ion battery products	850650	Cells and batteries; primary, lithium	Cells and batteries; primary, lithium
Biogas	Biogas compressors	841480	Pumps and compressors; for air, vacuum or gas, n.e.c. in heading no. 8414	Pumps and compressors; for air, vacuum or gas, n.e.c. in heading no. 8414
		841490	Pumps and compressors; parts, of air or vacuum pumps, air or other gas compressors and fans, ventilating or recycling hoods incorporating a fan	Pumps and compressors; parts, of air or vacuum pumps, air or other gas compressors and fans, ventilating or recycling hoods incorporating a fan
	Biogas gas storage and transport	731100	Containers for compressed or liquefied gas, of iron or steel	Containers for compressed or liquefied gas, of iron or steel
	Biogas purifier and liquifier	841960	Machinery; for liquefying air or gas, not used for domestic purposes	Machinery; for liquefying air or gas, not used for domestic purposes
		842139	Machinery; for filtering or purifying gases, other than intake air filters for internal combustion engines	Machinery; for filtering or purifying gases, other than intake air filters, catalytic converters or particulate filters for internal combustion engines
	Biogas turbine	841181	Turbines; gas-turbines (excluding turbo-jets and turbo-propellers), of a power not exceeding 5000kW	Turbines; gas-turbines (excluding turbo-jets and turbo-propellers), of a power not exceeding 5000kW
		841182	Turbines; gas-turbines (excluding turbo-jets and turbo-propellers), of a power exceeding 5000kW	Turbines; gas-turbines (excluding turbo-jets and turbo-propellers), of a power exceeding 5000kW
CCS	CCS compresors	841480	Pumps and compressors; for air, vacuum or gas, n.e.c. in heading no. 8414	Pumps and compressors; for air, vacuum or gas, n.e.c. in heading no. 8414

Net-zero Tech-nology	Subcategory	HS code	HS Description 2012	HS Description 2022
		841490	Pumps and compressors; parts, of air or vacuum pumps, air or other gas compressors and fans, ventilating or recycling hoods incorporating a fan	Pumps and compressors; parts, of air or vacuum pumps, air or other gas compressors and fans, ventilating or recycling hoods incorporating a fan
	CCS machinery	731414	Iron or steel; woven cloth, of stainless steel, (other than endless bands for machinery)	Iron or steel; woven cloth, of stainless steel, (other than endless bands for machinery)
		841960	Machinery; for liquefying air or gas, not used for domestic purposes	Machinery; for liquefying air or gas, not used for domestic purposes
		842139	Machinery; for filtering or purifying gases, other than intake air filters for internal combustion engines	Machinery; for filtering or purifying gases, other than intake air filters, catalytic converters or particulate filters for internal combustion engines
	CCS scrubbers	292211	Amino-alcohols, other than those containing more than one kind of oxygen function; their ethers and esters; salts thereof, monoethanolamine and its salts	Amino-alcohols, other than those containing more than one kind of oxygen function; their ethers and esters; salts thereof, monoethanolamine and its salts
		292212	Amino-alcohols, other than those containing more than one kind of oxygen function; their ethers and esters; salts thereof, diethanolamine and its salts	Amino-alcohols, other than those containing more than one kind of oxygen function; their ethers and esters; salts thereof, diethanolamine and its salts
		292214	Amino-alcohols, other than those containing more than one kind of oxygen function; their ethers and esters; salts thereof; dextropropoxyphene (INN) and its salts	Amino-alcohols, other than those containing more than one kind of oxygen function; their ethers and esters; salts thereof; dextropropoxyphene (INN) and its salts
Electrolyzers	Electrolyzer catalysts	381511	Catalysts, supported; reaction initiators, reaction accelerators and catalytic preparations, with nickel or nickel compounds as the active substance, n.e.c. or included	Catalysts, supported; reaction initiators, reaction accelerators and catalytic preparations, with nickel or nickel compounds as the active substance, n.e.c. or included
		381512	Catalysts, supported; reaction initiators, reaction accelerators and catalytic preparations, with precious metal or precious metal compounds as the active substance, n.e.c. or included	Catalysts, supported; reaction initiators, reaction accelerators and catalytic preparations, with precious metal or precious metal compounds as the active substance, n.e.c. or included
	Electrolyzer electrical component	850440	Electrical static converters	Electrical static converters
	Electrolyzer machinery	854330	Electrical machines and apparatus; for electroplating, electrolysis or electrophoresis	Electrical machines and apparatus; for electroplating, electrolysis or electrophoresis
	Hydrogen (gas)	280410	Hydrogen	Hydrogen
	Hydrogen compressors	841480	Pumps and compressors; for air, vacuum or gas, n.e.c. in heading no. 8414	Pumps and compressors; for air, vacuum or gas, n.e.c. in heading no. 8414

Net-zero Tech-nology	Subcategory	HS code	HS Description 2012	HS Description 2022
		841490	Pumps and compressors; parts, of air or vacuum pumps, air or other gas compressors and fans, ventilating or recycling hoods incorporating a fan	Pumps and compressors; parts, of air or vacuum pumps, air or other gas compressors and fans, ventilating or recycling hoods incorporating a fan
	Hydrogren gas storage and transport	731100	Containers for compressed or liquefied gas, of iron or steel	Containers for compressed or liquefied gas, of iron or steel
	Hydrogren purifier and liquifier	841960	Machinery; for liquefying air or gas, not used for domestic purposes	Machinery; for liquefying air or gas, not used for domestic purposes
Grid	Distribution cables	854449	Insulated electric conductors; for a voltage not exceeding 1000 volts, not fitted with connectors	Insulated electric conductors; for a voltage not exceeding 1000 volts, not fitted with connectors
	Electronic control boards	853710	Boards, panels, consoles, desks and other bases; for electric control or the distribution of electricity, (other than switching apparatus of heading no. 8517), for a voltage not exceeding 1000 volts	Boards, panels, consoles, desks and other bases; for electric control or the distribution of electricity, (other than switching apparatus of heading no. 8517), for a voltage not exceeding 1000 volts
		853720	Boards, panels, consoles, desks and other bases; for electric control or the distribution of electricity, (other than switching apparatus of heading no. 8517), for a voltage exceeding 1000 volts	Boards, panels, consoles, desks and other bases; for electric control or the distribution of electricity, (other than switching apparatus of heading no. 8517), for a voltage exceeding 1000 volts
		853810	Electrical apparatus; parts (e.g. boards, panels, consoles, desks, cabinets, other bases), for goods of heading no. 8537, not equipped with their apparatus	Electrical apparatus; parts (e.g. boards, panels, consoles, desks, cabinets, other bases), for goods of heading no. 8537, not equipped with their apparatus
	Grid electronical components	850440	Electrical static converters	Electrical static converters
		850450	Electrical inductors; n.e.c. in heading no. 8504	Electrical inductors; n.e.c. in heading no. 8504
		853210	Electrical capacitors; fixed, designed for use in 50/60 Hz circuits and having a reactive power handling capacity of not less than 0.5 kvar (power capacitors)	Electrical capacitors; fixed, designed for use in 50/60 Hz circuits and having a reactive power handling capacity of not less than 0.5 kvar (power capacitors)
		853221	Electrical capacitors; fixed, tantalum	Electrical capacitors; fixed, tantalum
		902830	Meters; electricity supply or production meters, including calibrating meters thereof	Meters; electricity supply or production meters, including calibrating meters thereof
	Grid insulators	850490	Electrical transformers, static converters and inductors; parts thereof	Electrical transformers, static converters and inductors; parts thereof
		854610	Electrical insulators; of glass	Electrical insulators; of glass

Net-zero Tech-nology	Subcategory	HS code	HS Description 2012	HS Description 2022
		854620	Electrical insulators; of ceramics	Electrical insulators; of ceramics
		854690	Electrical insulators; other than of glass and ceramics	Electrical insulators; other than of glass and ceramics
	Grid switchgears	853510	Electrical apparatus; fuses, for a voltage exceeding 1000 volts	Electrical apparatus; fuses, for a voltage exceeding 1000 volts
		853521	Electrical apparatus; automatic circuit breakers, for a voltage exceeding 1000 volts but less than 72.5kV	Electrical apparatus; automatic circuit breakers, for a voltage exceeding 1000 volts but less than 72.5kV
		853529	Electrical apparatus; automatic circuit breakers, for a voltage of 72.5kV or more	Electrical apparatus; automatic circuit breakers, for a voltage of 72.5kV or more
		853530	Electrical apparatus; isolating and make-and-break switches, for a voltage exceeding 1000 volts	Electrical apparatus; isolating and make-and-break switches, for a voltage exceeding 1000 volts
		853590	Electrical apparatus; n.e.c. in heading no. 8535, for switching or protecting electrical circuits, for a voltage exceeding 1000 volts	Electrical apparatus; n.e.c. in heading no. 8535, for switching or protecting electrical circuits, for a voltage exceeding 1000 volts
		853610	Electrical apparatus; fuses, for a voltage not exceeding 1000 volts	Electrical apparatus; fuses, for a voltage not exceeding 1000 volts
		853620	Electrical apparatus; automatic circuit breakers, for a voltage not exceeding 1000 volts	Electrical apparatus; automatic circuit breakers, for a voltage not exceeding 1000 volts
		853630	Electrical apparatus; for protecting electrical circuits, n.e.c. in heading no. 8536, for a voltage not exceeding 1000 volts	Electrical apparatus; for protecting electrical circuits, n.e.c. in heading no. 8536, for a voltage not exceeding 1000 volts
		853649	Electrical apparatus; relays, for a voltage exceeding 60 volts	Electrical apparatus; relays, for a voltage exceeding 60 volts
	Grid transformers	850421	Electrical transformers; liquid dielectric, having a power handling capacity not exceeding 650kVA	Electrical transformers; liquid dielectric, having a power handling capacity not exceeding 650kVA
		850422	Electrical transformers; liquid dielectric, having a power handling capacity exceeding 650kVA but not exceeding 10,000kVA	Electrical transformers; liquid dielectric, having a power handling capacity exceeding 650kVA but not exceeding 10,000kVA
		850423	Electrical transformers; liquid dielectric, having a power handling capacity exceeding 10,000kVA	Electrical transformers; liquid dielectric, having a power handling capacity exceeding 10,000kVA
		850432	Transformers; n.e.c. in item no. 8504.2, having a power handling capacity exceeding 1kVA but not exceeding 16kVA	Transformers; n.e.c. in item no. 8504.2, having a power handling capacity exceeding 1kVA but not exceeding 16kVA
		850433	Transformers; n.e.c. in item no. 8504.2, having a power handling capacity exceeding 16kVA but not exceeding 500kVA	Transformers; n.e.c. in item no. 8504.2, having a power handling capacity exceeding 16kVA but not exceeding 500kVA
		850434	Transformers; n.e.c. in item no. 8504.2, having a power handling capacity exceeding 500kVA	Transformers; n.e.c. in item no. 8504.2, having a power handling capacity exceeding 500kVA

Net-zero Tech-nology	Subcategory	HS code	HS Description 2012	HS Description 2022
	Transmission cables	854460	Insulated electric conductors; for a voltage exceeding 1000 volts	Insulated electric conductors; for a voltage exceeding 1000 volts
Heatpumps & geothermal	Geothermal electricity generator	850161	Generators; AC generators, (alternators), of an output not exceeding 75kVA	Generators; AC generators, (alternators), other than photovoltaic generators, of an output not exceeding 75kVA
		850162	Electric generators; AC generators, (alternators), of an output exceeding 75kVA but not exceeding 375kVA	Electric generators; AC generators, (alternators), other than photovoltaic generators, of an output exceeding 75kVA but not exceeding 375kVA
		850163	Electric generators; AC generators, (alternators), of an output exceeding 375kVA but not exceeding 750kVA	Electric generators; AC generators, (alternators), other than photovoltaic generators, of an output exceeding 375kVA but not exceeding 750kVA
		850164	Electric generators; AC generators, (alternators), of an output exceeding 750kVA	Electric generators; AC generators, (alternators), other than photovoltaic generators, of an output exceeding 750kVA
		850239	Electric generating sets; (excluding those with spark-ignition or compression-ignition internal combustion piston engines), other than wind powered	Electric generating sets; (excluding those with spark-ignition or compression-ignition internal combustion piston engines), other than wind powered
	Geothermal Heat exchanger	841950	Heat exchange units; not used for domestic purposes	Heat exchange units; not used for domestic purposes
	Geothermal Pumps	841370	Pumps; centrifugal, n.e.c. in heading no. 8413, for liquids	Pumps; centrifugal, n.e.c. in heading no. 8413, for liquids
	Geothermal steam turbine	840420	Boilers; condensers, for steam or other vapour power units	Boilers; condensers, for steam or other vapour power units
		840681	Turbines; steam and other vapour turbines, (for other than marine propulsion), of an output exceeding 40MW	Turbines; steam and other vapour turbines, (for other than marine propulsion), of an output exceeding 40MW
		840682	Turbines; steam and other vapour turbines, (for other than marine propulsion), of an output not exceeding 40MW	Turbines; steam and other vapour turbines, (for other than marine propulsion), of an output not exceeding 40MW
	Geothermal Turbine	840690	Turbines; parts of steam and other vapour turbines	Turbines; parts of steam and other vapour turbines
	Heat pump	841581	Air conditioning machines; containing a motor driven fan, other than window or wall types, incorporating a refrigerating unit and a valve for reversal of the cooling/heat cycle (reversible heat pumps)	Air conditioning machines; containing a motor driven fan, other than window or wall types, incorporating a refrigerating unit and a valve for reversal of the cooling/heat cycle (reversible heat pumps)

Net-zero Tech-nology	Subcategory	HS code	HS Description 2012	HS Description 2022
		841861	Heat pumps; other than air conditioning machines of heading no. 8415	Heat pumps; other than air conditioning machines of heading no. 8415
	Heat pump compressor	841430	Compressors; of a kind used in refrigerating equipment	Compressors; of a kind used in refrigerating equipment
	Heat pump heat exchanger	841950	Heat exchange units; not used for domestic purposes	Heat exchange units; not used for domestic purposes
	Heat pump pumps	841370	Pumps; centrifugal, n.e.c. in heading no. 8413, for liquids	Pumps; centrifugal, n.e.c. in heading no. 8413, for liquids
	Thermostats and regulators	903210	Regulating or controlling instruments and apparatus; automatic type, thermostats	Regulating or controlling instruments and apparatus; automatic type, thermostats
		903289	Regulating or controlling instruments and apparatus; automatic, other than hydraulic or pneumatic	Regulating or controlling instruments and apparatus; automatic, other than hydraulic or pneumatic
Solar energy	Solar PV components	381800	Chemical elements; doped for use in electronics, in the form of discs, wafers or similar forms; chemical compounds doped for use in electronics	Chemical elements; doped for use in electronics, in the form of discs, wafers or similar forms; chemical compounds doped for use in electronics
		392190	Plastics; plates, sheets, film, foil and strip, other than cellular	Plastics; plates, sheets, film, foil and strip, other than cellular
		700510	Glass; float glass and surface ground or polished glass, in sheets, non-wired, having an absorbent reflecting or non-reflecting layer	Glass; float glass and surface ground or polished glass, in sheets, non-wired, having an absorbent reflecting or non-reflecting layer
		700719	Glass; safety glass, toughened (tempered), (not of a size and shape suitable for incorporation in vehicles, aircraft, spacecraft or vessels)	Glass; safety glass, toughened (tempered), (not of a size and shape suitable for incorporation in vehicles, aircraft, spacecraft or vessels)
	Solar PV electrical components	850440	Electrical static converters	Electrical static converters
		850490	Electrical transformers, static converters and inductors; parts thereof	Electrical transformers, static converters and inductors; parts thereof
		854231	Electronic integrated circuits; processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock and timing circuits, or other circuits	Electronic integrated circuits; processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock and timing circuits, or other circuits
	Solar PV manufacturing	848610	Machines and apparatus of a kind used solely or principally for the manufacture of semiconductor boules or wafers	Machines and apparatus of a kind used solely or principally for the manufacture of semiconductor boules or wafers

Net-zero Tech-nology	Subcategory	HS code	HS Description 2012	HS Description 2022
		848620	Machines and apparatus of a kind used solely or principally for the manufacture of semiconductor devices or of electronic integrated circuits	Machines and apparatus of a kind used solely or principally for the manufacture of semiconductor devices or of electronic integrated circuits
		848690	Machines and apparatus of heading 8486; parts and accessories	Machines and apparatus of heading 8486; parts and accessories
	Solar PV panels	850171	#N/A	Electric generators; photovoltaic DC generators, of an output not exceeding 50W
		850172	#N/A	Electric generators; photovoltaic DC generators, of an output exceeding 50W
		850180	#N/A	Electric generators; (excluding generating sets), photovoltaic AC generators (alternators)
	Solar PV panels, modules and cells	854142	#N/A	Electrical apparatus; photosensitive semiconductor devices, photovoltaic cells not assembled in modules or made up into panels
	Solar thermal electric components	900190	Optical elements; lenses n.e.c. in heading no. 9001, prisms, mirrors and other optical elements, unmounted, of any material (excluding elements of glass not optically worked)	Optical elements; lenses n.e.c. in heading no. 9001, prisms, mirrors and other optical elements, unmounted, of any material (excluding elements of glass not optically worked)
		900290	Optical elements; n.e.c. in heading no. 9002 (e.g. prisms and mirrors), mounted, being parts or fittings for instruments or apparatus, of any material (excluding elements of glass not optically worked)	Optical elements; n.e.c. in heading no. 9002 (e.g. prisms and mirrors), mounted, being parts or fittings for instruments or apparatus, of any material (excluding elements of glass not optically worked)
	Solar thermal electric generator	840681	Turbines; steam and other vapour turbines, (for other than marine propulsion), of an output exceeding 40MW	Turbines; steam and other vapour turbines, (for other than marine propulsion), of an output exceeding 40MW
		840682	Turbines; steam and other vapour turbines, (for other than marine propulsion), of an output not exceeding 40MW	Turbines; steam and other vapour turbines, (for other than marine propulsion), of an output not exceeding 40MW
		850161	Generators; AC generators, (alternators), of an output not exceeding 75kVA	Generators; AC generators, (alternators), other than photovoltaic generators, of an output not exceeding 75kVA
		850162	Electric generators; AC generators, (alternators), of an output exceeding 75kVA but not exceeding 375kVA	Electric generators; AC generators, (alternators), other than photovoltaic generators, of an output exceeding 75kVA but not exceeding 375kVA
		850163	Electric generators; AC generators, (alternators), of an output exceeding 375kVA but not exceeding 750kVA	Electric generators; AC generators, (alternators), other than photovoltaic generators, of an output exceeding 375kVA but not exceeding 750kVA

Net-zero Tech-nology	Subcategory	HS code	HS Description 2012	HS Description 2022
		850164	Electric generators; AC generators, (alternators), of an output exceeding 750kVA	Electric generators; AC generators, (alternators), other than photovoltaic generators, of an output exceeding 750kVA
	Solar thermal electric structure	392690	Plastics; other articles n.e.c. in chapter 39	Plastics; other articles n.e.c. in chapter 39
		700991	Glass mirrors; unframed, excluding rear-view mirrors for vehicles	Glass mirrors; unframed, excluding rear-view mirrors for vehicles
		711590	Metal; precious or metal clad with precious metal, other than that of item no. 7115.10	Metal; precious or metal clad with precious metal, other than that of item no. 7115.10
		830621	Statuettes and other ornaments; of base metal plated with precious metal	Statuettes and other ornaments; of base metal plated with precious metal
		900580	Monoculars; other optical telescopes and astronomical instruments, excluding instruments for radio-astronomy	Monoculars; other optical telescopes and astronomical instruments, excluding instruments for radio-astronomy
	Solar thermal heaters	841911	Heaters; instantaneous gas water heaters, for domestic or other purposes	Heaters; instantaneous gas water heaters, for domestic or other purposes
Wind	Components of wind turbine gearboxes	848340	Gears and gearing; (not toothed wheels, chain sprockets and other transmission elements presented separately); ball or roller screws; gear boxes and other speed changers, including torque converters	Gears and gearing; (not toothed wheels, chain sprockets and other transmission elements presented separately); ball or roller screws; gear boxes and other speed changers, including torque converters
		848360	Clutches and shaft couplings (including universal joints)	Clutches and shaft couplings (including universal joints)
	Components of wind turbine generators	850163	Electric generators; AC generators, (alternators), of an output exceeding 375kVA but not exceeding 750kVA	Electric generators; AC generators, (alternators), other than photovoltaic generators, of an output exceeding 375kVA but not exceeding 750kVA
		850164	Electric generators; AC generators, (alternators), of an output exceeding 750kVA	Electric generators; AC generators, (alternators), other than photovoltaic generators, of an output exceeding 750kVA
		850300	Electric motors and generators; parts suitable for use solely or principally with the machines of heading no. 8501 or 8502	Electric motors and generators; parts suitable for use solely or principally with the machines of heading no. 8501 or 8502
	Components of wind turbine structure	730820	Iron or steel; structures and parts thereof, towers and lattice masts	Iron or steel; structures and parts thereof, towers and lattice masts
		730890	Iron or steel; structures and parts thereof, n.e.c. in heading 7308	Iron or steel; structures and parts thereof, n.e.c. in heading 7308

Net-zero Tech-nology	Subcategory	HS code	HS Description 2012	HS Description 2022
		761090	Aluminium; structures (excluding prefabricated buildings of heading no. 9406) and parts of structures, n.e.c. in heading no. 7610, plates, rods, profiles, tubes and the like	Aluminium; structures (excluding prefabricated buildings of heading no. 9406) and parts of structures, n.e.c. in heading no. 7610, plates, rods, profiles, tubes and the like
		848210	Ball bearings	Ball bearings
		848230	Bearings; spherical roller bearings	Bearings; spherical roller bearings
	Wind turbine	850231	Electric generating sets; wind-powered, (excluding those with spark-ignition or compression-ignition internal combustion piston engines)	Electric generating sets; wind-powered, (excluding those with spark-ignition or compression-ignition internal combustion piston engines)

Annex II: Country fiches

Submitted as a separate Annex.

Annex III: Semi-structured interviews

Overview

As outlined in Chapter 4, we organised 16 semi-structured interviews to further refine our understanding of the value chains of each technology and its key challenges and opportunities. For a full overview see the table below.

Table A 5 Overview of Task 1/3 interviews

Technology	Organisation	Date of the interview
Batteries and storage	European Association for Advanced Rechargeable Batteries	21.05.2024
	European Association for Storage of Energy	23.04.2024
Onshore wind and offshore renewables	Wind Europe	26.04.2024
	EIT InnoEnergy	13.05.2024
Solar photovoltaic and solar thermal	European Solar Manufacturing Council	25.04.2024
	Solar Power Europe	30.04.2024
Heat Pumps and geothermal	EU Heat Pump Association	30.04.2024
	International Energy Agency	30.04.2024
Electrolysers and fuel cells	European Hydrogen Sustainability and Circularity Panel	26.04.2024
	Hydrogen Europe	29.04.2024
Sustainable biogas/ biomethane	European Biogas Association	26.04.2024
	Norwegian Institute for Sustainability Research	02.05.2024
Carbon capture and storage	CCSA	15.05.2024
	CO_2 Value Europe	22.04.2024
Grid technologies	Current Europe	08.05.2024
	Europacable	23.05.2024

Interview minutes

The interview minutes are provided in a separate document labelled Annex III.1.

Annex IV: Survey Report

Introduction

The survey aimed to gather stakeholder views, notably from EU and national business associations, companies and Research and Technology Organisations, on the current situation at the EU and country levels for the eight technologies covered in this study. Stakeholders responded to a set of questions, tailored according to their profile, that covered the state of play in manufacturing capacities at the EU and Member State level, the current manufacturing capacities and future plans (for manufacturing companies), the regulatory framework including permitting and support structures, as well as the strengths, weaknesses, opportunities and threats for Net-Zero technologies.

Overview of respondents

A total of 97 respondents responded to the survey, which included 28 complete responses and 69 partial responses. Respondents belonged to companies (45% of respondents), national business associations (20% of respondents), EU business associations (18% of respondents) and Research and Technology organisations (9% of respondents). A small share of respondents (9%) belonged to other organisations such as port authorities, consultancies, international organisations or non-governmental organisations.

Main vulnerabilities and strengths by technology

Respondents first indicated the most important vulnerabilities for each of the technologies that were relevant to them. They ranked them from the most important to the least important vulnerability per technology. The figure below displays the most cited vulnerabilities for each of the eight Net-Zero technologies across Member States.

Table A 6 Vulnerabilities ranked as the highest for Net-Zero technologies

Vulnerabilities

Lack of funding and/or financing	5	5	2nd	4	3rd	2nd	1st	2nd
Competition	1st	4	4	5	6	7	6	4
Import dependencies	2nd	3rd	5	2nd	2nd	6	8	9
Cost of material or labour	3rd	2nd	3rd	3rd	4	4	3rd	7
Lack of skilled labour	4	6	4	3rd	5	5	7	6
Complex regulatory environment	6	1st	3rd	7	1st	1st	2nd	1st
Economic uncertainty	8	7	6	5	5	3rd	4	3rd
Lack of research and innovation	7	6	4	6	4	8	5	8
Lack of market demand	9	8	1st	1st	1st	5	4	5

From left to right, columns indicate Solar photovoltaic and solar thermal technologies, Onshore wind and offshore renewable technologies, Battery/storage technologies, Heat pumps and geothermal energy technologies, Electrolysers and fuel cells, Sustainable biogas/biomethane technologies, Carbon Capture and storage (CCS) technologies, Grid technologies.

Across Net-Zero technologies, stakeholders identified several cross-cutting vulnerabilities:

- The complex regulatory environment is cited as the main vulnerability for 4 technologies *(*Onshore wind and offshore renewable technologies, Electrolysers and fuel cells, Sustainable biogas/biomethane technologies, Grid technologies*),* but also as the second or third most significant vulnerability for 2 additional technologies *(*Battery/storage technologies, Carbon Capture and storage (CCS) technologies*).*
- The lack of market demand constitutes the most significant vulnerability for 3 technologies *(*battery/storage technologies, Heat pumps and geothermal energy technologies, Electrolysers and fuel cells*)*.
- The lack of funding and/or financing is one of the three most cited vulnerabilities for 5 technologies (Battery/storage technologies, Electrolysers and fuel cells, Sustainable biogas/biomethane technologies, Carbon Capture and storage (CCS) technologies, Grid technologies*)*
- Import dependencies is the second or third most cited vulnerability for 4 technologies (Solar photovoltaic and solar thermal technologies, Onshore wind and offshore renewable technologies, Heat pumps and geothermal energy technologies*)*
- And the cost of material or labour is the third most cited vulnerability for 4 technologies (Solar photovoltaic and solar thermal technologies, Battery/storage technologies, Heat pumps and geothermal energy technologies, Carbon Capture and storage (CCS) technologies*)*

Stakeholders mentioned additional vulnerabilities that cross-cut across technologies. Dumping practices and the increasing unfair competition from non-European companies were underscored as the main vulnerabilities for several technologies. Additionally, several stakeholders indicated the lack of knowledge (which covers both public knowledge and policy-making) as the most significant vulnerability for Carbon capture and storage and sustainable biogas/biomethane technologies.

It also should be noted that while 14 respondents ranked vulnerabilities for solar photovoltaic and solar thermal technologies, this number amounted to 3 for onshore wind and offshore renewable technologies, 6 for battery/storage technologies, 3 for heat pumps and geothermal technologies, 6 for electrolysers and fuel cells, 5 for sustainable biogas and geothermal technologies, 6 for Carbon capture and storage technologies, and 2 for grid technologies.

Regarding strengths, stakeholders selected which of the presented factors were the main strengths for each of the Net-Zero technologies. The results are presented in the below table.

Table A 7 Number of respondents citing the listed factors as main strengths for the Net-Zero technologies

									Total
Established existing manufacturing base	2	1	3	0	3	4	2	2	17
Research & development (R&D) and capacity to innovate	7	2	1	1	1	2	2	1	17
Availability of renewable energy sources	4	1	3	0	0	0	2	1	11
Educational institutions and training programs	4	0	0	1	3	0	2	1	11
Established industry clusters	2	2	1	0	3	1	1	1	11
Access to skilled labour	5	0	1	1	1	0	0	2	10
High demand from public or private clients	3	1	0	0	1	3	1	0	9
Supply chain integration and proximity to suppliers	3	1	0	0	0	0	2	2	8
Technological advancements (automation, AI, IoT)	2	1	1	0	2	1	0	1	8
Access to public funding	3	0	0	2	2	0	0	0	7
Environmental sustainability practices	4	0	0	2	0	1	0	0	7
Access to raw materials	2	0	1	0	0	2	1	0	6
Advanced infrastructure	1	0	1	0	0	2	1	1	6
Cost competitiveness of manufacturers	2	1	1	0	1	0	0	1	6
Current market shares of companies	1	1	1	0	1	1	0	1	6
Access to private capital	1	1	1	0	1	0	0	0	4
Regulatory framework (supporting policies, etc.)	1	0	0	2	0	0	1	0	4

From left to right, columns indicate Solar photovoltaic and solar thermal technologies, Onshore wind and offshore renewable technologies, Battery/storage technologies, Heat pumps and geothermal energy technologies, Electrolysers and fuel cells, Sustainable biogas/biomethane technologies, Carbon Capture and storage (CCS) technologies, Grid technologies.

For each technology and across Member States, the table displays the most cited strengths, These are ranked from the top to the bottom of the first column, across Member States per technology. The established existing manufacturing base is the most cited strength across technologies. The R&D and capacity to innovate also appear as a key strength for the solar industry. Another strength that is common to 5 of the technologies is the availability of renewable energy sources.

These main strengths were listed by 14 respondents for solar photovoltaic and solar thermal technologies, meanwhile, this number amounted to 5 for onshore wind and offshore renewable technologies, 7 for battery/storage technologies, 5 for heat pumps and geothermal technologies, 7 for electrolysers and fuel cells, 5 for sustainable biogas and geothermal technologies, 5 for Carbon capture and storage technologies, and 3 for grid technologies.

SWOT Reflections

The contributions from survey respondents to the SWOTs can be found in the separate Annex V.1 ‘Survey contributions to the SWOTs’. Respondents indicated if they strongly agreed, agreed, partially agreed or disagreed with the findings included in the SWOTs. We then used a scoring system to assign each finding a score based on survey responses (3 points for ‘strongly agree’, 2 points for ‘agree’, 1 for ‘partially agree’, -1 for ‘don’t agree’, 0 for ‘N/A’). This score helped identify the most relevant findings and refine the SWOTs. Additional feedback on the SWOTs was collected and integrated into the final SWOTs. Inputs were also integrated into Task 4 as reflected in the roundtable summary annexes (See Annex VI).

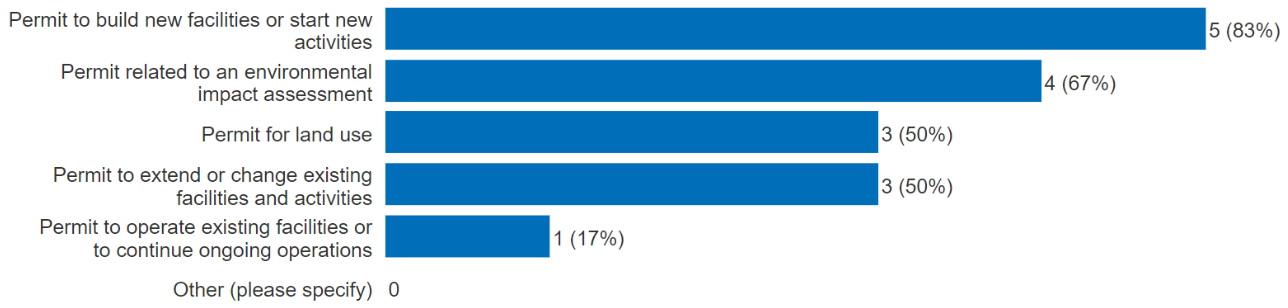
For the full SWOT findings, please refer to Annex V which presents the final SWOTs enriched with survey inputs.

Permitting in the EU and primary barriers for company expansion

The survey included a section dedicated to barriers to project expansion. It included questions where respondents (in this section, companies) were asked to select barriers, which included permitting processes. A full section was dedicated to permitting. Respondents were invited to provide information on permitting duration and factors contributing to lengthy procedures.

Some insights regarding the permitting procedures across the EU were shared by 17 company representatives, among whom 6 companies who applied to a permit in the last 5 years. In order to operate, these companies need the permits indicated in the figure below.

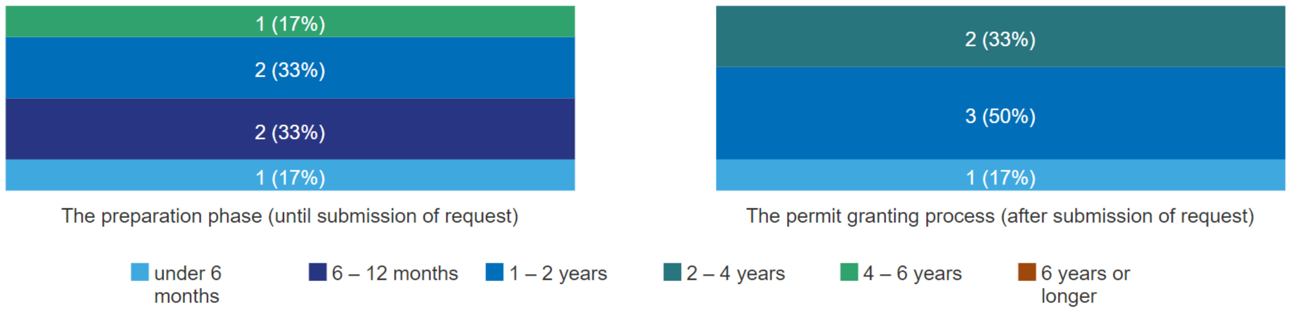
Figure A 1 Types of permits indicated by companies as necessary to operate



N 6

Regarding the length of permitting processes, a majority of stakeholders indicated that the preparation phase takes between 6 months and 2 years, while the permit granting process takes between 1 and 2 years among these respondents.

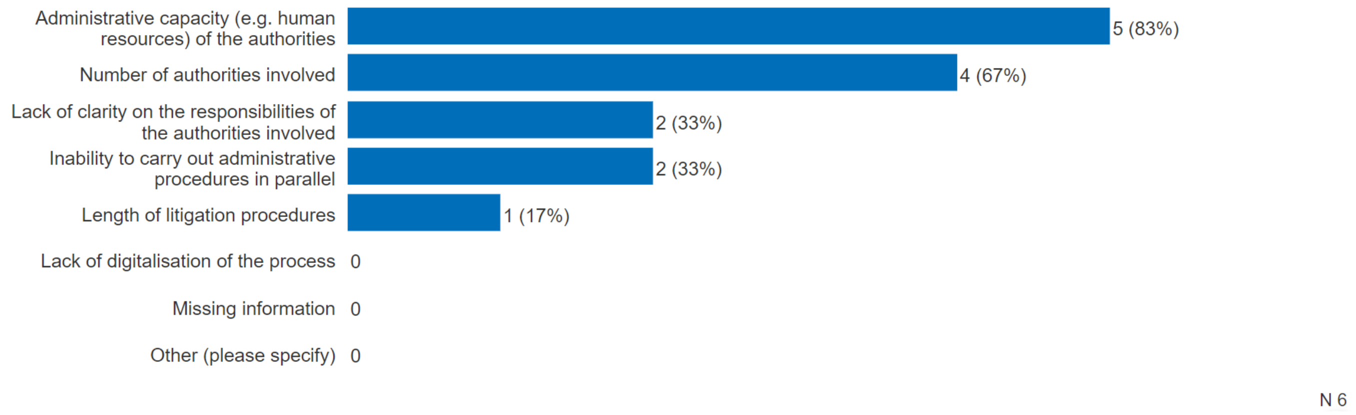
Figure A 2 Estimated durations of the preparation and the permit granting process



N 6

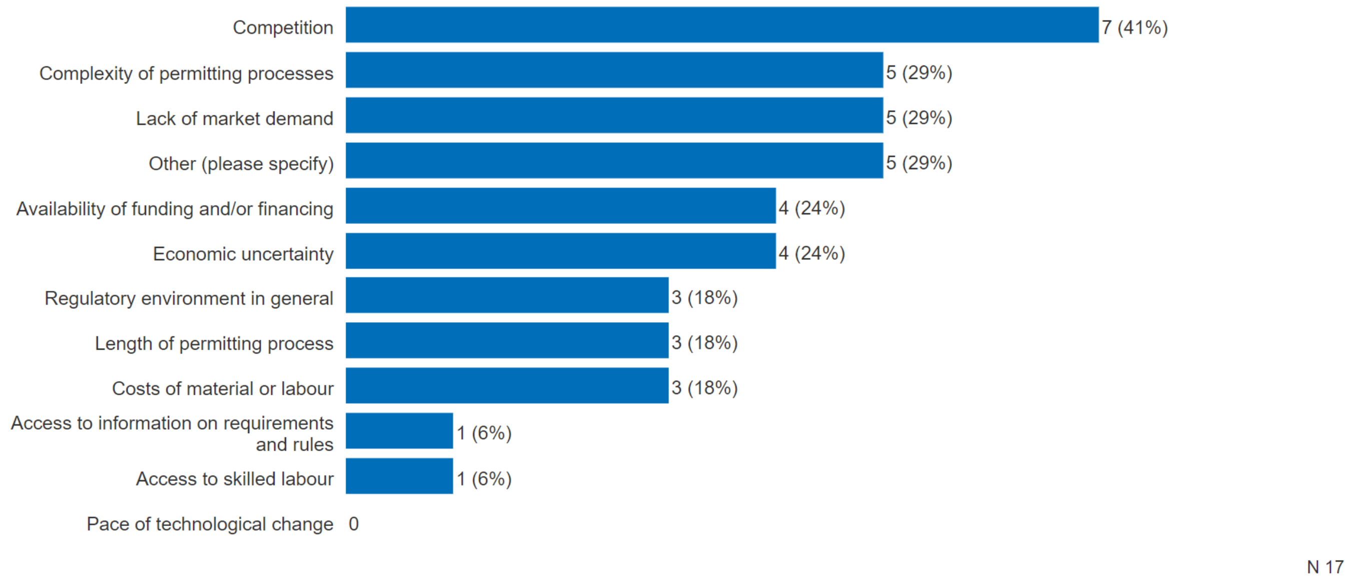
Several factors were cited among respondents as the main contributors to the lengthy administrative procedures. The administrative capacity of authorities and the number of authorities involved were mostly cited as shown in the figure below.

Figure A 3 Factors cited by respondents as contributing to the length of the administrative procedure



Among company representatives who provided inputs in the survey, 17 indicated the three most important barriers faced in the expansion projects for their facilities. The most cited barriers were competition, the lack of market demand and the complexity of permitting procedures. The complete list of the most barriers is presented below in Figure A 4.

Figure A 4 Main barriers to expansion projects at manufacturing companies' facilities across Net-Zero technologies



Additional barriers were cited by company representatives. Stakeholders notably mentioned competition with China and unfair or unclear practices. They also noted the lack of clear requirements to access the EU market and a different interpretation of the same rules within or outside of the EU. Lastly, the high cost of early deployment was cited, although as scaling occurs the cost will follow a downward curve.

Other findings

Several support mechanisms dedicated to Net-Zero technologies were also shared by respondents. Stakeholders cited examples of regulatory measures, incentive schemes, taxation measures, and skill and education policies that are detailed below in Table A 8.

Table A 8 Additional examples of support mechanisms on manufacturing of Net-Zero technologies provided by stakeholders

Regulatory measures (e.**g.** for permitting process, regulatory sandboxes, etc.)	**Incentive schemes**	**Taxation measures**	**Skills and education policies**	**Additional good practices**
• Climate Agreement (Klimaatakkoord) and Carbon Pricing Mechanisms	• Residential https://www.rews.org.mt/#/en/home - • Commercial https://maltaenterprise.com/support • EU incentives substantially more complex to apply for than DOE supports in the US • DEI+ (Demonstration Energy and Climate Innovation) • HER (Hernieuwbare Energietransitie) and WBSO (Research and Development Tax Credit) • SDE++ (Stimulation of Sustainable Energy Production and Climate Transition) • Inflation Reduction Act • Production Linked Incentive (PLI) • UK Heat Pump Investment Accelerator Competition https://www.gov.uk/government/publications/heat-pump-investment-accelerator-competition	• Energy Investment Allowance (EIA)	• TKIs (Top Consortia for Knowledge and Innovation) • GreenSkillsforH2	• In France, the “France 2030” program designed to develop industrial competitiveness and the technologies of the future, half of which for emerging players, and half for decarbonization initiatives. • Only one project was carried out unfortunately https://www.interregeurope.eu/good-practices/solar-photovoltaic-communal-farm-scheme Residential only - https://www.interregeurope.eu/good-practices/heat-pump-water-heaters-grant https://www.interregeurope.eu/good-practices/positive-energy-zero-carbon-dioxide-primary-school • The U.S. Regional Direct Air Capture Hubs Program in the US - administered by the Department of Energy. This is a $3.5bn fund requiring collaboration and consortiums to establish regional hubs.

Regarding inputs on policy recommendations, we gathered responses from 18 stakeholders in four policy areas: regulatory environment, incentive schemes, taxation measures, and skills and education. Some stakeholders provided other inputs that did not fit into these categories. Such policy recommendations have been integrated into the long list of policy options which can be found in Annex VII.

Regarding the capacity data for manufacturing companies, some data on the estimated annual manufacturing capacity was provided by 16 companies out of 37 company respondents. These were provided as detailed below:

- 6 respondents, with activities in Croatia, Austria, Luxembourg, Belgium and Italy for solar photovoltaic and solar thermal technologies,
- 3 respondents, with activities in the Netherlands and Bulgaria for battery/storage technologies,
- 3 respondents, with activities in the Netherlands, Belgium and Bulgaria for electrolysers and fuel cells,
- 4 respondents, with activities in the Netherlands, Italy, Germany, Poland and Sweden for sustainable biogas/biomethane technologies,
- 3 respondents, with activities in Italy, France and the Netherlands for CCS technologies,
- 1 respondent, with activities in France, for grid technologies.

Overall, it should be noted that the findings on policies, SWOTs, and manufacturing capacities collected throughout the survey have been integrated in their respective tasks.

Annex V: SWOT Assessments

Below we present the SWOT assessment of the Net-Zero technologies in the scope of this research. The assessments are based on the JRC CETO reports and were enriched from interviews, the survey and desk research. The number of survey responses differ between technology. The detailed methodology for SWOT Assessments is present under Annex X in the section 'Task 3 Methodology'.

SWOT Overview Solar photovoltaic technologies

Solar PV technologies

Strength

Finding	Topic	Score
Strong R&I activities regarding new materials (e.g., perovskites) and applications.	*Investment*	13
The low carbon footprint for EU-sourced and produced PV modules.	*Sustainability*	13
The EU has advanced manufacturing techniques.	*Skills*	7
Strong EU position and manufacturing capacity in inverters with a lot of it going to exports.	*Market Position*	7

Weaknesses

Finding	Topic	Score
Negative trade balance for the EU, particularly with China which can produce cheaper solar panels.	*Imports*	29
The limited support schemes for manufacturing do not follow the global market growth.	*Investment*	26
Energy and labour costs in the EU are significantly higher than for trading partners.	*Costs*	25
The EU has decreased its share in global inventions.	*Innovation*	23
Limited acceptance of low-profit margins in value chain parts of PV manufacturing.	*Costs*	21
Financing is a major issue in building PV manufacturing plants along the value chain.	*Investment*	18
Planning procedures and permitting are too long which increases costs.	*Administrative*	17

Opportunities

Finding	Topic	Score
PV is becoming one of the most important energy technologies which could lead to additional momentum and political support that could revitalise European industries.	*Policy*	24
Creation of green jobs in both the manufacturing and the deployment sectors. Out of 800,000 workers in the solar sector, manufacturing employs less than 15,000 and less than 40,000 are in inverters.	*Labour*	21
High automation in manufacturing will decrease labour costs.	*Costs, Labour*	20
The EU has several world-leading R&D clusters for silicon PV and thin film technologies.	*Research*	15
PV manufacturing in the EU could be competitive under the double condition that: i) it is done in very large gigawatt-scale factories, and ii) these factories are fully integrated across all stages of the value chain (ingot, wafer, cell, and module).	*Production*	14

Threats

Finding	Topic	Score
The overconcentration of supply from China poses a risk to supply security and resilience.	*Imports, Supply*	28
More direct and targeted support schemes for manufacturing are being applied in the US (IRA) and India (PLI).	*Competition, Investment*	24
Manufacturing overcapacity and oversupply of modules in Europe through imports and EU stocks.	*Supply*	24
The supply of critical raw materials used in current module designs may be a limitation, particularly for ingots and wafers.	*Material resources*	21

Note: The score is based on 11 survey responses.

SWOT Overview Solar thermal technologies

Solar thermal technologies

	Finding	Topic	Score	Finding	Topic	Score	
Strength	Covered by EU Ecodesign and Energy Label requirements for space and water heating.	*Sustainability*	3	Cost competitiveness is strongly dependent on the price of fossil fuels.	*Costs*	3	Weaknesses
	Well-established, mature technology with EU manufacturers leading in the main applications and collector types (except evacuated tubes).	*Technology*	2	Often not a standalone solution and requires integration with other heat or cool sources to meet demand at certain times.	*Supply*	2	
	No use of CRMs and good circularity potential (high recycling rates).	*Sustainability*	2	Low market demand, which is growing but slowly	*Demand*	N/A	
	Strong EU manufacturing base that has been constantly growing and which has a positive trade balance.	*Production*	1	Low and decreasing investment in R&D at the EU level	*Innovation*	N/A	
	Finding	**Topic**	**Score**	**Finding**	**Topic**	**Score**	
Opportunities	EU policy targets to decarbonise the heating (and cooling) sector could increase demand.	*Policy, Sustainability*	3	Competition from alternative technologies such as lower-cost PV and heat pump systems.	*Competition, Costs*	3	Threats
	Potential to supply the high temperatures required by many industrial processes.	*Supply*	2	Several EU companies are traditional leaders in this technology but now face stiff competition from China	*Competition*	3	
	CSP technology has made big steps forward in cost reduction and reliability	*Costs, Innovation*	1	Competition from imported solar heating and cooling systems that have lower costs.	*Imports*	-1	
	Potential for large-scale deployment in buildings and integration with heat pumps for renewable heat solution	*Synergies*	N/A				

Note: The score is based on 1 survey response. N/A score means that the finding was added after the survey.

SWOT Overview Onshore and offshore wind technologies

Onshore and offshore wind technologies

Strength: Finding	Topic	Score	Weaknesses: Finding	Topic	Score
Strong presence in the EU with 31% of global manufacturing facilities.	*Market position*	8	Slow permitting process for new installations, however, this is gradually improving due to good EU rules and tools.	*Administrative*	8
EU is a global leader in wind technological development.	*Technology*	8	Stronger emphasis is needed on Marine Spatial Planning (MSP) and coexistence among sectors.	*Policy, Cooperation*	7
Leading in floating offshore wind development with first pre-commercial wind farms in EU waters, however strong competition with South Korea, Japan, the USA and China.	*Market position*	7	Stronger emphasis is needed on circularity by design, environmental impact and human capital agenda.	*Sustainability*	6
Strong EU manufacturing supply chain.	*Production*	7	Varying financing conditions and costs among Member States.	*Costs*	5
Onshore and offshore wind reached commercial readiness with EU players at the forefront of R&I.	*Investment*	6	Potential bottlenecks and supply risks for critical raw materials (Rare Earth Elements) and processed materials (e.g. NdFeB magnets, balsa wood, steel).	*Materials*	4
Cost competitiveness in both onshore and bottom-fixed offshore wind, however strong cost competition from China.	*Competition*	6			
EU companies hold a very strong market share in the EU and a good market share globally, contributing to a positive trade balance	*Trade*	6			

Opportunities: Finding	Topic	Score	Threats: Finding	Topic	Score
Annual deployment rates need to increase significantly to reach ambitious 2030 targets. WindEurope is expecting Europe to install 116 GW of new wind farms over the period 2022-2026.	*Investment*	8	Rare earth elements used in the permanent magnets of the turbine generators are identified as critical raw materials and show a high supply risk as EU sourcing relies almost entirely on a single country.	*Material resources*	7
Offshore wind R&I priorities should focus on system integration, efficient transmission & interconnection, and O&M.	*Investment*	8	Increased Levelized Cost of Electricity (commodity price inflation, increased transportation costs, supply chain risk).	*Costs*	7
Investment in offshore manufacturing capabilities, EU ports and new vessels.	*Investment*	8	Trade barriers have the potential to distort trade and cause unintended effects on investment across value chains, hindering the competitiveness of EU companies.	*Competition, Investment*	7
Floating offshore wind enables MSs with steeper shorelines to harvest offshore wind and exploit existing potentials.	*Geographic*	7	To deliver the 2030 targets, the industry needs to recruit and train an additional 200,000 workers.	*Labour*	6
Increased recycling and circularity approaches could help optimise manufacturing processes.	*Innovation, Production*	6	Supply chain bottlenecks might emerge in the EU if production needs to be ramped up in the short term.	*Supply*	6

Note: The score is based on 3 survey responses.

SWOT Overview Ocean Energy

Ocean Energy

Strength

Finding	Topic	Score
Multiple European companies have project experience and knowledge.	*Skills*	3
EU is in a good position in terms of publications, patents, private and public R&I.	*Research*	3
Reduced visual impact, leading to increased public acceptance.	*Demand*	2
Tidal energy is a predictable source of energy, while wave energy can produce energy even under the mildest conditions.	*Production*	2
A large number of projects are in the pipeline.	*Investment*	1

Weaknesses

Finding	Topic	Score
Due to the immaturity of the sector, there are still high initial costs (CAPEX) which are expected to decrease as deployments increase.	*Investment, Costs*	3
Limited data on the length of a lifetime leads to conservative assumptions of the lifetime for the calculations of cost.	*Research*	2
Geographically limiting factors, especially for tidal energy where most of the developed devices require strong tidal currents in order to operate.	*Geographic*	2
Maintenance can be costly/ difficult, leading to higher operational costs (OPEX).	*Investment, Costs*	1

Opportunities

Finding	Topic	Score
EU companies are leading the field so there are substantial export opportunities for both technology and knowledge.	*Skills, Market position*	3
Due to their capabilities both for energy production and also for alternative uses (desalination, aquaculture etc.), they have the potential to drive a blue economy.	*Sustainability*	2
Under favourable regulatory and economic conditions, ocean energy could contribute to around 10% of the EU's electricity demand by 2050.	*Supply*	2
Co-development of ocean energy sources with other renewable sources of energy or other activities in common platforms.	*Cooperation*	1

Threats

Finding	Topic	Score
The number of commercial projects in the pipeline has increased but more is needed to achieve ambitious targets.	*Investment*	3
Ocean energy technologies are more costly compared to other marine renewables.	*Investment*	3
Administrative barriers. Due to not well-defined procedures and environmental impacts, licensing procedures are often long and complicated.	*Administrative*	2

Note: The score is based on 1 survey response.

SWOT Overview Batteries and storage technologies

Batteries and storage technologies							
	Finding	Topic	Score	Finding	Topic	Score	
Strength	Well-educated workforce for research and technological leadership.	*Skills, Research*	14	Battery packs produced in the EU are more expensive than the similar size packs produced in China (and the USA), however, price differences between Europe and China have been decreasing from 60% in 2021, to 33% in 2022, and 20% in 2023.	*Costs, Competition*	16	Weaknesses
	Strong EU demand for batteries, accounting for almost a quarter of the entire global demand (20-25%) driven by European electric vehicle manufacturers which account for around 90% of the battery market.	*Demand*	13	High energy prices and labour costs.	*Costs*	15	
	Strong EU support for R&D (i.e. EUR 925 million through the BATT4EU Partnership) and deployment.	*Funding*	13	Complex EU legislation and bureaucracy make investment approval process lengthy.	*Administrative*	15	
	The two IPCEI on batteries are promoting battery production.	*Funding*	12	EU-head-quartered companies do not have extensive experience in the mass production of Li-ion batteries and battery cell production equipment is mainly imported from Asia.	*Skills*	14	
	General awareness of the need to mitigate climate change and for high environmental standards.	*Demand, Sustainability*	12	Regulations and standards are not developed enough and lack harmonisation in objectives (electrification, digitalisation, decarbonisation and environmental objectives)	*Policy*	14	
	New CO_2 emission standards and the mandatory phase-out of the internal combustion engine (ICE) in the EU ensure a sustained source of demand for batteries, however, recent political changes have increased attention again for e-fuels and put in question the ICE phase-out.	*Demand, Sustainability*	6	Shortage of workers specialised in battery manufacturing. Estimates differ, but expected are 150,000 to 250,000 jobs in battery cell production.	*Labour*	10	

Batteries and storage technologies

Opportunities: Finding	Topic	Score	Threats: Finding	Topic	Score
Both global installed energy storage capacity and annual battery demand are expected to increase four- to six-fold from 2023 to 2030 according to the IEA's scenarios.	*Demand*	**15**	Critical raw materials account for 50-70% of battery costs. Future prices are sensitive to CRM prices and cannot be reliably predicted due to the high volatility of prices.	*Costs, Materials*	**18**
Synergies with other value chains, e.g. hydrogen or other forms of energy storage such as pumped-storage hydropower.	*Cooperation*	**14**	The EU battery industry is highly dependent on third countries for sourcing of raw materials such as lithium, graphite, cobalt and nickel and the EU has no lithium refining capacity. In addition, this supply is often concentrated in countries/regions with high geopolitical risks.	*Supply, Materials*	**18**
Enabler for a wide deployment of Renewable Energy Sources and electrification of mobility.	*Cooperation*	**13**	Customers might be unwilling to pay higher prices for EU-produced batteries (even if technically better).	*Competition, Costs*	**16**
New battery technologies are emerging, such as sodium-ion (NA-ion) and redox-flow (RFB), which do not require critical raw materials, are safer, and potentially cheaper. The JRC expects their role to increase significantly. However, China and other third countries have been faster and work at a higher scale.	*Innovation, Materials, Costs*	**12**	Risks from toxic materials in battery production, use, and recycling if not properly managed, while simultaneously overly strict restrictions or bans could constrain the industry.	*Sustainability*	**14**
Development of local value chains with reduced geopolitical risks for more sustainable and cheaper (RFB, Na-ion, Znbased) or more performant (silicon or metal Li anode, solid state, Li-S, etc.) battery solutions.	*Production*	**11**	The emergence of third countries dominant in cheap, less performant battery technologies (flow batteries, Na-ion technology) while the EU's limits itself to high-performance batteries used in EVs, ignoring batteries that are of high importance for stationary storage.	*Competition, Costs*	**12**
Shape and contribute to the development of missing international regulations and standards on batteries.	*Policy*	**10**	Strong international competition for attracting the value chain. Subsidies and politically based decisions in third countries pose a risk to EU competitiveness.	*Competition, Investments*	**11**
Life-cycle carbon footprint requirements as provided in the Battery Regulation and generally more information and transparency on supply chains and environmental and social aspects could benefit European producers.	*Policy*	**N/A**			

Note: The score is based on 7 survey responses. N/A score means that the finding was added after the survey.

SWOT Overview Heat pumps and geothermal technologies

Heat pumps and geothermal technologies

Strength: Finding	Topic	Score	Weaknesses: Finding	Topic	Score
No specific supply risk, a high degree of component commonality with other products, and lifetimes of around 17 years.	*Supply*	10	Barriers to deployment for multi-family houses such as apartment buildings as the majority of owners need to agree to renovations.	*Investment, Demand*	10
Very mature technology, no breakthroughs needed in the short term; high activity in incremental innovation, e.g., cost, efficiency, size, noise, refrigerants.	*Innovation*	10	General shortage of labour in the EU for manufacturing (gas boiler phaseout might help somewhat).	*Labour*	9
High market share of EU manufacturers (73%) although imports from China are growing.	*Market position*	9	Beyond manufacturing, a shortage of specialised profiles needed for installation and maintenance (e.g. plumbers, electricians, engineers, architects).	*Skills, Labour*	8
Relatively common raw materials; few heat pump-specific components; relatively straightforward assembly. Like other EU manufacturing sectors in terms of energy and resource consumption, processes, labour costs, etc	*Material resources, Production, Costs*	8	In the short-term customers in several countries are experiencing delays.	*Supply*	6
Strong investment pipeline to 2026 (~ EUR 7 billion) on track to deliver projected sales in the medium term (i.e. 2030).	*Innovation*	8			
The expansion of manufacturing capacities is quick for heat pumps compared to other technologies.	*Production*	7			
Rapid sales growth (+33% in 2023, +38% in 2022, +34% in 2021) sustaining high revenues although 2023 constitutes a first drop in sales for air-source heat pumps after years of continuous increase which creates uncertainty.	*Sales*	6			
Manufacturing sites in several Member States; a mix of EU ownership/headquarters (e.g. Viessmann, Bosch) and some local subsidiaries (e.g. Daikin).	*Production*	6			
High local content in the sector: renovation and construction workforce are highly local.	*Labour*	6			

Heat pumps and geothermal technologies

Opportunities – Finding	Topic	Score	Threats – Finding	Topic	Score
A strong technological lead of EU companies. The EU is particularly strong in geothermal and large heat pumps, for which the development of district heating represents an opportunity.	*Skills, Market position*	11	Longer term, the research activity of China and other third countries and regions the in terms of patenting and publications could threaten the technological leadership of the EU.	*Research, Innovation, Competition*	9
The benefits of heat pumps will be amplified as the decarbonisation of the power sector will decrease emissions.	*Sustainability*	11	An increasing share of extra-EU imports is a threat for EU manufacturing. Imports from China have been rising for the past two years but from a low base and in the context of very rapid deployment overall. EU manufacturing capacity is adjusting, and extra-EU manufacturers may create subsidiaries in the EU, if they have not already, threatening current leaders.	*Imports, Market position*	8
Early integration with smart grids would increase interoperability and benefits for users.	*Technology*	10	Volatile or increasing electricity prices affect operational costs and the gas-to-electricity ratio, which can therefore impact demand.	*Demand, costs*	6
Exploiting synergies across heating and cooling systems in the building sector can provide a framework for reaching decarbonisation objectives, with high-efficiency heat pumps a significant source of change.	*Cooperation*	10	Extra-EU manufacturers may create subsidiaries in the EU, if they have not already, threatening current leaders.	*Imports, Market position*	5
Experience of EU manufacturers with refrigerants alternative to F-gases. The phaseout of such refrigerants may represent an opportunity for the EU heat pump value chain overall in the medium term. Under the Montreal Protocol, all countries have binding obligations to reduce HFCs that are used in heat pumps. Heat pumps avoiding these substances will also find markets outside the EU.	*Production, Skills*	9			
Automation or improvements in manufacturing can lead to cost reduction due to the straightforward assembly.	*Innovation, Costs*	8			
While entry of heat pump manufacturers from outside the EU could be a threat, acquisitions or creation of subsidiaries new entrants could also bring capital investment, innovation and economies of scale.	*Investment, Innovation*	5			

Note: The score is based on 5 survey responses.

SWOT Overview Electrolysers and fuel cells

Electrolysers and fuel cells

	Finding	Topic	Score	Finding	Topic	Score	
Strength	The development of the financing scheme via the Hydrogen Bank (financing facility) to guarantee the purchase of produced hydrogen between the producers and the offtakers.	*Investment*	17	The lack of fully mature markets for clean hydrogen is a barrier to the uptake of electrolyser and fuel cell manufacturing as the market is still at an early stage and demand is missing.	*Demand*	19	Weaknesses
	Important public finance pipeline for hydrogen projects (IPCEIs, Innovation Fund, Recovery and Resilience Plan, etc.) incentivising electrolyser production.	*Investment*	15	Lack of harmonisation and standardisation when it comes to manufacturing of components and the supply chain, incl. a harmonised European testing method to demonstrate that European systems are performance-based.	*Standardisation*	18	
	European companies have a strong presence as international patent holders.	*Innovation*	15	Hydrogen value chains are strongly dependent on investments in infrastructure and renewable electricity generation.	*Infra-structure*	17	
	Strong momentum in the European and Global markets. Ambitious targets at the EU level.	*Demand*	14	At the current scale, European manufacturing costs for the electrolyser systems are high compared to those in China. Contributing factors are labour and energy costs, access to critical materials, and environmental requirements.	*Costs*	16	
	Europe is the most advanced technologically with a good presence in the PEM electrolysers market and is leading the development of Solid Oxide electrolysers.	*Innovation*	14	Lack of standardisation hampers harmonisation and integration of European technologies globally weakening the influence of European industry in shaping international regulation.	*Standardisation*	16	
	Strong European regulatory framework with the Net Zero Industry Act identifying water electrolysis, and fuel cell technology as strategic ones. They would enjoy faster permitting and access to funding.	*Policy*	14	Emerging challenges for Research and Innovation, such as those related to the replacement or substitution of materials in the membranes of electrolysers, some of which contain the PFAS.	*Research*	16	
	A significant number of European manufacturers of Electrolysers and manufacturing capacity can be called up relatively fast.	*Production*	12	Lack of long-term, large-scale operational experience (e.g., on performance degradation, scale effects, optimization strategies for balance-of-plants components and on-site infrastructure, etc.)	*Production*	12	

Electrolysers and fuel cells

Opportunities: Finding	Topic	Score	Threats: Finding	Topic	Score
There is a strong interest in developing the scale of the European electrolysers manufacturing and deployment industries.	*Policy*	17	The USA and China maintain or accelerate their public financing efforts in advancing the deployment of low-carbon and renewable hydrogen production capacities as well as manufacturing capacities of hydrogen technologies.	*Competition, Policy*	19
Research and Innovation initiatives are pursuing opportunities to substitute PFAS, and CRMs and define recycling solutions.	*Innovation*	15	Lack of official international codes and monitoring exercises for hydrogen and hydrogen technologies able to capture the technological complexity of the current markets.	*Standardisation*	18
General momentum with the manufacturing industry announcing the establishment of gigawatt factories in Europe.	*Policy*	14	Strong international competition combined with subsidies and laxer regulations abroad can lead to further price competition.	*Costs, Competition*	17
The implementation of the Important Projects of Common European Interest (IPCEI) for hydrogen paves the way for creating economies of scale and manufacturing capacities in Europe, however, deployment of financing and project implementation is slow.	*Investment*	13	Strong EU dependence on concentrated supplies of critical raw materials and components necessary for the development of electrolysers manufacturing at scale. This is partly addressed through the proposal on the Critical Raw Materials Act.	*Materials*	16
The increase in the cost of natural gas provides an opportunity for renewable hydrogen to achieve more easily cost competitiveness against fossil-based hydrogen. On the other hand, the spikes in prices of electricity in European markets have shown this as a hurdle to competitiveness, and additional renewable energy sources are needed to enable this opportunity	*Costs*	13	The certification schemes at the international level will have to be put in place, requiring an agreement or consensus with regard to the criteria applied to the imported hydrogen, so as to avoid "greenwashing" or inappropriate treatment of imported hydrogen.	*Policy*	16
Completion of the EU regulatory framework for renewable and low-carbon hydrogen and gasses (e.g. Delegated Regulation on Additionality), including sub-targets for use in industry and transport can both induce demand and also establish Europe as a leader in sustainable hydrogen.	*Policy*	11	Rising costs of electricity in the context of European economies have an impact on the cost competitiveness of electrolyser technology and on the levelized cost of hydrogen.	*Costs*	14
Potential in the longer term following more widespread deployment to enable reuse of materials and reduce dependencies by developing a recycling infrastructure.	*Materials*	10			

Note: The score is based on 8 survey responses.

SWOT Overview Sustainable biogas/biomethane technologies

	Sustainable biogas/biomethane technologies						
	Finding	Topic	Score	Finding	Topic	Score	
Strength	Anaerobic digestion technologies are available and demonstrated from small to large-scale	*Technology*	17	Permitting takes too long which is impacting the speed of deploying new biogas plants	*Permits*	16	Weaknesses
	Biofuels can use existing fuel infrastructure and can be blended with fossil fuels, or used as drop-in fuels without modifications to engines	*Infrastructure, Readiness*	17	High capital cost and operation costs also compared to natural gas	*Costs*	11	
	Several biogas upgrading technologies to biomethane available developed by EU companies	*Technology*	16	Economic viability depends mostly on investment cost but also on the availability of low-cost feedstock	*Costs*	11	
	Can be produced from a wide range of sustainable feedstocks like waste and residue (available in substantial amounts in some areas)	*Sustainability*	16	Additional CAPEX for grid injection	*Costs*	11	
	Many manufacturers of biogas and biomethane plants exist in the EU	*Production*	15	Grid injection is not always possible, as biogas and biomethane plants are built in areas where feedstock is available	*Geographic*	8	
	Strong EU position in the global biogas and biomethane market	*Market position*	14	Biogas and biomethane facilities are often at small to medium scale, due to the availability of feedstock, leading to high costs of biomethane and preventing benefits from scale effects	*Costs, Efficiency*	7	
	Biomethane can replace natural gas in the short term in hard-to-electrify industries, such as chemical, steel and transport	*Technology*	13	Small-scale facilities, but complex logistics for collection, transport and storage	*Production*	5	
	EU technology providers have a strong market position with some competition from North America	*Market position, Competition*	12				

Sustainable biogas/biomethane technologies

	Finding	Topic	Score	Finding	Topic	Score	
Opportunities	Biomethane can replace natural gas in existing infrastructure to be used in many sectors (industry, transport, etc.)	*Technology*	18	Low public acceptance, and public perception (due to the smell of biogas plants, additional traffic, etc.)	*Demand*	13	Threats
	CO_2 captured can be used in several sectors such as in the food and beverage industry, as a feedstock in the chemical industry or for power-to-X to produce synthetic methane	*Technology*	16	High market volatility, lack of long-term predictability of natural gas prices	*Production*	10	
	Anaerobic digestion can support the circular economy targets to increase the separation of organic waste. It is an opportunity to treat this waste well and reduce GHG emissions.	*Sustainability*	16	Limited availability of waste feedstock also due to sustainability constraints and competition with alternative uses of feedstock	*Material resources, Sustainability, Competition*	9	
	The REPowerEU targets for energy supply diversification and energy security represent a good opportunity for the development of the sector	*Policy*	15	Lack of viable business case without incentives for biogas production leading to slow market uptake and lack of competitivity with fossil energy	*Market, Demand, Competition*	9	
	Digestate is a co-product that can be used or sold as low-GHG emissions fertilizer	*Technology*	14	High investment costs related mostly to the manufacturing of the biogas production plant and upgrading section	*Costs, Investment*	8	
	Driver of agriculture and industrial development in rural areas and diversification of the rural & circular economy	*Innovation*	14				
	Strong synergies with other sectors such as the chemical industry and Carbon Capture, Storage and Utilisation	*Cooperation*	12				
	A wide range of feedstocks and organic wastes are available	*Material resources*	10				

Note: The score is based on 6 survey responses.

SWOT Overview Carbon capture and storage technologies

Carbon capture and storage technologies

Strength | **Weaknesses**

Finding	Topic	Score	Finding	Topic	Score
Broad application and link to other clean energy technologies	*Technology*	8	Long lead times for CCS projects, low actual investments in the value chain up to today	*Investment*	9
Growing political and public support	*Demand*	8	Environmental concerns	*Sustainability*	7
Strong pipeline of projects to be developed in Europe by 2030	*Investment*	8	Lack of developed storage sites and limited track record blocks investment across the whole value chain	*Investment*	6
Leading position of the EU in CCS in industry and CO2 capture technologies	*Market position*	6	Perceived risks and lack of investor confidence	*Investment*	6
Significant share (24%) of key players are European or are active in the field through their European subsidiaries	*Market position*	5	Relatively expensive and costs of components are highly variable	*Costs*	5
			Strong opportunity costs for aging gas fields	*Costs*	4

Opportunities | **Threats**

Finding	Topic	Score	Finding	Topic	Score
Rapidly growing sector in the near future	*Production*	8	Lack of EU CO2 storage and transport infrastructure leading to coordination problems with capturing projects, risking underdevelopment of the EU value chain	*Cooperation, Supply*	8
Accelerate project development through international collaboration	*Cooperation*	8	Risk of reduced access of EU industry to CCS as an abatement option, which for some sectors is still the only deep decarbonisation option	*Sustainability*	7
Strong EU Research and Innovation landscape	*Research, Innovation*	7	Government regulations lack long term approach for technology and lead to lack of investment	*Policy, Investment*	7
CCS projects profitable with forecasted carbon prices, allows hard-to-abate industries to decarbonise	*Sustainability*	7	Further cost reductions are crucial for mass adoption	*Costs*	6
New revenue streams for oil and gas companies in transition	*Technology*	7	Lack of public acceptance or national legal barriers as barrier to deployment	*Policy, Demand*	5
More affordable and reliable renewable energy	*Sustainability*	7	Potential disruptions in the supply chain due to economic/geopolitical circumstances	*Supply*	4
Mathematical modelling can help decision-making	*Technology*	6			

Note: The score is based on 5 survey responses.

SWOT Overview Grid technologies

Grid technologies							
	Finding	**Topic**	**Score**	**Finding**	**Topic**	**Score**	
Strength	Europe companies currently hold a leadership market position in the production of HVDC cables and a relevant market share in HVDC converters manufacturing.	*Competition*	6	The transformation of the power system relies both on increased cross-border cooperation and stronger adaptation to local needs. This will entail a shift in the tasks of Transmission System Operators (TSOs) and requires good cooperation and strong commitments to provide planning certainty to grid manufacturers.	*Cooperation, Acceptance*	7	Weaknesses
	High-Voltage Direct-Current (HVDC) systems are already a mature and well-established technology.	*Technology*	5	Lack of qualified workforce, notably qualified electrical engineers, electrical installers and project managers to install and deploy the grid components.	*Labour*	6	
	The market for smart meters is highly competitive, still, European companies play a significant role in the market with numerous companies present in the overall global picture.	*Competition*	3	Regarding the supply chain of HVDC systems, the only relevant concern is associated with high-power semiconductors (a key component of converter valves), whose production is concentrated in Taiwan.	*Material resources*	2	
	The smart electricity meter technology is mature and continuously evolves to reduce costs and increase functionalities.	*Technology*	2	Lack of standardisation and interoperability both for grid technologies and smart meters led the former to the need to re-engineer instead of following standardised requirements.	*Policy*	1	
	The EU is providing substantial funding to HVDC-related research activities, with 6 funding calls and a total budget of 1300 MEUR in the Horizon Europe program	*Research, Innovation*	2				
	Several EU programmes exist both for innovation (e.g., NER300) and for implementing projects (e.g., TEN-E smart electricity, and gas, grids). The digitalisation of the European energy sector remains high on the EU agenda.	*Innovation*	1				

Grid technologies							
	Finding	**Topic**	**Score**	**Finding**	**Topic**	**Score**	
Opportunities	The increase in electricity demand fostered by the electrification of end-uses and regional availability of considerable potential for renewable energy sources support the development of new electricity transmission projects.	*Demand*	9	Procurement lead times appear to be increasing in the last period, mostly due to increasing worldwide demand and extra-European countries that can place bulk orders at competitive prices and with more relaxed standards.	*Procurement, Competition*	7	Threats
	The positive future outlook of the global HVDC market with an expected Compound Annual Growth Rate (CAGR) over the next 10 years is estimated between 7.1% and 10.6%. Further demand is expected worldwide, especially in Southeast Asia.	*Demand*	5	The recent worldwide interest in grid upgrades could lead to capacity issues in the global value chain with a risk of shortage in the availability of components (HTLS conductors, DLR, transformers etc.) and workforce.	*Capacity*	7	
	HVDC systems are establishing themselves as a fundamental enabling technology for the decarbonisation of the energy system thanks to their increased capacity and lower losses over long distances.	*Demand, Investment*	5	Third country dependencies on material supply, for example, China is the major producer of refined metal used for grids, while Chile and Peru are the major producing countries of copper.	*Materials*	6	
	There are significant opportunities for energy companies both for the production, installation, and use of smart meters, but also for innovations in the context of smart homes and the Internet of Things.	*Production, Innovation*	4	Material prices for aluminium and copper are expected to increase due to increasing demand as the USA, China and other countries are electrifying.	*Material, Costs*	6	
	There will be a strong demand in Europe over the next years as the rollout of smart electricity meters in Europe has been slow and delayed. The mandatory 80% target by 2020 envisioned in the relevant Directive was only half met in 2022 (¬43%). Close to 225 million smart meters for electricity and 51 million for gas will be rolled out in the EU by 2024. This represents a potential investment of EUR 47 billion.	*Demand, Investment*	2	Climate change and extreme weather events can pose risks to transmission infrastructure, increasing capital and O&M costs	*Costs*	4	
				From a patenting perspective, the most active companies in this field are Chinese (State Grid Corporation of China and China Southern Power Grid). European companies such as Alstom (France) and ABB (Sweden-Switzerland) exhibit smaller patenting volumes.	*Innovation*	4	
				The digitalisation of the energy sector relies on a series of technologies and materials where the EU is not the leader (e.g., chip manufacturing).	*Material resources*	3	

Note: The score is based on 4 survey responses.

Annex VI: Summary of the Roundtables

The summaries of the roundtables are submitted in a separate document.

Annex VII: Long list of proposed policies

The long list of identified policies is provided as a separate document.

Annex VIII: Works cited

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Annex IX: Database of national measures and interventions

Submitted as a separate Annex

Annex X: Methodology

Overall Methodology

The project is composed of four key tasks which were carried out over a period of seven months, between March and September 2024:

- Task 1: Mapping strategic Net-Zero manufacturing technologies;
- Task 2: Mapping Net-Zero regulatory frameworks;
- Task 3: Analysis of opportunities, bottlenecks and barriers; and
- Task 4: Recommendations.

Work across the tasks has been closely coordinated to ensure that results are mutually reinforcing and sufficiently integrated. The project team has worked collaboratively, avoiding silos, to deliver coherent outcomes. Three key methodological tools were used to deliver the results, these are desk research; data analysis and mining; and stakeholder consultations. These methodological tools were used horizontally to feed information into all tasks.

Desk research composed of a literature review sourced information from academic resources and grey literature to supplement the data findings of industrial capacity mapping at the EU and national levels in Tasks 1 and 2. Data was collected on industrial production, deployment and trade for each EU MS and value chain component of each Net-Zero technology. Data sources included the Eurostat PRODCOM database, at the 8-digit level as well as additional data sources referenced in the relevant chapters. In addition to data and information collection, the project included wide-ranging stakeholder consultation composed of EU and MS level interviews covering all 27 countries as well as survey and roundtable consultations. The project team has also participated in the DG ENER workshop of July 10, presenting the early findings of this research to EU, MS and industry representatives. The figure below provides an overview of the methodology, activities and research tools.

Figure A 5 Overview of the methodology and research tools

Task 1 Methodology

Summary of data sources and limitations

The findings reported in this chapter build on a combination of data collection and analysis, desk research, and consultations with stakeholders. We have collected data on four fronts; the first is industrial production. To map industrial production in each EU Member State and Net-Zero technology, we collected data from Eurostat's PRODCOM database, which provides detailed product-level information on manufacturing across Europe.[603] This data collection involved a careful selection of 149 relevant products, classified at the 8-digit level according to the PRODCOM classification.[604,605]

Data was also collected on deployment, for both existing and announced projects and facilities (see Table A9 below for an overview of datasets), and on manufacturing capacity. Capacity data was collected at the level of individual companies and then aggregated at the Member State level. Data is drawn from a variety of publicly available sources and is complemented by proprietary databases such as BloombergNEF and S&P Global Commodity Insights. Since information on capacity is business sensitive, the amount of data that is publicly available is limited. Data on capacity is available for solar and wind power; batteries; and electrolysers. For other technologies, we primarily rely on data on industrial production.

603 PRODCOM covers over 4,000 individual products (classified at the 8-digit level) each year. The database provides data from 1995 to 2022. The 8-digit level is the most granular level at which regionally comparable data is available.

604 The list is provided in full in Annex I. We provide one list of components for each technology, accompanied by their 8-digit level PRODCOM codes and 6-digit HS codes; and a product description.

605 For a recent review of the use of PRODCOM to map EU clean technology manufacturing patterns, see Bontadini, F. and Vona, F. 2023. Anatomy of Green Specialisation: Evidence from EU Production Data, 1995–2015. *Environmental and Resources Economics*. Available at the following link.

Table A 9 Overview of deployment databases

Net-Zero technology	Database	Source	Comments
Electrolysers and fuel cells	IEA Hydrogen Production Projects database	International Energy Agency	Covers deployment capacity for EU MS
	Hydrogen production	EU Hydrogen observatory	
Battery and energy storage	Database of the European energy storage technologies and facilities	DG ENER	Only electrochemical storage capacities
Heat pump and geothermal	Renewable capacity statistics 2024	International Renewable Energy Agency (IRENA)	Capacity of installed energy production capacities
	SHARES (energy used by heat pumps used for heating; geothermal energy for electricity and heat generation)	Eurostat	
Sustainable biogas/biomethane Technologies	SHARES	Eurostat	Biogas used for energy and heat production
	Renewable capacity statistics 2024	International Renewable Energy Agency (IRENA)	Capacity of installed energy production capacities
Carbon capture and storage	IEA CCUS Projects Database	International Energy Agency	Covers deployment capacity for EU MS
Solar photovoltaic and solar thermal energy	Global solar energy tracker	Global energy monitor	Contains solar deployment facilities larger than 1MW, but excludes household deployment
	SHARES	Eurostat	
Onshore wind and offshore renewables	Global wind power tracker	Global energy monitor	Contains a full dataset of on and offshore wind facilities larger than 10MW, and other facilities of <10MW

The fourth and final source of data is on international trade, which we collected to map each EU Member State's international position and dependencies. We carried out this analysis for each technology and at the level of individual components. Trade data was sourced from the *Centre* d'Etudes Prospectives et d'Informations Internationales's (CEPII) BACI database, which provides harmonised data on bilateral transactions for all countries in the world at the 6-digit Harmonised System (HS) level.[606]

Our data has limitations. Taken together, data on industrial production and manufacturing capacity can be used to provide a mapping of the manufacturing landscape across EU Member States. However, these two sources are different in nature. Data on production is drawn from a full coverage survey and maintained by Eurostat. Data collected on capacity is currently drawn from a variety of sources, including industry

606 Shifting from the 8- to the 6-digit level entails a small loss of granularity. This is necessary as internationally comparable trade data is only available at the 6-digit level. We matched product codes between the PRODCOM and HS classifications using Eurostat's concordance tables. The matching procedure we followed is described in Box 1 in Section 2.2. We chose BACI because it uses a detailed and consistent reconciliation process to handle discrepancies between importer and exporter-reported data. This process involves reconciling discrepancies in trade values and quantities using a reliable weighting method, which improves the consistency and reliability of the data. BACI provides data on approximately 5,000 products and 200 countries. For more information on the BACI database, see Gaulier, G. and Zignago, S. 2010. BACI: International Trade Database at the Product Level. CEPII WP 2010-23. Available at the following link.

associations and proprietary databases. Moreover, the two data sources use different underlying product classifications and different units of measure.[607]

Production data is classified using PRODCOM's classification, which can be easily matched to the Combined Nomenclature (CN). These classifications were developed for statistical and customs use. By contrast, manufacturing capacity is reported at the level of industrial components, without following a statistical classification. While all industrial components are listed in PRODCOM, these are not necessarily technology-specific. For example, PRODCOM lists and provides data on the production of silicon wafers (listed under PRODCOM code 20595300), which is a key component in the production of solar PV modules. However, silicon wafers can be used for other purposes too. In other words, many industrial components have a dual use. A related issue is that while Eurostat's product classification is granular, it is not always sufficiently granular to identify all components that are likely to become relevant for the Net-Zero Industry Act (NZIA).[608] One example is electrolysers, which are grouped with machinery for electroplating.

These differences mean that while industrial production data is statistically representative, it only provides an imperfect picture of the state of play of each Net-Zero technology due to the issue of dual use. By contrast, data on manufacturing capacity is less representative. When it is available, it provides a more accurate picture at the level of individual technologies. Wherever possible, we compared and benchmarked production data with capacity data to understand the extent to which the former reflects Net-Zero manufacturing rather than broader industrial activities.

Deployment data, in turn, does not necessarily reflect domestic industrial production as Net-Zero projects can be deployed with imported technology and components. Finally, it is important to note that the Net-Zero manufacturing industry is dynamic, experiencing frequent changes as companies evolve or cease operations. Consequently, all information in this chapter reflects the industry status as a snapshot in time.

Listing and product codes for data collection

The list of components was developed based on a number of distinct sources and complemented by experts and stakeholder inputs. The first source for the list of components is the JRC Clean Energy Technology Observatory (CETO) reports. However, as not all CETO reports provide detailed lists, we added the following additional sources: the OECD CLEG list,[609] the US Department of Energy's work on clean supply chains,[610] the 2023 Communications from the United Kingdom to the World Trade Organization (WTO) in the context of the Trade and Environmental Sustainability Structured Discussions (TESSD),[611] and academic and policy work focussed on the identification of product codes that are relevant for the transition to net zero.[612]

Based on these sources, we listed potentially relevant product codes under each of the eight Net-Zero technologies. This selection of components was submitted for validation to our Expert Advisory Group. Based

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607 Industrial production data is available in terms of either monetary value (EUR) or physical volume (Kg); whereas capacity data is available in terms of generation capacity, typically—but not always—expressed in MW/y (and in MWh/y for battery and storage technologies).

608 Stakeholders consulted for this study emphasised, that in the context of the NZIA, it is important to have agreement on a list of components for each technology. Regarding less mature technologies and value chains, such as electrolysis and fuel cells, stakeholders highlighted the need for more harmonised information on the structure of the value chain and its key components. Stakeholders also agreed that there is a need for more granular product codes facilitating clearer identification of technology-specific components.

609 See, for instance, Sauvage, J. 2014. The Stringency of Environmental Regulations and Trade in Environmental Goods. OECD Trade and Environment Working Papers 2014/03. Available at the following link.

610 US Department of Energy. 2022. America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition U.S. Department of Energy Response to Executive Order 14017, "America's Supply Chains". Available at the following link. For solar PV, the US

611 These are available here, with a focus on solar PV, and here, with a focus on offshore wind power.

612 See, for instance, Bontadini, F. and Vona, F. 2023. Anatomy of Green Specialisation: Evidence from EU Production Data, 1995–2015. *Environmental and Resources Economics*. Available at the following link; Vossenaar, R. 2013. The APEC List of Environmental Goods. ICTSD Programme on Trade and Environment. Available at the following link; and World Economic Forum, 2022. Accelerating Decarbonization through Trade in Climate Goods and Services. Available at the following link.

on this first round of review, the lists were then submitted to all stakeholders we interviewed. Through these inputs, and during the course of our research, we modified the lists according to the inputs we received. Since product codes differ across the classifications we used, we matched them using the process described in Box 1 below.

Box 9 Matching product codes across the PRODCOM and HS classifications

Since our starting points are PRODCOM codes, these need to be matched to their equivalent HS codes. To do so, we have used the 2023 concordance table provided by Eurostat. The concordance overlaps for both typologies. This implies that some categories are more detailed in PRODCOM than in CN, and vice versa. To match the relevant product categories, all relevant codes in both types were kept in a master file. Product categories with multiple sub-codes are combined into a new category containing a new product identifier code. The relevant data from PRODCOM is extracted using the selected codes. The values of the combined codes are added, after which the data from both sources is matched using the master file and the new identifiers.

Data analysis

The data analysis focussed on providing a descriptive, quantitative picture of the deployment, manufacturing, and international trade state of play of each EU MS and each Net-Zero technology. In order to identify patterns and derive indicators in the trade data, we then provided an assessment of each Member State's positioning in the value chain, dependence on third countries, and international positioning and competitiveness. We calculated the following key indicators:

- Trade balance;
- Export concentration, calculated as a Herfindahl–Hirschman index (HHI) at the level of individual components;
- Import dependence, calculated as the simple ratio of EU to non-EU imports in a Member State's import basket; and
- Revealed comparative advantage (RCA) indices.

The RCA is an index which we calculated following Balassa's original formulation, which is as follows.

$$RCA_{ji} = \frac{X_{ji} / \sum_{p \in P} X_{jp}}{X_{wi} / \sum_{p \in P} X_{wp}}$$

Based on this formula, a country *j* is said to have a revealed comparative advantage in a given product *i* when the ratio of its exports (marked as *X*) of product *i* to its total exports of all products *p* in its product basket (marked as *P*) exceeds that same ratio for the global economy (marked as *w*) as a whole. When a country's RCA in a given product is higher than 1, it can be considered a competitive producer and exporter of that product relative to all other countries in the world that produce and export that same product at or below the world average.

The idea behind the RCA index is that trade flows can reflect the relative costs of industrial production (such as materials, labour, and energy) as well as differences in non-price factors, such as policies, incentives, technical regulations, or market size, between countries.[613] If a country exhibits strong export performance

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[613] It is worth noting that in Balassa's original formulation, the RCA index depends not only on a country's average intensive margin (i.e. the volume of exports) in product *p,* but also on *p*'s prevalence on world markets. This implies that it is more difficult for a country to have a high RCA in the export of products that are more widely produced and traded worldwide (e.g. cement or fuels). This does not have a large impact on our findings, as the vast majority of the components analysed in this study are not very widely produced.

in a certain component, it can be understood as being able to efficiently allocate resources and compete in the global market. The RCA is a simple gauge of a country's relative export and industrial production performance, which can be calculated at the level of individual components and at different levels of aggregation. By analysing trade data through the RCA index, we gain insights into the underlying factors driving a country's comparative export performance, including both price-related aspects and broader structural and policy-related influences on industrial production and trade dynamics.

Bringing it all together: factsheets and an assessment of our confidence level

Having collected and analysed the data, we first compiled eight technology-specific databases, providing an overview of the manufacturing state of play at the EU and individual Member State levels. Based on these databases we compiled 27 country factsheets. The factsheets report findings from both Task 1 and Task 2 and are annexed to this report.

Insofar as Task 1 is concerned, findings in the country factsheets are reported following a scorecard approach. We selected the following key indicators to report:

4. a country's total manufacturing capacity, expressed, typically, in MW, alongside the share of EU manufacturing capacity; If no aggregated values of manufacturing capacity is available for the technology, the number of identified relevant facilities is reported. Additionally, announced facilities (and their capacity where available) are reported up to 2025 and after 2025.
5. a country's share of EU industrial production, together with the percentage of missing components due to confidentiality;
6. the share of extra-EU imports in a country's total import basket for each technology.

While indicators (1) and (2) are purely descriptive, indicator (3) can be used to score countries. Import dependence indices are marked as green when they are below 0.5, meaning that less than 50% of a country's imports originate from outside the EU; amber when they are between 0.5 and 0.75; and red when they are above 0.75, indicating that over 75% of a country's imports originate from outside the EU. In addition, we report a country's overall international position in the industrial production of each technology, as proxied by a combination of their RCA; export potential; and the degree of market concentration they face in each Net-Zero technology.

All indicators can be accompanied by a footnote when additional information is available that shows either of the two indicators does not provide useful information in a given context.[614] These decisions were taken in the context of a process of triangulation, which we have undertaken for all the factsheets by cross-checking results from the data analysis with inputs from the interviews and desk research, with a focus on general and specialist news outlets, industry reports, and in some instances, academic literature.

In addition to contextualising findings, when compiling the factsheets, we also performed an assessment of the coverage and reliability of data and developed a scorecard to provide an interpretative guide to the reader. Figure A 6 below provides an overview of the scorecard.

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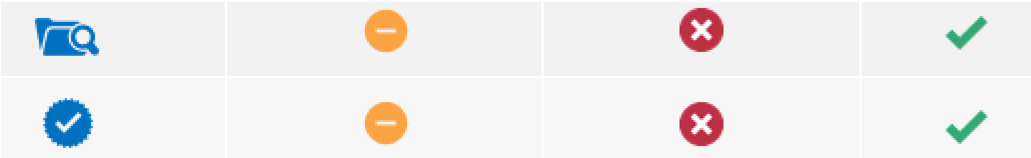
[614] To give an example, Austria is well-positioned in the production and export of tanks and containers that can be used in hydrogen storage; this drives up Austria's ranking in the Electrolysers and fuel cells technology. However, while tanks and containers are an important balance-of-plant component, they are not regarded by experts and interviewees as particularly critical for the development of the hydrogen economy.

Figure A 6 Confidence level scorecard overview



The scorecard has two dimensions: data coverage (or availability), reported in the first row in Figure A 6 and reliability, reported in the lower row. Data is reported as having low, medium, or good levels on both dimensions. For coverage, assignment into the scorecard is based on the following criteria:

- Low coverage is reported when over 50% of data is missing, due to issues of unavailability or confidentiality. Data availability is the main issue with regard to information on manufacturing capacity. Data confidentiality issues impact data in PRODCOM.
- Medium coverage is reported when between 30% and 50% of data is missing due to availability and confidentiality;
- Good coverage is reported when less than 30% of the data is missing, and when our findings have either been validated or have not been challenged directly by interviewees, experts, or findings from the desk research.

It is worth noting that the country factsheets tend to always report data on manufacturing capacity as having "medium" coverage, this does not fully reflect the underlying dynamics in each technology. As we state in the introduction to this chapter, coverage tends to be substantially better for solar PV, wind power, batteries, and electrolysers, than for other technologies, on which coverage is close to zero.

Reliability scores are assigned based on the following criteria:

- Low reliability is reported in those instances where findings from the data analysis are in direct conflict with either our desk research, findings from the interviews, or experts' inputs.
- Medium reliability is reported in two instances:
  - whenever findings from the interviews, experts' inputs, or desk research do not validate, or cast doubts on the findings from our data analysis. These instances are also highlighted in the factsheets using footnotes. Indicators are computed based on trade data for countries where re-exports are estimated to represent at least 20% of total exports. These countries are the Netherlands, Belgium, Luxembourg, and Lithuania.[615]
- Good reliability is reported when findings from the data analysis have been validated by either desk research or inputs from interviewees or experts.

Task 2 Methodology

Following the inception phase, the rollout of the country research commenced. The exact scope of the research, data specifications, and guidance documents were defined and agreed upon with DG ENER in advance. As there is already a clear overview of relevant support mechanisms within the NZIA and across other EU instruments, our approach combined desk research in national languages with two dedicated

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615 To the best of our knowledge, the Netherlands is currently the only EU Member State which reports updated information on its re-exports. According to the Dutch statistical office (CBS), re-exports accounted for over half of the country's total exports in 2022. With regard to the other countries, a recent estimate based on the World Input Output Database (WIOD) suggests that almost 15% of Belgium's exports are accounted for by re-exports, although it notes that the estimate is conservative. In the case of Lithuania, a 2015 analysis found that re-exports represent approximately 40% of the country's exports.

interviews per country to understand the regulatory framework and support mechanisms for investments in the industrial production of NZ technologies better.

To support the work of country researchers and ensure alignment across countries, we prepared the following documents:
- excel template for the actual country level data collection;
- email template and interview guide for the country-level interviews;
- detailed guidance document explaining the scope and objectives of the research, providing tips and sources identified through the horizontal research.

During the data collection phase, country researchers screened a variety of sources, including websites, reports, studies, grey literature, focusing on the regulatory and support framework relevant for the industrial production of net zero technologies. Task 2 mostly focused on supply-side incentives and measures at national level[616] including fiscal and non-fiscal schemes that target Net-Zero technologies. However, as the policy initiative around the NZIA is relatively recent, research also included supply-side measures that do not explicitly target Net-Zero technologies, but due to their design and objectives (support to green transition, sustainability) can benefit them. Demand-side measures are included in the mapping if they include requirements to install Net-Zero technologies produced within the EU. For skill programmes, the research focused on programmes that make an explicit link to Net-Zero technologies and the capacity of people to manufacture the respective products. Research on the regulatory environment concentrated on four distinct elements, namely the presence of related and dedicated policy and legislation in place to support investment in and industrial production of Net-Zero technologies, the permitting processes, including their duration, elements, support mechanisms and authorities involved, the presence and design of relevant regulatory sandboxes, as well as dedicated requirements on Net-Zero technologies in procurement.

The methodology for the mapping of Member States' regulatory frameworks consisted of an integrated data collection strategy that combined desk research and interviews with relevant stakeholders across the EU. As there is already a clear overview of relevant support mechanisms within the Net-Zero Industry Act and across other EU instruments, our approach combined desk research in national languages with up to two dedicated interviews per country to better understand the regulatory framework and support mechanisms for investments in the industrial production of NZ technologies. The exact scope of the research, data specifications, and guidance documents were defined and agreed with DG ENER during the inception phase.

The research on the enabling framework reflects key areas of action as defined in the provisions of the NZIA. Specifically, the research explored the regulatory and policy frameworks in each Member State, identified instruments to stimulate investment, and mapped relevant skill programmes and policies:
- Regulatory framework: research focused on the identification of policies and strategies that develop a vision or specify objectives, targets, and milestones relevant for the eight technologies captured by this study. Research also captured relevant legislation that includes provisions in relation to Net-Zero technologies which usually aim at facilitating investment in and build-up of industrial production capacities. In line with the ambitions of the NZIA, the mapping put particular emphasis on gathering information on permitting processes, their duration and authorities involved, the presence and design of relevant regulatory sandboxes, as well as dedicated requirements on Net-Zero technologies in procurement.
- Investment support: the data collection at national level explored any type of fiscal schemes, tax and support measures that provide monetary incentives to invest in the manufacturing capacity for Net-Zero technologies and their components in the EU, and which help to close a potential financing gap.

[616] Thus, incentives and measures that support the development of technologies (notably support and incentives for innovation, research and development), and incentives and most measures that support the uptake of the technologies are out of the scope of this project.

- Skills policies: regarding skill policies, the mapping specifically aimed to identify relevant re-skilling and upskilling programmes and projects across Member States that address the skills needed for the industrial production of the technologies and components covered by the study.

The scope of the research encompassed EU Member States and explored both existing and planned measures. Due to the focus on manufacturing capacity, particular emphasis was placed on measures at national level[617], including fiscal and non-fiscal schemes targeting the supply side i.e. the industrial production of Net-Zero technologies and their components themselves, rather than their installation and deployment. However, since the policy initiative around the NZIA is relatively recent, the research also included supply-side measures that do not explicitly target Net-Zero technologies but can benefit them due to their design and objectives (supporting the green transition and sustainability). Demand-side measures were included in the mapping if they are geared towards inducing supply, for example if they feature requirements to install Net-Zero technologies produced within the EU. For skill programmes, the research focused on programmes that make an explicit link to Net-Zero technologies and the capacity of people to manufacture the respective products.

The table below provides an overview of the data specification for each type of measure, as agreed with DG ENER.

Overview of data points captured in the data collection

Information collected for the regulatory environment
• **Policy and legislation**: ○ Is there a policy/ strategy/ legislation that facilitates the manufacturing of Net-Zero technologies? Yes/ no ○ (*for each*) Name of policy/ strategy/ legislation ○ (*for each*) Main objectives and measures foreseen to strengthen manufacturing capacity • **Permitting procedure:** ○ Necessary permits for the production of Net-Zero technologies (incl. specific to any technologies) ○ Length of permitting procedure and its drivers (e.g. number of administrative steps, administrative capacity, dependences between different procedures etc.) ○ Level of digitalisation ○ One-stop shop (if any) for obtaining permits and its characteristics (e.g. scope, name, authority in charge, capacity, purpose etc.) ○ Any other mechanisms available for accelerated permitting ○ Characteristics of litigation procedure ○ Best practices • **Public procurement:** ○ Minimum requirements for Net-Zero technologies and their characteristics ○ Procurement rules favouring the purchase, installation or use of Net-Zero technologies and their characteristics • **Regulatory sandboxes:** ○ Are there regulatory sandboxes that manufacturers of Net-Zero can benefit from? Yes/ No ○ (if applicable) underlying regulatory framework ○ Capacity (number of participating projects, planned and actual to-date) ○ Entity acting as regulator

[617] Thus, incentives and measures that support the development of technologies (notably support and incentives for innovation, research and development), and incentives and most measures that support the uptake of the technologies are out of the scope of this project.

<table>
<tr><td colspan="3"></td></tr>
<tr><th colspan="3">Information collected across intervention types</th></tr>
<tr><td colspan="3">• Name of the instrument: specification of the official name in national language
• Name in English (translated)
• Specific type of instrument: the sub-category into which the instrument falls
• Are strategic Net-Zero technologies targeted explicitly? Yes/No
• Duration: (planned) year of introduction and end date (if applicable)
• Strategic Net-Zero technologies covered: which of the eight technologies the measure targets
• Eligibility/Scope: conditions for access to the instrument
• Geographical scope: national/ regional
• Brief description
• Links to sources</td></tr>
<tr><th colspan="3">Intervention specific variables</th></tr>
<tr><th>Incentive schemes</th><th>Taxation and fiscal schemes</th><th>Skills and education policies</th></tr>
<tr><td>• Origin: is it a national instrument or an EU instrument implemented by the MS
• Total amount available: in EUR, total and per year;
• Share of the amount available for Net-Zero manufacturing capacity (if applicable)
• Support per project: conditions such as upper ceiling for support co-financing etc.
• Authority in charge</td><td>Design features: a brief description of the design features, including the scope and type of expenses covered if relevant (e.g. specify whether it applies to capital investments, operational expenditures, etc.)</td><td>• Skills targeted: description of the relevant skills targeted by the policy
• Type of support: how the policy promotes the targeted skills
• Link to strategic Net-Zero technologies: how the policy promotes the manufacturing capacity for strategic Net-Zero technologies
• Authority in charge</td></tr>
</table>

Country research was conducted from April until the end of June 2024. As this coincided with the entry into force of the NZIA, it is likely that the number of relevant measures and initiatives at the national level will increase in the near future. Therefore, where relevant, the research also included information on planned measures.

To support the work, country researchers were provided with a comprehensive set of guidance documents and templates for their mapping. A pilot was performed for France to ensure that the guidance and data specifications were fit for purpose. A helpdesk for country researchers was set up to provide continued support during implementation and to ensure consistency in the information collected.

During the data collection phase, country researchers screened a variety of sources, including websites, reports, studies, and grey literature, focusing on the regulatory and support framework relevant for the industrial production of Net-Zero technologies.

Country researchers were asked to frontload the desk research while reaching out to organise interviews as quickly as possible. The table below provides an overview of the research per country, detailing the number of interviews and interview partners for each Member State.

Overview of progress made for the country research

MS	Desk research	Number of interviews	Interviewee	Date of interview
Belgium	Yes	2	VLAIO	27/05/2024
			Vlaams Energie- en Klimaatagentschap	14/05/2024
Bulgaria	Yes	2	Ministry of Economy and Industry	24/04/2024
			InvestBulgaria Agency	08/05/2024
Czechia	Yes	2	Ministry of Industry and Trade	28/05/2024
			Ministry of Regional Development	17/06/2024
Denmark	Yes	1	Danish Business Authority	11/06/2024
Germany	Yes	1	Federal Ministry for Economic Affairs and Climate Action	27/05/2024
Estonia	Yes	3	The Estonian Investment Agency	21/05/2024
			Estonian Cleantech business association	30/05/2024
			EAS (enterprise estonia/ eis)	30/05/2024
France	Yes	2	Ministry of Economics and Finance	24/04/2024
			Ministry of the Ecological transition	26/04/2024
Croatia	Yes	2	Ministry of Economy and Sustainable Development	03/05/2024
			Chamber of Commerce- Hrvatska Gospodarska komora	16/05
Italy	Yes	2	Ministry of the Environment and Energy Security	Written input
			Ministry of Enterprises and Made in Italy	10/06/2024
Latvia	Yes	3	Latvia Development Agency	15/05/2024
			Latvian Solar Energy Association	13/05/2024
			Latvian Wind energy association	05/03/2024
Lithuania	Yes	3	Ministry of the Economy and Innovation; Industry Policy Division	30/04/2024
			Ministry of the Economy and Innovation; Industry Policy Division	30/04/2024
			Ministry of Environment	30/04/2024
Luxembourg	Yes	2	Ministere de l'Économie	02/05/2024
Hungary	Yes	2	DLA piper	26/04/2024
			Hungarian Photovoltaic Industry Association	30/05/2024
Malta	Yes	2	Malta Enterprise	24/04/2024
			Ministry for the Economy, Enterprise and Strategic Projects Malta	12/06/2024
Netherlands	Yes	3	Solarge	30/04/2024
			Netherlands Enterprise Agengy (RVO)	17/05/2024
			Ministry of Economic Affairs and Climate Policy	22/05/2024
Austria	Yes	1	Chamber of Commerce	27/05/2024
Poland	Yes	1	Agency for Industry Development	26/04/2024
Portugal	Yes	1	Directorate-General for Energy and Geology (DGEG)	28/05/2024
Romania	Yes	1	Ministry of Energy	30/05/2024
Slovenia	Yes	1	Government of Slovenia	20/06/2024
Slovakia	Yes	2	Ministry of Economy	22/05/2024
			Ministry of the Environment	Written input
Finland	Yes	2	Ministry of Economic Affairs	03/06/2024
			Regional State Administrative Agency	13/05/2024
Sweden	Yes	2	Research Institute of Sweden	25/04/2024

MS	Desk research	Number of interviews	Interviewee	Date of interview
			Ministry of Climate and Enterprise	27/06/2024
Greece	Yes	1	Regulatory Authority for Energy (RAE)	14/05/2024
Spain	Yes	1	Institute for Energy Diversification and Saving	28/06/2024
Ireland	Yes	0		N/A[618]
Cyprus	Yes	0		N/A

Task 3 Methodology

Our approach built upon the foundational Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis initially identified by the European Commission in its Commission Staff Working Documents (SWD)[619] [620] on Net-Zero technologies and the JRC CETO[621] reports. Integrating these initial assessments with our findings from Tasks 1 and 2, we have developed an enhanced SWOT assessment enriched by the following methodologies:

- Semi-structured interviews with technology and industry experts: 16 interviews were organised (2 per technology). The findings have been used to support Task 1 in component selection and understanding of the value chain, providing additional findings for Task 2 on the current regulatory environment, and enriching the SWOT assessments per technology (see Annex III for the interview minutes).
- A survey with associations, businesses, and research and technology organisations: The survey targeted EU and national business associations, companies, and RTOs and aims to validate the findings of Task 1 and gather stakeholder views on the current situation in their country (and in the EU) on each of the eight technologies. 97 respondents replied to the survey, which included 28 complete responses and 69 partial responses. A majority of responses were from companies followed by national business associations (see Annex IV for a report on the findings). A scoring system was then used to identify the most relevant findings and refine the SWOTs by assigning each finding a total score, based on survey responses.[622]Roundtable discussions organised for each technology: Finally, preliminary findings on the key issues were presented in discussion papers and then discussed with industry experts from EU and national-level associations, researchers, and representatives from European institutions in online roundtable discussions (see Annex VI for the summaries of the discussions and discussion papers).

One challenge was the broad scope of the eight technologies, which sometimes encompassed several distinct technologies within a single category. Generally, we focused on the most relevant technology within each group. However, in certain cases, we provided separate SWOT assessments, such as for solar photovoltaic and solar thermal, as well as for onshore and offshore wind and ocean energy. Annex V presents the full SWOT assessments.

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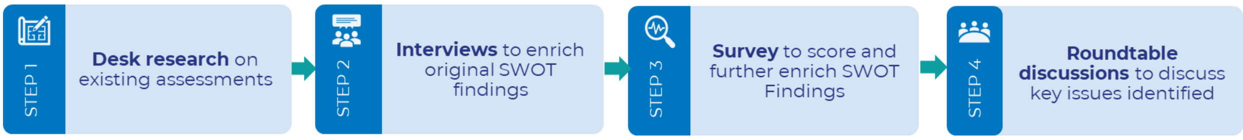
618 Despite considerable efforts made, no interview secured.

619 European Commission (2023): Staff Working Document on Investment needs assessment and funding availabilities to strengthen EU's Net-Zero technology manufacturing capacity, SWD_2023_68_F1_STAFF_WORKING_PAPER_EN_V4_P1_2629849.PDF (europa.eu).

620 European Commission (2023): Staff Working Document on establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net Zero Industry Act), https://single-market-economy.ec.europa.eu/document/download/9193f40c-5799-4b1d-8dfc-207300e9610d_en?filename=SWD_2023_219_F1_STAFF_WORKING_PAPER_EN_V9_P1_2785109.PDF.

621 Joint Research Center (2023):Clean Energy Technology Observatory, https://setis.ec.europa.eu/publications/clean-energy-technology-observatory-ceto/ceto-reports-2023_en.

622 Each contribution from respondents was assigned points, which were then summed into a score per finding, with 3 points for 'strongly agree', 2 points for 'agree', 1 for 'partially agree', -1 for 'don't agree', 0 for 'N/A'



Task 4 Methodology

In our approach, we developed a long list of policy recommendations, which was filled over the course of our research. It was first enriched with inputs from the interviews and then complemented with inputs collected throughout the survey from companies, research and technology organisations, EU and national business associations. Ahead of the technology-specific roundtables, we enriched the longlist with inputs from our desk research and eventually finetuned policy recommendations based on inputs gathered during these discussions with experts (see Annex VI Summaries of the roundtables). As a final step, we reviewed the collected inputs and connected them with the key issues identified in the earlier tasks.

Annex XI: Research challenges

Challenges related to data collection

Availability and reliability of data has been an important challenge for Task 1. Data on manufacturing capacity is generally not available in a harmonised format across all Net-Zero technologies. The proprietary databases we used to complement the analysis do contain facility-level data on manufacturing capacity for wind power; solar power; batteries; and electrolysers. For the other technologies, no information on capacity is available. For this reason, we have used a combination of desk research and stakeholder outreach to fill the gaps and identify missing companies, industrial production sites, and their capacities. Since capacity data is typically not publicly reported, companies and industrial production sites which were missing from the proprietary data were targeted by a survey, coordinated under Task 3.

Given the paucity of information that is available publicly, the survey was considered the best option to gather new information on manufacturing capacity - particularly for those Net-Zero technologies on which we know less. However, it is worth noting that the survey was based on purposeful sampling, and that it is likely to be biased towards larger and more established firms and facilities. In addition, since information on manufacturing capacity can be considered sensitive business information, almost no company who received the survey decided to share data with us—only 16 firms out of 37 responding firms reported some data on their capacity as part of the survey. Industrial associations were also cautious with data, and the vast majority of associations we consulted during the study did not disclose their data with us.

The scarcity of information on manufacturing capacity is also what motivated us to carry out data collection on industrial production data, using the PRODCOM database. PRODCOM is a statistically representative and comparable data provided by Eurostat. However, not all countries choose to report data on industrial production in PRODCOM, chiefly due to confidentiality issues. Gaps in data availability due to confidentiality range from over 70% to as low as 10%, depending on the country and Net-Zero technology.

With regard to Task 2, defining the scope of research has posed challenges across various aspects For example, some regulatory sandboxes lack specificity in describing eligible projects, making it difficult to determine whether manufacturers of Net-Zero technologies can utilize them. Similarly, certain planned skills and education policies offer limited clarity regarding the specific skills they target and whether they lean more towards the deployment or manufacturing of Net-Zero technologies.

Obtaining information on the permitting processes via desk research has proven challenging due to the limited existing research on the topic. In addition, the required information tends to be highly technical and specific to individual cases, complicating efforts to create a comparable and comprehensive overview. Furthermore, acquiring this information through interviews presents its own set of challenges, as multiple authorities are typically involved in different permits, making it rare to find a single source that can provide a comprehensive overview. The short timelines have also proved challenging in terms of already incorporating all the findings of the desk research and the performed interviews into this report.

Challenges related to consultation activities

In terms of stakeholder consultations at the Member State level, gaining access to representatives of public authorities has proven to be challenging in some cases. This has impacted the timeline of the country fiches. We have reached out to the permanent representations of Member States to facilitate the responsiveness of the national competent authorities.

Despite a robust stakeholder mapping and engagement exercise during which we contacted 697 relevant actors, our online survey received a relatively low number of complete responses. This may be due to a combination of factors including the complexity of the survey and data confidentiality. The majority of responses arrived from companies, potentially signalling that they were interested in providing details but not to the level expected in the survey. We carried out several awareness-raising and stakeholder mobilising activities through various channels to increase participation.

Regarding the implementation of the roundtable discussions, a notable challenge was the diverse scope of the eight technologies, which sometimes encompass multiple distinct technologies (and technological processes) within a single category. While we generally focused on the most pertinent technology within each group, there were instances where separate SWOT assessments were warranted, such as for solar photovoltaic and solar thermal, as well as for onshore and offshore wind and ocean energy. In future research projects, both on the EU and Member State level, we recommend further subdivisions to these technologies.

Annex XII: Manufacturing capacity by Member State

Operational manufacturing capacity of selected Net-Zero Technologies in 2023

	Solar PV (MW)			Wind (MW)			Electrolyzer (MW)	Battery (MWh)
	PV cells	Wafers	Modules	Blade	Nacelle	Tower		
Austria			400 - 800					800 - 850
Belgium			100 - 150				250 - 650	
Bulgaria			75 - 125				10 - 25	
Croatia			300 - 350					
Cyprus								
Czechia						700 - 750		1000 - 1100
Denmark			25 - 75	5500 - 5600	5850 - 6700	4700 - 5000	400 - 650	
Estonia			50 - 100					
Finland			100 - 200					
France	100 - 150	200 - 200	1400 - 2250	3300 - 3500	2400 - 2500	1700 - 1850	60 - 160	14500 - 16000
Germany	1600 - 2500	250 - 250	5900 - 8500	450 - 500	11400 - 17750	3800 - 4200	3300 - 3500	55000 - 60000
Greece						500 - 550		5300 - 11000
Hungary	200 - 200		200 - 200					40000 - 42000
Ireland								
Italy	1200 - 1300		1500 - 1500	2500 - 2700		1000 - 1100	310 - 325	200 - 350
Latvia								
Lithuania	50 - 50		400 - 450					
Luxembourg			25 - 75					
Malta								
Netherlands			350 - 550		300 - 350			300 - 500
Poland			400 - 450	2000 - 2500		1750 - 2000		85000 - 90000
Portugal			50 - 100	3500 - 3750		2400 - 5550	450 - 500	
Romania			100 - 250					0 - 200
Slovakia			50 - 150					5000 - 5250
Slovenia			700 - 800					
Spain			500 - 650	8000 - 8250	5000 - 5250	15500 - 18500	500 - 600	
Sweden			120 - 250					15500 - 16000
EU Total								

Announced facilities 2024-2025

Country	Solar PV (MW)	Wind (MW)	Electrolyzer (MW)	Battery (MWh)
Austria				
Belgium				
Bulgaria				
Croatia				
Cyprus				
Czechia				400 - 500
Denmark		2200 - 2300	400 - 500	
Estonia			150 - 250	
Finland				
France	150 - 5100		1355 - 1855	16000 - 43000
Germany	900 - 10400	900 - 1100	4250 - 4550	11200 - 171000
Greece				
Hungary	150 - 250			15000 - 16500
Ireland	250 - 350			
Italy	3400 - 4250		1900 - 2100	600 - 5000
Latvia				
Lithuania	50 - 100			
Luxembourg				
Malta				
Netherlands	400 - 500			
Poland		5000 - 5150		13500 - 14500
Portugal			375 - 500	4750 - 5250
Romania	1200 - 6500			1750 - 2000
Slovakia				6750 - 7250
Slovenia				950 - 1050
Spain	0 - 2400	900 - 1100	450 - 550	12000 - 12250
Sweden	100 - 200			24000 - 25000
EU Total	6600 - 30800	9000 - 9650	8880 - 10305	106900 - 303300

Announced facilities 2026-2030

Country	Solar PV (MW)	Wind (N/A) (MW)	Electrolyzer (MW)	Battery (MWh) (MW)
Austria				
Belgium			900 - 1100	2900 - 3200
Bulgaria	950 - 1050			
Croatia	350 - 550			
Cyprus				
Czechia				3750 - 4000
Denmark			350 - 600	
Estonia			900 - 1100	
Finland				29000 - 31000
France	8500 - 14000		900 - 1000	117000 - 215000
Germany	8000 - 14000		2100 - 3200	110000 - 173000
Greece			1250 - 1500	
Hungary	1750 - 2000			98000 - 155000
Ireland				
Italy	2000 - 8500		300 - 600	35500 - 113000
Latvia				
Lithuania	900 - 1000			
Luxembourg	50 - 150			
Malta				
Netherlands	5500 - 6000			
Poland	1750 - 2000			3000 - 7000
Portugal				9000 - 11000
Romania	13000 - 14000			22000 - 50000
Slovakia				28000 - 60000
Slovenia				
Spain	900 - 1000		400 - 600	90000 - 100000
Sweden	500 - 600		700 - 800	60000 - 150000
EU Total	44150 - 64850		7800 - 10500	608150 - 1072200

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