European Environment Agency

Clean energy technologies in the European Union
Implications for quality jobs, skills and a just transition

EEA report

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Publications Office
of the European Union

EEA report 08/2026

ISBN: 978-92-9480-789-2
ISSN: 1977-8449
TH-01-26-037-EN-N
doi:10.2800/4663174

Cover design: © European Environment Agency
Cover image: © European Environment Agency
Layout: Eworx/European Environment Agency

Contents

Acknowledgements

The European Environment Agency (EEA) would like to thank its partners from the European Environment Information and Observation Network (EEA member countries and European Topic Centres), its Scientific Committee, the Directorate-General (DG) for Environment, DG for Climate Action, DG for Regional and Urban Policy, DG Research and Innovation, DG for Energy, DG for Employment, Social Affairs and Inclusion, the European Commission Joint Research Centre, the European Foundation for the Improvement of Working and Living Conditions (Eurofound) — in particular for its guidance on the analysis of European Working Conditions Survey (EWCS) data — the European Labour Authority (ELA), the European Centre for the Development of Vocational Training (Cedefop) and the European Investment Bank (EIB) for their valuable input at different stages of the project. It would also like to acknowledge the contributions and analytical support of Prognos AG and Ramboll Management Consulting under contract to the European Environment Agency, as well as all the participants in the expert workshops.

Key messages

- Important progress has been made towards the European Union's (EU's) ambition to ensure access to clean, affordable and secure energy; the share of energy consumption from renewable sources has more than doubled since 2005. Against this backdrop, **Europe's transition to climate neutrality is reshaping parts of its industrial base and labour markets**.

- Among the clean energy technologies studied in this report, **wind energy was the largest employer with an estimated 273,500 direct jobs** in the EU in 2023. While manufacturing remains an important value chain segment for wind energy, around **77% of jobs are in downstream activities in the operations segment**.

- **The solar photovoltaic (PV) energy technology sector directly employs over 227,000 people**, with operations representing roughly half of the workforce and construction activities accounting for 36%.

- **The heat pump sector directly employs an estimated 80,100 workers, mostly in construction activities** (65%). While heat pumps remain under-deployed across the EU, this technology holds strong growth potential.

- **The battery sector has experienced the fastest employment growth**, with the number of jobs expanding rapidly between 2018 and 2023. With a total workforce of around 33,000 workers, most jobs are in manufacturing. Research and development (R&D) remains vital for next-generation battery technologies.

- Despite ongoing industry uncertainty and challenges, employment in the clean-tech sector is expected to continue growing. **By 2030, wind, solar PV, batteries and heat pumps could each employ hundreds of thousands of workers.**

- **Across Member States, Germany accounts for the largest workforce in absolute terms in wind (125,000 jobs), solar PV (nearly 84,000 jobs) and batteries (12,300 jobs)**, but not the largest share relative to total employment in the country. Portugal, Spain and Italy account for the highest absolute number of heat pump related jobs. **Hungary and Poland show the fastest employment growth in the battery sector**.

- The expansion of clean energy technologies does not automatically translate into inclusive labour markets. **Women remain significantly under-represented**, with a participation rate ranging from 26% in wind and batteries to 14% in the heat pump sector, highlighting the need to ensure that the clean energy transition delivers inclusive employment outcomes.

- Workers aged 15-24 accounted for only 6-7% of the workforce across the value chains for wind, solar PV and heat pumps in 2023. **Young people must be better integrated** into the transition, particularly at a time when digitalisation and artificial intelligence are becoming critical enablers.

- **Skill shortages threaten the deployment of clean energy technologies**; most Member States report gaps in critical installation- and construction-related technical roles. Coordinated policy action is needed in to expand training, reskilling and workforce availability at scale.

- **Job quality must improve to attract and retain workers.** The quality of jobs is currently variable in terms of remuneration, employment status and contractual stability, physical risks and worker health and safety.

- **A competitive and just clean-tech transition requires strong social and territorial cohesion** to ensure that investments in skills, job quality and inclusion translate into high-quality, futureproof employment, while advancing Europe's climate and competitiveness goals.

Executive summary

The European Union (EU) is rapidly transforming its economy to achieve climate neutrality, guided by legally binding emissions targets. At the same time, it faces ongoing geopolitical uncertainties, including recent tensions in the Middle East. As such, it is necessary to accelerate the EU's clean transition and further reduce its dependence on imported fossil fuels and vulnerability to energy price shocks.

Europe's transition to climate neutrality is reshaping its industrial and employment landscape, although clean energy technologies in the EU face structural challenges such as relatively high energy and labour costs, permitting and planning bottlenecks, and some limitations in access to critical raw materials (CRMs). In spite of this, clean tech is becoming an essential pillar of the transition, accounting for a growing share of economic activity and job creation.

The evolving policy framework at the EU level signals a shift from a predominantly market-led industrial policy to a more integrated, strategic and state-supported approach. This shift is happening against a backdrop of intensifying global competition, shifting supply chains and growing geopolitical pressures.

Crucially, Europe's long-term competitiveness and climate neutrality objective will depend on this kind of enabling policy and regulatory framework, innovation and investment. It will also rely on a skilled workforce and quality employment. Ensuring that workers have the right skills, that job quality keeps pace with expanding labour demand and that opportunities are accessible across regions and social groups are all key factors for a just transition.

This study examines these dimensions by analysing employment trends, workforce composition, skill needs, labour shortages and job quality across four clean energy technologies (wind energy, solar photovoltaics (PV), heat pumps and batteries). The aim is to inform evidence-based policymaking and the EU's evolving industrial transition agenda — spanning the Net-zero Industry Act (NZIA), the Clean Industrial Deal (CID), the proposed Industrial Accelerator Act and AccelerateEU — and to support quality jobs, skills initiatives and just-transition instruments.

A fast-growing economic and employment engine

The clean energy sector has become an important and fast-growing part of the EU economy, employing close to one million people and generating EUR 138 billion in gross value added (GVA) in 2023.

The EU maintains a strong position globally in the wind energy sector — particularly in offshore wind — in spite of increasing competition. Based on the modelling approach used in this report, in 2023 wind energy remained the largest employer of the four featured technologies, with approximately 273,500 direct jobs. Around 77% of employment in wind energy is concentrated in the operations segment of the value chain. At the same time, it retains a mature and well-established industrial base.

Solar PV follows with 227,300 people directly employed in 2023. This sector is driven by a continued increase in the capacity of installed PV. The construction segment (e.g. infrastructure work, site preparation, grid connection) contributes significantly to job opportunities (36% of the total solar PV workforce), while operational activities still represent the largest share (48%). However, European manufacturers remain under significant pressure in the context of relatively high production costs in the EU, combined with very low prices and oversupply of PV modules from China.

Heat pumps are a key technology for reducing emissions in the building sector, but they currently remain under-deployed across the EU for a range of interacting reasons (including a relatively high upfront cost). As such, there is significant growth potential in the heat pump sector. At the global level, the European heat pump industry is well positioned. In 2023, just over 80,000 people were directly employed in the sector in the EU, with a moderate annual growth rate of 3.3% between 2010 and 2023. The construction segment of the value chain is currently the most significant, with 51,900 people employed in 2023 (65% of the total workforce).

Batteries are the most dynamic sector; their GVA increased from nearly zero in 2018 to EUR 2.2 billion in 2023. The sector has the smallest workforce of the four clean energy technologies featured in this report (around 33,000 people employed in 2023). However, employment grew by nearly 35% annually between 2010 and 2023, particularly from 2018.

This trend confirms batteries as one of the EU's fastest-growing net-zero industries, despite significant challenges due to high energy and labour costs as well as competition with well-established battery producers globally. Manufacturing is currently the most significant value chain segment in terms of employment. Meanwhile, the small workforce in research and development (R&D) is key to enabling the EU to keep pace with rapid developments in the field and position itself as a global innovation hub for next-generation batteries.

Geographical distribution of employment in clean technology

Clean-tech employment in Europe is shaped by divergent national employment patterns. In absolute terms, Germany has the largest workforces in wind and solar PV (125,000 and 83,800 people directly employed in 2023, respectively) and also in the batteries sector (12,300), due to its strong automotive industrial base. Other countries also play important roles in wind energy employment: France and Poland have seen sustained growth; Denmark is a key hub for offshore wind manufacturing; Spain is combining manufacturing and operational activities.

In the solar PV sector, Spain, Italy and then Poland follow Germany in terms of workforce size, albeit with considerably fewer jobs. While Italy has had a relatively large workforce, it now stands out for a declining trend in recent years. In the battery value chain, Hungary and Poland are emerging as manufacturing hubs next to Germany, with rapid employment growth as new production facilities scale up. Portugal has the largest heat pump workforce due to labour-intensive activities in the construction segment, while Spain continues to expand.

These territorial disparities highlight the importance of supporting all regions — especially those dependent on carbon-intensive industries — to manage the socio-economic implications of the transition.

Gender and age imbalances in the clean-tech workforce

At present the benefits of the transition are shared unequally across population groups. Women remain under-represented, with a participation rate ranging from 26% in wind and batteries to 14% in the heat pump sector. At the same time, women made up just over 10% of the workforce in the construction segment of the value chain in 2023. Their participation is higher in R&D roles; however, these jobs account for a smaller share of total employment across the featured technologies. Gender imbalances also persist in leadership positions.

Workers aged 15-24 are also under-represented, accounting for only 6-7% of the workforce across the wind, solar PV and heat pump value chains. This reflects a broader demographic challenge linked to an ageing European workforce.

It is essential to attract more women and young people into the workforce to sustain growth and achieve an inclusive and just transition. Without targeted action, these disparities may limit the availability of workers and weaken the social foundations of the transition.

Growing demand for labour, but a critical bottleneck due to skill shortages

Future demand for labour in the wind energy, solar PV, heat pump and battery sectors is expected to grow. Projections indicate that there will be up to twice as many people employed in wind and solar PV by 2030.

Growth dynamics for jobs related to heat pumps are expected to remain more moderate based on past trends, although recent energy shocks have shown that demand can change rapidly, highlighting its sensitivity to external factors. Meanwhile, the Electrification Action Plan supports the deployment of heat pumps through a range of policy levers.

Similar uncertainty applies to battery technologies — notably due to international competition and ongoing sector restructuring. However, the sector is receiving large investments. The recent Battery Booster strategy aims to make domestically produced battery cells and components cost-competitive. Financial backing is supporting a growing number of EU manufacturers.

Delivering the EU's net-zero transition will also depend on the capacity of labour markets to provide enough workers with the right skills, training and experience across relevant occupations. While there is demand for diverse roles in the clean-tech workforce, technical and vocational occupations remain central — notably in manufacturing and construction.

Labour shortages remain a significant challenge across the EU in some of the key occupations. This is especially the case for building electricians, plumbers, electrical mechanics, technicians and engineers. This reflects high and growing demand for specialised skills. Without accelerated skills provision, workforce bottlenecks will slow deployment and undermine the EU's ambitions.

The EU has launched major initiatives — net-zero industry academies, the Union of Skills, skills guarantee pilots and numerous Erasmus+ projects — to scale up training, support job-to-job transitions and develop cross-technology competence frameworks.

Looking ahead, artificial intelligence (AI) is becoming a critical enabler of the clean energy transition; it can improve the efficiency, flexibility and scalability of low-carbon energy systems. As such, there are diverse implications for the labour force and related skill needs.

Job quality varies widely across technologies and value chain segments

Labour shortages are closely tied to job quality; demanding physical conditions, lower wages and more precarious forms of employment mean that certain occupations are less attractive and make recruitment and retention more difficult. Wages and salaries vary significantly across the clean energy technologies featured in this report. Jobs in the construction segment have the lowest average wages, including when compared with the economy as a whole.

Construction roles also have the highest share of self-employment (22%) — substantially higher than the share for operational activities and R&D — and the second-lowest incidence of permanent contracts among employees. Contractual stability is higher in the manufacturing segment.

When looking at the physical working environment and related risks, both construction and manufacturing involve higher levels of exposure to noise, smoke, vapours and chemicals compared to other value chain segments and the EU-wide average. Construction workers, in particular, are exposed to extreme temperatures; meanwhile, chemical exposure is considerably higher for the manufacturing workforce. These risks highlight the need to monitor health and safety standards across the clean-tech value chain.

Policy directions for a just and competitive clean-tech transition

Social, employment and territorial considerations must be at the heart of Europe's industrial strategy to deliver a just and competitive clean-tech transition. In practice, this requires policy initiatives and funding instruments to actively promote quality jobs, fair working conditions and strong skills development in line with evolving labour market needs. They must also ensure that all regions are equipped to manage the transition and capture new clean-tech opportunities. Targeted support for workers and territories facing deeper restructuring remains essential to ensure that the benefits of the transition are broadly shared. This will be key to achieving a transition that is not only economically ambitious, but also socially inclusive and regionally balanced.

1 Introduction

The European Union (EU) is undergoing a profound transformation as it accelerates the transition towards climate neutrality. This shift is anchored in the European Climate Law, which establishes a legally binding 2040 climate target to reduce greenhouse gas (GHG) emissions by 90% compared to 1990 levels. This in turn builds on the target to reduce GHG emissions by 55% by 2030. It also sets out a path towards the objective to achieve climate neutrality by 2050.

The transition is supported by a clean industrial policy framework and a set of initiatives which aim to address key challenges related to competitiveness, energy security and strategic autonomy. Policies further aim to leverage decarbonisation as a driver of economic transformation to generate new, high-quality employment opportunities across Europe.

At the heart of this transition lie clean energy technologies. These include:

- renewable energy generation technologies (e.g. solar, wind, hydro);
- energy conversion and storage technologies (e.g. batteries, hydrogen);
- energy system integration and efficiency technologies (e.g. grids, heat pumps);
- carbon capture and storage (CCS).

These technologies are indispensable for meeting Europe's decarbonisation and climate neutrality targets; they also have the potential to contribute to industrial renewal, create quality employment across value chains, strengthen regional supply chains and support innovation across multiple sectors.

Box 1.1

Defining the terminology — clean, renewable and net-zero technologies

In academic and grey literature, the terms 'clean technologies' (clean tech), 'renewable energy' and 'net-zero technologies' are often used interchangeably. However, they refer to overlapping but distinct concepts:

- **Renewable energy** relates to technologies that generate energy from naturally replenished sources such as solar, wind, hydro, geothermal and bioenergy. These categories are defined and recognised relatively consistently at the international level (e.g. by the United Nations (UN), Intergovernmental Panel on Climate Change (IPCC), International Energy Agency (IEA) and Eurostat).

- **Clean tech** encompasses a broader range of technologies that reduce environmental impacts, particularly GHG emissions and resource use, compared to conventional solutions. For example, they may improve resource efficiency, encourage the use of sustainable resources and environmental protection, or reduce waste. There is no universally agreed definition of clean tech (see Shakeel, 2021).

- **Net-zero technologies** refer specifically to the 19 legally defined net-zero technologies deemed essential to achieving climate neutrality and industrial resilience. They are set out in the EU's Net-Zero Industry Act (NZIA). They include renewables and enabling technologies (e.g. batteries, grids, transport of carbon dioxide (CO_2)), as well as low-carbon non-renewable solutions such as nuclear and CCS.

Whether the benefits of these technologies can be realised at scale remains uncertain. It will largely depend on Europe's ability to compete in an increasingly contested global market and to address critical dependencies across global supply chains. Deploying clean tech can enhance Europe's competitiveness by reducing exposure to volatile fossil fuel markets and cutting energy prices.

However, the transition requires significant upfront investment, stable policy frameworks and predictable demand. Likewise, there are currently several bottlenecks restricting the expansion of Europe's production capacity for clean technologies. These include permitting delays, access to critical raw materials (CRMs) and high production costs. These factors may limit how quickly Europe can build its strategic autonomy and strengthen its long-term economic resilience.

At the same time, the employment dimension of the clean energy transition is increasingly central, since the rapid expansion of the clean-tech sector offers significant opportunities for creating employment across Europe. As countries accelerate their sustainability transitions, demand is rising for a wide range of new and transformed occupations, with openings for workers at different skill levels and opportunities for regional economic revitalisation.

These benefits are unlikely to be distributed evenly. This raises important just-transition challenges for workers and regions that may face job displacement, skills mismatches or limited capacity to benefit from new investment. Moreover, the creation of large numbers of jobs is not sufficient on its own; the transition must ensure that these are high-quality jobs.

These opportunities are emerging alongside important challenges: persistent labour and skills shortages, limited training capacity in rapidly evolving technical fields and aging workforce that is constraining the future size of the workforce. It is essential to overcome these challenges in order to fully harness the job creation potential of clean technologies and ensure that the transition is not only fast, but also fair and inclusive.

The EU policy landscape has evolved significantly to address the key barriers to scaling up Europe's clean-tech industrial base. It is shifting from a predominantly market-driven model to a more strategic, industry-oriented policy framework aimed at:

- strengthening European competitiveness;
- improving energy security;
- advancing strategic autonomy;
- delivering on climate goals.

Equally, policies increasingly emphasise the need to deliver a socially just green transition through the creation of quality jobs, inclusive access to employment opportunities and substantial investment in upskilling and reskilling.

One key measure is the Net-zero Industry Act (NZIA), adopted in June 2024. It includes targets for:

- EU clean-tech manufacturing;
- streamlined permitting in manufacturing;
- support for priority projects;
- the establishment of net-zero industry academies to provide training and education on net-zero technologies.

Building on the NZIA, the CID was launched in February 2025 as a strategic roadmap for competitiveness and decarbonisation. It covers both energy-intensive industries and clean-tech value chains, including sector-specific transition pathways. As part of the CID implementation package, in March 2026 the European Commission (EC) presented the Industrial Accelerator Act. This is a legislative proposal to increase demand for low-carbon, European-made technologies and products.

In addition and in response to the energy crisis triggered by the situation in the Middle East, the AccelerateEU initiative was launched in April 2026. This aims to address rising energy costs and support the EU's shift to homegrown clean energy.

In this context, quality job creation and skills are recognised in the EC Competitiveness Compass as core enablers of Europe's transformation towards cleaner and more circular industry. Several targeted initiatives are already in place — including the Union of Skills and the Quality Jobs roadmap — alongside the forthcoming Quality Jobs Act. These initiatives complement other established just-transition instruments, such as the Just Transition Fund (JTF) and the European Social Fund Plus (ESF+). These funds provide financial support to workers and territories to ensure that the industrial transformation is just and inclusive.

In the context of this evolving landscape, this report documents the expansion in the manufacture and deployment of clean energy technologies in Europe. It also examines the implications for job creation, workforce needs and job quality as fundamental pillars of a just transition. It does so by analysing both aggregate employment dynamics and aspects of workforce composition, occupations and skills. It also considers job quality from a value chain perspective.

As traditional industries restructure, the clean-tech sector could play a central role in absorbing displaced workers and creating accessible, high-quality career pathways. Achieving this will depend on equipping the workforce with relevant skills and ensuring that labour market institutions and social protection systems adapt to rapid technological and policy shifts. Given the uneven spatial distribution of clean-tech investment and job creation, the opportunities will also hinge on whether workers are able and willing to move across regions and borders.

This report focuses on four clean energy technologies:

- onshore and offshore wind;
- solar photovoltaics (PV);
- heat pumps;
- batteries.

This reflects their importance both for current employment and future job creation, and their relevance for near-term EU industrial policy. By consolidating evidence on labour dynamics in the clean-tech industry, the study aims to support policies that align climate and industrial goals with fair, high-quality job creation across Europe, to ensure a more sustainable transition.

The report is structured as follows:

- **Chapter 2** provides an overview of the evolving EU policy framework that underpins the clean-tech transition, including the strategic, regulatory and financial instruments shaping industrial development, labour market needs and just-transition measures.
- **Chapter 3** examines Europe's clean-tech industry in transition, specifically focusing on wind, solar PV, heat pumps and batteries; it covers their economic value and market growth, as well as their strengths and vulnerabilities in a global context.
- **Chapter 4** analyses employment patterns across the clean-tech sector, including current workforce trends, future labour market projections, geographical disparities and the participation of women and young people in the clean-tech workforce.
- **Chapter 5** examines occupational profiles, skill needs, labour shortages and job quality indicators across value chains.
- **Chapter 6** summarises the main findings and provides policy lessons to support a competitive, resilient and socially just clean-tech transition across Europe.

A methodological annex provides detailed information on data sources, modelling approaches and analytical boundaries.

2 Reshaping the EU's industrial policy framework — balancing decarbonisation, competitiveness and a just transition

Europe's transition to a climate-neutral economy is unfolding in a context of intensifying global competition, heightened geopolitical and energy security risks, accelerating technological change, and labour and skills constraints driven by demographic change. These drivers underpin shifts in the European Union's (EU's) industrial policy and shape the labour market transformations analysed in this report.

In this context, the EU's response has moved from a predominantly market-driven approach towards a strategic and industry-focused policy framework. The aim is to strengthen European competitiveness, enhance energy security and boost strategic autonomy, in line with its climate ambitions. There is also consistent recognition that, beyond technological and financial constraints, demographic imbalances constitute a critical risk for the clean tech transition. Without targeted measures to expand labour force participation, attract talent and reskill workers, aging workforce could slow the uptake of investment, delay project delivery and undermine Europe's ability to build competitive clean tech value chains.

This chapter provides an overview of the transformation in the EU industrial policy landscape. It begins by outlining the key policy and regulatory frameworks that underpin the development of the EU's clean tech sector. It also discusses crucial funding instruments. It then examines how just-transition principles are integrated into this evolving industrial policy landscape, analysing both the social and territorial dimensions.

2.1 Supporting the EU clean energy transition — strategic, regulatory and financial foundations

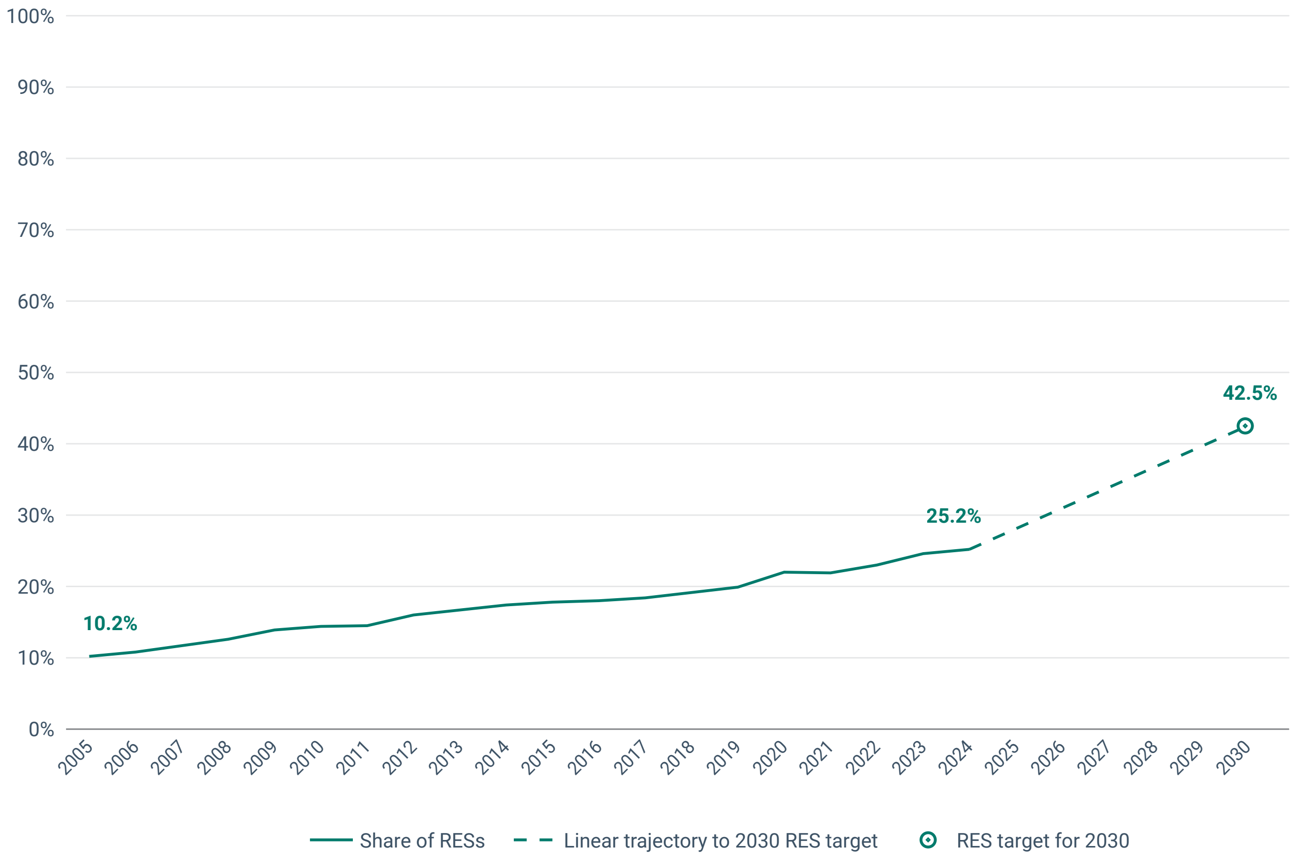
2.1.1 The foundational policy and legislative framework

The foundations of the EU's green policy are set out in the European Green Deal (EC, 2019), anchored in the EU Climate Law (EU, 2021b), and operationalised through the Fit-for-55 EU policy package (EC, 2021).

Further-reaching EU ambitions were then introduced in 2022 via the RepowerEU plan (EC, 2022). This explicitly links the deployment of renewables to the goal of phasing out the EU's dependency on Russian fossil fuels.

The EU's increased renewable energy ambitions were reflected in the revised Renewable Energy Directive (RED III) (European Parliament and Council, 2023) adopted in 2023. The Directive sets a binding target to raise the share of energy from renewable sources in the EU's gross final consumption from 32% to a minimum of 42.5% by 2030, with an ambition to reach 45%. In 2024, 25.2% of all final energy consumed in the EU was obtained from renewable sources, giving an indication of progress towards this goal (Figure 2.1).

Figure 2.1 **Progress towards renewable energy targets**



Note: The figure shows the share of renewable energy sources (RES) in gross final energy consumption in the 27 EU Member States (EU-27) since 2005.

Source: EEA, 2025c.

All Member States are required to contribute to the EU-level renewable energy target, although no binding national targets have been set. The EU-level target provides an overall framework for expanding the use of renewables, without prescribing the energy mix. This leaves room for national diversification according to domestic resources and infrastructure.

National contributions to the EU renewable energy target are explicitly included in the updated national energy and climate plans (NECPs). According to the EC's EU-wide assessment of final updated NECPs (European Commission, 2025d), more than two-thirds of Member States have significantly raised their ambition levels and the 42.5% RED III target is within reach, although a 1.5% gap remains.

In May 2025, the EC presented the REPowerEU roadmap (European Commission, 2025e) — its plan to gradually phase out Russian gas, oil and nuclear energy imports. On June 2025, the EC then tabled a legislative proposal (European Commission, 2025g) effectively to ban all imports of Russian gas and ensure that Russian oil is phased out. In December 2025, a historic agreement was reached to stop Russian gas imports and phase out Russian oil by November 2027 at the latest.

Importantly, in July 2025 the EC also put forward a proposal to amend the EU Climate Law by introducing a 2040 climate target to reduce net greenhouse gas emissions (GHG) by 90% relative to 1990 levels. In December 2025, the European Parliament and the Council reached a provisional political agreement to make this a legally binding target. The target was formally adopted by the European Council on 5 March 2026.

The agreement includes a provision allowing the use, from 2036 onwards, of high-quality international carbon credits as a contribution towards the 2040 target, up to a limit of 5% of the EU's net emissions in 1990. This means that at least 85% of emissions reductions must be achieved within the EU.

2.1.2 The Net-Zero Industry Act

It is also essential for the clean transition to nurture the EU's own industrial base by boosting domestic manufacturing capacity and reinforcing resilience in clean technology value chains. To achieve this, the Green Deal Industrial Plan (GDIP) was presented in 2023 (EC, 2023a). One of its key legislative initiatives is the Net-Zero Industry Act (NZIA), which entered into force in 2024 (EU, 2024b). This introduces a target-driven approach to industrial policy.

The NZIA emerged against a backdrop of intensifying global competition in clean technologies, including substantial domestic industrial support measures in the United States — with its Inflation Reduction Act (IRA) of 2022 — and expanding clean-tech production capacity in China.

While net-zero technologies span a wide range of sectors, the NZIA applies specifically to a subset of 19 net-zero technologies. It establishes two overall benchmarks for manufacturing capacity for net-zero technologies in the EU:

- for the EU to produce at least 40% of its annual deployment needs by 2030;
- for the EU to produce 15% of world needs, according to value, by 2040.

To boost the manufacturing capacity for net-zero technologies in the EU, the NZIA seeks to reduce the administrative burden for manufacturers by streamlining and accelerating permitting procedures. Additionally, it recognises and promotes strategic projects, i.e. large-scale or critical net-zero technology manufacturing and infrastructure projects that are considered essential for achieving EU climate and industrial objectives.

It also envisages that Member States may designate specific areas as net-zero acceleration valleys to accelerate net-zero activities (see more on this in Section 2.2.3). It also introduces governance innovations to encourage experimentation and reduce administrative barriers, such as:

- one-stop shops, which centralise administrative procedures so project developers can deal with a single authority rather than multiple bodies;
- technology-neutral procurement rules, which ensure that public authorities select projects based on performance criteria rather than favouring specific technologies;
- regulatory sandboxes, which allow companies to test innovative technologies in a controlled real-world environment under simplified regulatory conditions.

The NZIA is supported by new coordination mechanisms such as the Net-Zero Europe Platform (NZEP), which monitors progress towards the 2030 manufacturing target and facilitates dialogue on permitting, financing and market access.

Complementary to the NZIA, the Critical Raw Materials Act (CRMA) also entered into force in 2024 (EU, 2024a). This aims to secure access to materials like rare earths that are essential for net-zero technologies. In July 2025, the EC launched the Energy and Raw Materials Platform to support the implementation of the CRMA. This platform is designed to match supply and demand for energy and critical raw materials (CRMs) across Member States and partner countries, thereby supporting competitiveness and decarbonisation.

In addition, the EC's 2026 work programme announced the creation of the Critical Raw Materials Centre to monitor, jointly purchase and stockpile key inputs needed for the clean-tech, digital, automotive, space and defence industries (EC, 2025b). The aim is to further strengthen Europe's industrial resilience and sovereignty.

2.1.3 The Clean Industrial Deal

The strategic turn towards a broader, more coordinated and cross-sectoral framework for industrial policy was further consolidated in early 2025 with the publication of the EC Communication on the Clean Industrial Deal (CID) (European Commission, 2025f). This marked a significant evolution in EU industrial policy, as it highlights the intrinsic link between industrial competitiveness and decarbonisation.

Building on the Letta report on the Single Market (Letta, 2024), the Draghi report on the future of European Competitiveness (Draghi, 2024) and the 2025 competitiveness compass (European Commission, 2025a), the CID aligns with the EU's political priorities for 2024-2029. These place industrial resilience and circularity, technological sovereignty and a just green transition at the core of the EU's growth model.

Functioning as a large-scale business plan to further support the competitiveness and resilience of EU industry, the CID aims to simultaneously accelerate decarbonisation and boost EU manufacturing. In this context, the clean-tech sector is central to future competitiveness and essential for driving industrial transformation and achieving decarbonisation.

The CID also emphasises the importance of enabling conditions such as affordable energy — addressed through the affordable energy action plan (EC, 2025c) — facilitating investment and demand-side incentives for clean-tech products.

In addition and as part of the CID implementation package, in March 2026 the EC presented a legislative proposal to increase the demand for low-carbon, European-made technologies and products. This is known as the Industrial Accelerator Act (IAA). The IAA is a key initiative to strengthen Europe's industrial base and create jobs. It also seeks to raise manufacturing's share of EU gross domestic product (GDP) from 14.3% in 2024 to 20% by 2035, while reducing strategic dependencies, in particular on China.

The IAA covers strategic sectors accounting for 15% of the EU's manufacturing production, including both net-zero technologies and energy-intensive industries. To deliver on this, the act will:

- support lead markets for 'Made in EU' and low-carbon products by introducing requirements for public procurement and public support schemes;
- ensure that foreign direct investment (FDI) brings value to the EU and guarantee a minimum level of European employment of 50%;
- streamline and digitalise permitting procedures for industrial projects;

- introduce industrial acceleration areas designed to enable industrial symbiosis and encourage the creation of clean manufacturing project clusters.

Another key implementation measure under the CID is the Electrification Action Plan, adopted in July 2026. The plan aims to accelerate the uptake of electricity-based solutions across industry, transport and buildings and sets an indicative target of increasing the share of electricity in the EU's final energy consumption from around 23% today to 46% by 2040. It promotes the deployment of clean technologies and recognises that accelerated electrification can strengthen Europe's net-zero technology manufacturing capacity, support industrial competitiveness and create quality jobs.

2.1.4 AccelerateEU

In response to rising energy costs triggered by the conflict in the Middle East in March 2026 and the closure of the Strait of Hormuz, the EC took action to accelerate Europe's clean energy transition and strengthen energy resilience. AccelerateEU, published in April 2026, outlines a plan to deliver swift short-term relief for consumers and industries affected by rising energy costs, while reducing structural dependency on imported fossil fuels in the long term.

It couples immediate relief measures (including targeted income-based support, energy vouchers for vulnerable households, social leasing, VAT reductions and tax incentives) with a broader push to accelerate the transition to more homegrown clean energy. The approaches used to achieve this include further electrification and the deployment of renewable energy sources.

AccelerateEU calls for annual renewable electricity deployment to be scaled up to 100 gigawatts (GW), supported by:

- new large-scale renewable projects;
- faster solar roll-out capable of delivering quick results;
- maximising existing renewable energy assets (e.g. by upgrading and modernising existing renewable plants).

In particular, AccelerateEU explicitly recognises the need to accelerate the replacement of gas and oil boilers with heat pumps. This is based on evidence that doubling commercial and residential heat pump capacity could lower fossil fuel consumption by approximately 200 terawatt hours (TWh) annually.

AccelerateEU also recognises that a resilient energy system based on clean, domestic sources depends on sufficient electricity and thermal storage as well as system flexibility, including batteries and pumped hydro. EU storage capacity must expand rapidly from around 55GW today to 200GW by 2030. Batteries will drive much of this growth. In this context, early and sustained political support for projects already in development is crucial.

2.1.5 Strengthening financial support for clean tech

At the EU level, funding for clean technologies has evolved into a multi-layered and increasingly interconnected framework. It combines several instruments and funding streams that interact and reinforce one another. The Recovery and Resilience Facility (RRF) (EU, 2021a) is at the heart of the REPowerEU plan (EC, 2022), which sets out the strategic agenda for reducing fossil fuel dependency and boosting clean energy uptake. The EC has mobilised nearly EUR 300 billion for this.

The Innovation Fund, financed by the Emissions Trading System (ETS), remains a reliable instrument allowing EU industries to secure financing for industrial decarbonisation and clean-tech manufacturing projects. It is one of the world's largest funding programmes for innovative low-carbon technologies. Estimates indicate that it will provide around EUR 40 billion in funding from 2020 to 2030. The fund awards grants through calls for proposals and through competitive bidding procedures (auctions).

In December 2025, the EC announced three new funding opportunities under the Innovation Fund, backed by EUR 5.2 billion from EU ETS revenues. These funds will be used to accelerate Europe's clean industrial transformation. The 2025 net-zero technologies call (EUR 2.9 billion) will fund innovative projects in renewable energy, energy storage, heat pumps, hydrogen production and electric vehicle batteries. In 2024, there was a EUR 1 billion call for proposals specifically targeting electric vehicle battery cell manufacturing. Another call in 2023 allocated EUR 1.4 billion to clean-tech manufacturing for renewable energy, energy storage, heat pumps and hydrogen production.

Since June 2025, as part of the renewed and strengthened agreement with the EC for project development assistance (PDA) under the Innovation Fund, the European Investment Bank (EIB) has been offering enhanced technical and financial advisory support for innovative decarbonisation projects. As one of the world's largest providers of climate finance, the EIB Group plays a pivotal role in leveraging and attracting additional private investment.

The EIB has expanded its clean-tech portfolio and announced increased support for the European battery manufacturing value chain. It is also supporting the clean-tech sector through the TechEU programme; this finances the development, manufacture or deployment of innovation in the EU. It achieves this by supporting innovating companies throughout their investment journey and it complements the EC's startup and scaleup strategy. TechEU will provide EUR 70 billion in EIB Group equity, quasi-equity, loans and guarantees from 2025 to 2027; it also aims to crowd in private capital to generate at least EUR 250 billion in investment.

The InvestEU Fund offers lending and guarantee instruments for investment in renewable energy, energy efficiency and electricity network projects. It aims to mobilise more than EUR 372 billion in public and private investment through an EU budget guarantee of EUR 26.2 billion implemented in partnership with selected financial partners, including the EIB and other financial institutions. A revised InvestEU Regulation was adopted in December 2025, as part of the Omnibus II investment simplification package, increasing the EU guarantee and supporting investments aligned with the Clean Industrial Deal. The Modernisation Fund, also financed by ETS revenues, is supporting targeted investments in renewable energy, energy efficiency, energy storage, energy networks and a just transition in 13 Member States, primarily in Eastern Europe and the Baltic region. It is a key part of the GDIP and its total revenue will amount to EUR 57 billion from 2021 to 2030.

Horizon Europe is the EU's key funding programme for research and innovation; its funding for the period 2021-2027 is expected to total EUR 93.5 billion. Horizon Europe finances research and pilot production through initiatives such as BATT4EU and Battery 2030+, the co-programmed European Partnership for Innovation in Solar PV (EUPI-PV) and the advanced manufacturing technologies for leadership of EU manufacturers in products for the net-zero industry (Made in Europe Partnership).

Another key instrument is the Strategic Technologies for Europe Platform (STEP), established in 2023. STEP is not an independent funding programme; rather, it consolidates resources from 11 EU programmes to finance strategic technologies and the skilled workforce needed to implement them. Support can be cumulative, with funding from multiple sources (e.g. combining Innovation Fund grants with Cohesion Fund). The STEP Seal (or Sovereignty Seal) is a quality label for excellent projects; it is designed to facilitate this combined funding approach.

It is important to note that no dedicated new funding has been earmarked for implementing the NZIA. Instead, the act is being implemented through existing EU funding instruments, including the Recovery and Resilience Facility, InvestEU, the cohesion policy programme and the Innovation Fund.

In addition, STEP will coordinate and channel EU funding to support clean-tech value chains, including the net-zero technologies covered by the NZIA. The act also encourages Member States to allocate up to 25% of the revenue they derive from the EU ETS to support clean-tech manufacturing (EPRS, 2025a).

The CID expands this funding landscape by setting out an ambition to enhance the synergies between existing funding instruments, as well as proposing new instruments, such as an Industrial Decarbonisation Bank. The latter is expected to mobilise over EUR 100 billion to strengthen the business case for clean manufacturing within the EU; funding for this will come from the Innovation Fund, additional revenues resulting from parts of the ETS as well as the revision of InvestEU. The Industrial Decarbonisation Bank is being tested through a pilot launched in 2025 with a EUR 1 billion auction on the decarbonisation of key industrial processes across various sectors supporting industrial decarbonisation and electrification. Table 2.1 provides an overview of the main EU funding instruments presented above.

Table 2.1 Main funding instruments for clean technologies at the EU level

Instrument	Funding size	Funding type	Focus areas	Key features
RRF	Climate expenditure ~EUR 275 billion; >EUR 184 billion allocated to energy-related measures	Grants and loans to Member States	Reduce fossil fuel dependency and accelerate clean energy deployment	Central pillar of REPowerEU
Innovation Fund	~EUR 40 billion (2020-2030) EUR 2.9 billion (net-zero technologies call, 2025)	Grants and auctions	Innovative low-carbon technologies	Financed by the ETS
EIB	EUR 70 billion (TechEU Programme, 2025-2027) Crowd in private capital to generate ~EUR 250 billion in investments	Loans, equity, quasi-equity, guarantees	Development, manufacturing or deployment of innovation in the EU	Major climate finance provider; PDA support under Innovation Fund
InvestEU	Mobilises >EUR 372 billion (with EUR 26.2 billion guarantee)	Lending and guarantees	Renewables, energy efficiency, electricity networks	Revised regulation increasing the EU guarantee and aligned with CID
Modernisation Fund	~EUR 57 billion (2021-2030)	Grants	Renewables; energy efficiency, storage, networks; just transition	ETS financed; focus on Eastern Europe and Baltic region
Horizon Europe	EUR 93.5 billion (2021-2027)	Grants (primary instrument)	Advanced clean-tech research; pilot production	Examples: BATT4EU, Battery 2030+, EUPI-PV, Made in Europe Partnership
STEP	No standalone budget; consolidates 11 programmes	Combined funding	Scale-up of strategic technologies and related skills	Enables cumulative funding (e.g. Innovation Fund + Cohesion Fund); Sovereignty Seal as quality label
Industrial Decarbonisation Bank	Mobilises >EUR 100 billion Pilot with EUR 1 billion auction	Combined funding; auctions	Strengthens the business case for clean manufacturing within the EU; supports industrial decarbonisation and electrification	Based on funds in the Innovation Fund; additional revenues resulting from parts of the ETS as well as the revision of InvestEU The bank will be placed under the governance of the future Competitiveness Fund

Source: EEA compilation.

The EC has also simplified existing state aid rules and adopted in June 2025 the CID State Aid Framework (CISAF) (European Commission, 2025b), which facilitates national-level support for accelerating the clean energy roll-out. The CISAF will also permit technology-specific support schemes — notably for wind and solar power — and further facilitate aid for non-fossil flexibility solutions (1) and capacity mechanisms that accelerate the decarbonisation of energy systems. In addition, the updated rules will allow support for expanded clean-tech manufacturing — including batteries and renewable technologies — by revising provisions applicable to investments in manufacturing capacity for strategic net-zero equipment. The CISAF is expected to remain in force until December 2030.

In the context of the Middle East crisis and the conflict in Iran, the EC adopted on 29 April 2026 the Middle East crisis temporary state aid framework to enable Member States to support the EU economy. This will be in place until December 2026, and it

(1) Technologies and measures that provide flexibility to the energy system without relying on fossil fuels.

also includes temporary amendments to the CISAF to allow for higher aid intensity of electricity price relief schemes.

Measures to stimulate demand for clean products were also announced as part of the CID, for example opportunities for social leasing to help citizens access clean technologies. These measures will be supported by the Social Climate Fund (SCF), which targets vulnerable people and small businesses who are most affected by rising energy and transport costs as Europe moves towards climate neutrality. The SCF can indirectly accelerate the deployment and diffusion of clean technologies across the EU by removing economic barriers that prevent vulnerable customers and small businesses from switching to cleaner and more energy-efficient solutions. In the Electrification Action Plan, the Commission proposes guidance to Member States on social leasing and support schemes for example on. household batteries and battery electric vehicles, clean energy and heating and cooling products.

Strategic public procurement also increasingly underpins the industrial finance mix by crowding in private capital and creating predictable demand. The Industrial Accelerator Act foresees the use of public procurement to boost demand for EU clean-tech industry and products, while a broader review of the EU public procurement framework was announced in the CID.

Looking ahead, the next Multiannual Financial Framework (MFF) for 2028-2034 will be a crucial driver of the clean transition. The proposed European Competitiveness Fund, as part of the post-2027 MFF, is also expected to provide robust support for innovative industries, enabling sustainable investments and offering simplified, one-stop access to EU funding. Clean tech and decarbonisation is one of the four areas it is expected to support.

Finally, while public financing instruments can play a critical role in signalling confidence to private investors and mobilising private capital for European clean-tech investments, Europe still faces an investment gap both in the start-up and growth phases (Cleantech for Europe, 2025). Public money alone cannot cover the significant investment needs. To help mobilise private investment, the EC adopted a clean energy investment strategy in March 2026. It will also host a clean energy investment summit in 2026. This will bring the financial services industry together with industrial leaders, project developers and public financiers, with the aim of accelerating private financing.

FDI is also an important driver in scaling up clean technologies in industry. Recent analysis by the Organisation for Economic Co-operation and Development (OECD), based on research funded by the Directorate-General for Regional and Urban Policy (DG REGIO), shows that nearly 95% of greenfield FDI in clean technologies across OECD and EU countries is directed towards manufacturing; this indicates that investors primarily target large-scale production rather than research and development (R&D) (Bianchini et al., 2025).

2.2 A just transition to net-zero industry — social and territorial considerations

2.2.1 Enhancing skills for quality job creation

Skills development and quality job creation have become central pillars of the EU's industrial policy frameworks. This reflects the growing need for a sizeable skilled workforce to drive the clean transition and maintain EU competitiveness. As industries scale up net-zero technologies, demand for specialised skills in areas such as renewable energy and clean-tech innovation is accelerating. Investing in people is no longer an adjunct to industrial policy — it is a strategic necessity for achieving a fair, inclusive and sustainable industrial transformation.

Enhancing skills had already been identified as one of the four key pillars of the GDIP. The NZIA provides for the establishment of the net-zero industry academies, with the aim to strengthen upskilling and reskilling programmes in strategic net-zero industries, thereby helping to address skills shortages.

The EC supports the establishment of European net-zero industry academies. EU funding is allocated to support their launch, through existing programmes. The aim is then for them to achieve financial sustainability within three years, including contributions from the private sector. Member States will assess whether academy learning programmes are equivalent to nationally required qualifications for regulated professions relevant to the net-zero technology industry. Where appropriate, they will also facilitate the recognition of resulting credentials (EPRS, 2025a). Chapter 3 provides more details on industry-specific academies for the technologies in focus.

These academies complement the EU renewable energy skills partnership, a large-scale, sector-wide cooperation initiative launched in March 2023 under the EC's Pact for Skills. It aims to ensure that Europe has a skilled and diverse workforce sufficient to deliver the rapid deployment of renewable energy technologies needed to meet EU climate and energy objectives.

The NZIA also explicitly acknowledges that creating quality jobs in net-zero technologies is in line with the European Pillar of Social Rights. It also recognises that better working conditions are essential to attract workers and help address labour shortages.

Building on the Draghi report (Draghi, 2024), the CID also identifies skills and quality jobs as key enablers of the clean industrial transformation, emphasising the importance of reskilling/upskilling and education initiatives to ensure that workers can adapt to technological shifts while also securing quality jobs.

Under the CID, the Union of Skills was launched in March 2025 as the new overarching skills strategy for the EU (European Commission, 2025k). It aims to ensure that workers are supported to acquire the skills needed for the green transition and that industry and companies have better access to these skills.

In November 2025, the EC launched the European skills guarantee. This is an initiative that aims to help workers transition into strategic industries, access new jobs and develop the necessary skills. As a first step, the EC has introduced the skills guarantee pilot, with a budget of EUR 14.5 million; this will focus on workers from the automotive industry and its supply chains who are at risk of unemployment. The pilot will test different job-to-job transition schemes. Grant projects will run for up to 24 months, until summer 2028. The results of the pilot will inform the design of the future skills guarantee scheme.

The Union of Skills will also aim to support the free movement of workers, for example via the skills portability initiative. This will support people with the right skills and qualifications to move between Member States, independently of where they received their training. The EC will also establish an EU talent pool to help recruit jobseekers from outside the EU at all skill levels, with a particular focus on occupations that have skills shortages.

Also under the CID umbrella, the EC has recently published the Quality Jobs roadmap (European Commission, 2025h). This sets out the EU's renewed commitment to fostering quality employment in a competitive economy. It defines priority areas for action to create and maintain quality jobs, ensure fairness and adapting the world of work to the digital and green transitions. Additionally, it aims to support workers through labour market transitions.

The roadmap emphasises:

- the role of social dialogue;
- stronger enforcement of social rights;
- resilient productivity supported by skills development and upskilling;
- improved anticipation and management of restructuring;
- fair wages and collective bargaining;
- high standards of occupational safety and health.

A Quality Jobs Act is expected to follow in 2026. This will be a legally binding instrument that should further strengthen job quality initiatives. In this context, there are ongoing discussions about a proposal for a just transition directive (EPRS, 2025b) (Picard, 2025) to address the challenges and opportunities of a just-transition in the workplace; notably this will focus on anticipating and managing change and the right to training.

To inform initiatives for a just transition, the EC launched the European Fair Transition Observatory in March 2026, led by the Directorate-General for Employment, Social Affairs and Inclusion (DG EMPL). The observatory will strengthen the evidence available on the employment implications of the green transition, including quality job creation, workforce reskilling and job-to-job transitions.

Finally, the CID also recognises the importance of using social conditionalities in public funding [2] not only to ensure support for economic or industrial objectives, but also to deliver social benefits.

(2) Requirements that link financial support to social objectives or standards.

Box 2.1

Key areas of stakeholder debate on the just-transition principles in the CID

The CID constitutes a significant evolution in EU industrial policy — from fragmented, market-driven approaches to a more coordinated and interventionist framework that aims to address the challenges of competitiveness, decarbonisation, economic resilience and security simultaneously. Yet, this new architecture remains subject to extensive debate.

While stakeholders broadly endorse the overall direction and ambition of the EU's clean-tech industrial strategy, they diverge on its scope, enforceability and ability to deliver a genuinely fair transition. These tensions reflect the growing complexity of balancing industrial competitiveness, decarbonisation ambition and social fairness within a rapidly changing global landscape.

While the CID acknowledges the social dimension of the green transition — mainly with regard to workforce reskilling and job quality initiatives — stakeholders across trade unions, civil society and think tanks consider this aspect of policy to be underdeveloped and lacking specifics. There are calls for social objectives to be placed on an equal footing with industrial goals and for core aspects of a fair green transition to involve enforcing and monitoring these objectives.

While trade unions in the EU generally welcome the inclusion of social conditionalities in the CID, they have been critical of the absence of concrete proposals. They have also flagged the need for binding requirements for social conditions and to ensure that public funding, public procurement and state aid genuinely benefit workers and support a just transition (IndustriAll, 2025). Trade unions also stress that robust social dialogue and collective bargaining should be part of these conditions and that stronger measures are needed to protect workers during industrial restructuring and to deliver a truly fair and socially balanced industrial policy.

Additionally, civil society organisations note that industrial change affects not only workers, but entire communities and territories, and that the impact of the transition on vulnerable and marginalised groups is overlooked, notably beyond employment and skills (e.g. access to essential services, social protection systems, social inclusion, etc) (Solidar, 2025).

It is furthermore argued that the regional dimension is also critical and not sufficiently addressed in the CID. Regional decarbonisation trajectories are highly path-dependent and shaped by long-standing industrial legacies and governance capacities. This underscores the need for place-sensitive strategies and context-sensitive planning. While the promotion of industrial clusters has various economic benefits, there are also risks associated with 'picking winners' (European Commission, 2025j) and deepening geographical inequalities, particularly in regions already facing industrial decline. Concentrating developments spatially could run counter to the EU's long-standing objectives for regional convergence. Without attention to where jobs are created or lost, industrial strategies risk reinforcing existing employment hubs while offering little to regions already declining, thereby deepening existing divides.

Financial support for skills development and just transition

In setting its priorities for the 2021-2027 budget cycle, the EU has allocated billions of euros to skills, notably via the Cohesion Fund (EUR 44.2 billion). The vast majority of this money comes from the European Social Fund Plus (ESF+) (EUR 40.4 billion), followed by the Just Transition Fund (JTF) and the European Regional Development Fund (ERDF) (EC, 2024). In addition, upskilling and reskilling is one of the seven priority spending areas of the Recovery and Resilience Facility (RRF).

The ESF+ is the EU's primary financial instrument for investing in people and delivering on the European Pillar of Social Rights. With a total budget of EUR 142.7 billion for 2021-2027, the ESF+ funds job-search assistance, training and reskilling programmes, as well as labour market integration for vulnerable groups. The skills guarantee pilot mentioned above will be implemented under the ESF+. The NZIA also encourages Member States to use the ESF+ to support the roll-out of learning content for net-zero academies (EPRS, 2025a).

While ESF+ focuses directly on people, employment and training, the ERDF strengthens the structural, industrial and innovation foundations that enable skills development and quality job creation. This means that it is also a key instrument for workforce development in the context of the green and clean industrial transition, albeit less directly.

The JTF focuses on the regions most affected by the transition towards climate neutrality, with a total 2021-2027 budget of EUR 19.7 billion. It helps in particular regions dependent on solid fossil fuels and on high-emission industries to cushion the socio-economic impacts of their transformation towards cleaner industries.

In Poland, for example, the JTF has invested around EUR 2.4 billion to support retraining for 100,000 workers in the fossil fuel sector in Silesia and Western Małopolska. It has equipped them with new skills to work in renewable and climate-neutral industries. Several other examples across Europe illustrate how the JTF can support the deployment of renewable energy and play a pivotal role in the long-term revitalisation of regions reliant on declining fossil fuel industries, while simultaneously benefiting local communities and workers (EEB, 2024).

The EU's cohesion policy is its main investment policy to strengthen economic, social and territorial cohesion within the EU, with the aim of addressing imbalances between countries and regions. In 2020, the EC set up the Just Transition Platform (JTP) to unlock funding from the Just Transition Mechanism (JTM). It is managed by DG REGIO.

The JTP supports the EU regions, industries and workers most affected by the shift towards climate neutrality. It serves as a hub for technical assistance, guidance on funding and knowledge sharing, helping stakeholders access resources such as the JTF and develop sustainable economic alternatives to greenhouse gas (GHG) emission-intensive activities. By connecting governments, businesses and communities, the JTP aims to ensure that the transition to greener practices is fair and inclusive, minimising social and economic disruption while promoting long-term resilience and new job opportunities.

Cohesion policy is also one of the main contributors to fulfilling the STEP objectives. As of July 2025, STEP had received EUR 9.1 billion in funding via cohesion policy for the 2021-2027 period. Within this framework, one targeted intervention — 'Support for the development of skills or access to employment in clean and resource-efficient technologies' — provides funding to 11 Member States through the ESF+, the ERDF (3) and the JTF.

Italy receives the largest allocation, exceeding EUR 500 million, followed by Germany which receives EUR 88 million. The remaining Member States receive between EUR 16 and EUR 30 million each, while the Netherlands (EUR 1 million) and Lithuania

(3) While the ESF+ focuses directly on people, employment and training, the ERDF strengthens the structural, industrial and innovation foundations that enable skills development and quality job creation; this means that it is also a key instrument for workforce development in the context of the green and clean industrial transition.

(EUR 80,000) receive the lowest levels of support. In total, the EU funding for this intervention amounts to EUR 700 million (EC, 2026a).

As part of the cohesion policy mid-term review, in September 2025 the European Council adopted amendments to existing regulations on the JTF, as well as the ESF+, ERDF and the Cohesion Fund. These aimed to maximise the contribution of cohesion policy to evolving political priorities and strategic challenges.

While in the initial proposal for the MFF 2028-2034 the EC did not include a stand-alone JTF, it did include Specific Objective 1.3 'support to just transition'. Furthermore, the proposal prioritises delivery of the European Pillar of Social Rights by investing in quality jobs, skills, education and social inclusion. This will be achieved through the ESF+ as well as national and regional partnership plans tailored to local needs and aimed at strengthening economic, social and territorial cohesion. The expectation is that at least 14% of national and regional partnership plans will be dedicated to social expenditure (European Commission, Directorate-General for Budget, 2025).

In addition to the Cohesion Fund, Erasmus+ — the EU's programme for education, training, youth and sport for the 2021-2027 period — also supports skills development in the transition to net-zero industry. With an estimated budged of EUR 26.2 billion for 2021-2027, Erasmus+ plays a central role in implementing the European skills agenda, the Pact for Skills and sectoral skills partnerships linked to EU industrial ecosystems. Examples of initiatives funded by Erasmus+ to support skills development across different technologies are presented in Section 5.3.1. Table 2.2 provides an overview of the funding instruments supporting skills developments in the EU.

Table 2.2 Key EU funds supporting skills

Funding instrument	Investment in skills	Purpose/focus
Cohesion Fund (incl. ESF+, JTF, ERDF)	EUR 44.2 billion for skills: • ESF+ (EUR 40.4 billion) • JTF (EUR 2.3 billion) • ERDF (EUR 1.5 billion)	The ESF+ is the main EU instrument for investing in people, employment and social inclusion. The JTF supports regions most affected by the transition to climate neutrality. The ERDF indirectly supports skills via industrial modernisation and job creation.
RRF	Total financial envelope of EUR 577 billion; no EU-level share of total RRF funds used for upskilling and reskilling; skills-related RRF spending varies across national recovery and resilience plans (NRRPs)	Upskilling/reskilling is one of seven priority areas, meaning skills investments appear across multiple RRF pillars.
Erasmus+ (2021-2027)	Programme ~EUR 26.2 billion	This plays a central role in implementing the European skills agenda, the Pact for Skills and sectoral skills partnerships linked to EU industrial ecosystems.

Source: EEA compilation based on EC, 2024, 2026c, 2026e.

2.2.2 Inclusion of women, young people and third-country nationals in the net-zero sectors

The NZIA recognises the importance of achieving a more diverse workforce in net-zero technology industries by supporting a number of different groups to seek employment: more women and young people who are not in education, employment or training (NEET), as well as people with a migrant background and those who have qualifications from third countries, older persons and persons with disabilities.

There are several systemic barriers driving women's under-representation in the clean-tech sector. These are apparent across the entire education-to-employment pipeline. One of them is the considerable gap in science, technology, engineering and mathematics (STEM) education and training pathways. Net-zero technology sectors largely depend on STEM-intensive and technical roles. However, women represent only 1 in 3 STEM graduates (European Commission, 2025l). Despite modest progress, the energy sector remains one of the most male-dominated sectors in the EU economy, with women's participation only increasing from 20% in 2010 to 25% in 2022 (EC, 2024).

STEM education is high on the EU agenda; meanwhile, gender inclusion is seen both as a social objective and as critical to meeting Europe's skills shortages — which are hampering competitiveness (Binder, 2025). The Union of Skills explicitly aims to reduce gender imbalances in STEM education and careers, with key initiatives such as the STEM education strategic plan — with a goal to train 1 million women and girls by 2028 via the 'Girls go STEM' initiative — and the forthcoming vocational, education and training (VET) strategy, which is expected to strengthen the attractiveness and inclusiveness of VET. The European Alliance for Apprenticeships (EAfA) has also reinforced its commitment to gender inclusion in apprenticeship.

Additionally, the EU promotes the inclusion of women in net-zero industry through a range of specific initiatives. The Empowering Underrepresented Women in the Energy Sector (EUWES) project was designed to address gender inequalities in Europe's energy sector by increasing the representation, visibility and influence of women, particularly in decision-making and leadership roles. Funded under the Citizens, Equality, Rights and Values Programme, the project was implemented in Croatia, Germany, Spain and Slovenia between 2023 and 2025.

The W4RES project, a three-year initiative launched in 2020 under Horizon 2020, promoted gender inclusiveness in the renewable heating and cooling sectors, including solar thermal technologies. Operating in Belgium, Bulgaria, Denmark, Germany, Greece, Italy, Norway and Slovakia, the project provided services to support women-led initiatives and capacity-building in the sector.

Examples of complementary initiatives include:

- the Equality Platform for the energy sector, which aims to strengthen the commitment to equality in all its dimensions, including gender and age;
- the Women in Energy Award, dedicated to recognising women who have made impactful contributions to Europe's clean energy transition;
- the Solar Diversity Charter and Solar Diversity Champion Award, which celebrates organisations that have been successful in achieving a gender-balanced and diverse workplace.

Gender diversity efforts are further strengthened through initiatives at the global level such as the Women in Wind Global Leadership Program and the Women in the Global Battery Industry. Moreover, the JTF has set up a working group on equal opportunities, supporting investment in the needs of vulnerable groups in just-transition regions, like women, young people and elderly people.

The EC also recognises that youth engagement is essential to delivering a just and successful energy transition, including renewables and clean technologies. In this context, the young energy ambassadors programme was launched in 2023 as part of its youth engagement strategy for the clean energy transition.

As a relatively young sector — particularly in areas such as battery production — the net-zero industry has the potential to attract younger cohorts who can align their education and training with the needs of emerging technologies. In contrast, older workers may face higher barriers to entry or career transitions, as their educational backgrounds were often shaped before the establishment and rapid growth of net-zero technologies.

Third-country nationals have also made important contributions to the twin transition in the EU by filling labour and skills gaps. However, they still represent only 4% of the workforce in green jobs [(4)]. This signals untapped potential (JRC, 2024).

The evidence available in the net-zero industry, however, is uneven and most insights are derived from case-specific examples. In the battery sector, for instance, over 50 nationalities were represented among the workers at Northvolt's first Swedish gigafactory (OECD, 2023). Meanwhile, Hungarian battery plants have been relying heavily on non-EU agency workers, often under precarious conditions (Czirfusz, 2025).

In the solar industry, German employers have initiated pilot recruitment schemes to attract workers from India (Hooper and Huang, 2024). EU-funded initiatives such as POWGEN illustrate attempts to address this need by training third-country nationals for roles in renewable energy and construction. As part of the Union of Skills strategy, the EU will set up an EU talent pool to recruit jobseekers from outside the EU at all skills levels, especially for jobs facing skill shortages.

2.2.3 Regional industrial clusters

The NZIA promotes geographically and technologically focused net-zero acceleration valleys as designated industrial clusters that:

- foster industrial symbiosis;
- streamline permitting;
- attract manufacturing investment;
- ensure the availability of skilled labour and infrastructure;
- support a just transition — especially in coal regions in transition.

Their aim is to reduce environmental impacts while boosting efficiency and competitiveness. Member States may designate and support net-zero acceleration valleys through comprehensive plans that:

- define the manufacturing activities being covered;
- streamline environmental impact assessments;
- mitigate environmental effects;
- provide time-bound national support measures — such as infrastructure investment, cost-reduction instruments and innovation incentives.

(4) In the Joint Research Centre (JRC) study, these are defined as jobs involving a minimum of 10% environmental-related activities.

These measures are designed to attract and secure industrial and private investment. Member States are encouraged to establish net-zero acceleration valleys in less developed and transition regions.

Although national governments retain primary responsibility for officially designating and planning net-zero acceleration valleys, the initiative is coordinated by the NZEP. This ensures that implementation is harmonised across Member States.

As of May 2026, two net-zero acceleration valleys had been formally designated. Following an application submitted to the Ministries of Economic Affairs in the German Federal States of Saxony and Brandenburg in March 2025, Lusatia became Europe's first net-zero acceleration valley (Business Saxony, 2025). Another region in Germany, North-West Lower Saxony, has also established itself as an net-zero acceleration valley (Niedersachsen, 2024). Two more regions, the Rhenish mining region (again in Germany) and Navarra in Spain are currently undertaking the process for designation (European Commission, 2026b).

Although formal designation of other net-zero acceleration valleys is still pending, an analysis of factors that feed into the choice of location can help to identify cluster potential. A study by the Centre for European Policy provides this kind of preliminary assessment, based on indicators capturing the quality of infrastructure (capacity in the areas of e.g. transport, information and communication technology, research base and public administration) and linkages with regional industry (Wolf A., 2024).

The analysis highlights significant spatial disparities across EU regions in terms of their readiness to develop net-zero industrial clusters. It also indicates that Central European high-tech manufacturing regions — particularly Czechia, Denmark, Germany (especially south-western Germany), the Netherlands and northern Italy — are especially well positioned. Meanwhile, despite strong employment potential, many lower-income eastern regions risk lagging behind due to shortcomings in infrastructure, notably in their knowledge and innovation systems.

More recently, the IAA introduced industrial acceleration areas. These are designed to enable industrial symbiosis and encourage the creation of clean manufacturing project clusters. Such clusters should facilitate investment in key energy infrastructure and allow for area-wide permitting. Projects situated within these areas should also avail of profiling with investors and access to support for skills development. Member States will be responsible for deciding which areas become industrial manufacturing acceleration areas, in alignment with strategic projects and other initiatives, including net-zero acceleration valleys.

Against this backdrop, there are ongoing regional disparities in industrial transformation and empirical evidence confirms that decarbonisation trajectories differ significantly between regions. This is due to path-dependent industrial structures and varying governance capacities (Bourdin and Perrot, 2025).

Indeed, many carbon-intensive regions continue to face structural barriers rooted in historical industrial specialisation, ageing infrastructure and institutional inertia. These factors can be described as elements of a 'regional carbon trap'. Addressing these entrenched dependencies requires not only investment in clean technologies, but also innovation in governance and coordinated industrial diversification strategies capable of breaking long-standing path dependencies.

As such, instruments designated by cohesion policy — particularly the JTM — are critical to support the transition. Ensuring sustained political commitment and stakeholder engagement remains key to preventing new forms of spatial inequality during the transition.

Figure 2.2 **The overarching industrial policy framework supporting a clean and just energy transition in the EU**

Foundational policy and legislative framework

European Green Deal (2020) and Fit for 55 (2022); EU Climate Law (2021) and 2025 amendments; REPowerEU (2022) and REPowerEU roadmap (2025); Renewable Energy Directive (RED III) (2023)

Green and clean industrial competitiveness

Net-Zero Industry Act (2024):
- target for manufacturing capacity for net-zero technologies (40% of EU annual deployment needs by 2030)
- streamlined permitting, one-stop shops, regulatory sandboxes
- strategic projects and net-zero acceleration valleys

Clean Industrial Deal (2025):
- a joint roadmap for competitiveness and decarbonisation
- builds on 'Draghi report' (2024) and 'competitiveness compass' (2025)
- focus: affordable energy, boosting demand for clean products; financing the transition; circularity and access to materials; acting on a global scale; skills and quality jobs
- **Industrial Accelerator Act (2026)**: 'Made in EU' and/or low-carbon requirements for public procurement and public support schemes; FDI conditionalities, 50% minimum level of European employment
- **Electrification Action Plan (2026)**: an indicative electrification target of 46% by 2040 (electricity share in final energy consumption); boosting the electrification potential to support Europe's net-zero technology manufacturing base and related value chains

AccelerateEU (2026):
- addresses the EU's rising energy costs amid volatile fossil fuel markets and aims to accelerate the transition to more homegrown clean energy and strengthen energy resilience

Strengthening financial support for clean tech

Clean Industrial Deal financing initiatives (2025 communication):
- CID state aid framework; strengthened Innovation Fund; proposal for an industrial decarbonisation bank; revised InvestEU Regulation

Horizon Europe:
- EU's key funding programme for research and innovation

Strategic Technologies for Europe Platform (2023):
- consolidates resources from 11 EU programmes to finance strategic technologies and related skills development needs

Workforce, skills and quality jobs

EU Pact for Skills (2020):
- EU Renewable Energy Skills Partnership (2023)

NZIA workforce dimension (2024):
- Net-Zero Industry Academies to support upskilling and reskilling in strategic net-zero industries

CID social fairness initiatives (2025-2026):
- Union of Skills and European skills guarantee
- Quality Jobs roadmap and forthcoming Quality Jobs act
- European Fair Transition Observatory

Overarching Just Transition Instruments and financial support for skills development

Just Transition Mechanism and Just Transition Fund:
- support regions and workers affected by industrial restructuring

Social Climate Fund:
- supports vulnerable people and small businesses who are most affected by rising energy and transport costs

European Social Fund Plus:
- the EU's main fund for skills, reskilling, inclusion, and worker support

Erasmus +:
- the EU's programme for education, training, youth, and sport — also supports skills development in the transition to net-zero industry

Source: EEA compilation.

3 Europe's clean-tech industry in transition

In the context of the strategic industrial policy framework outlined in Chapter 2, Europe's net-zero industry is now transitioning from planning to concrete action. The Net-Zero Industry Act (NZIA) and Clean Industrial Deal (CID) have established the foundations for scaling up clean-tech manufacturing and strengthening the resilience of value chains. Meanwhile, the industrial landscape shows both significant achievements and enduring vulnerabilities.

This chapter examines the industrial and economic reality of the European Union's (EU's) clean energy technology industry. It has a specific focus on wind energy, solar photovoltaics (PV), heat pumps and batteries. It introduces the technologies and their respective roles in the transition, their economic significance and growth potential, alongside their strengths and vulnerabilities in a global context.

3.1 Overview of clean energy technologies

The EU's clean energy technology sector encompasses a broad range of technologies essential for achieving climate neutrality by 2050. These technologies span the entire clean energy value chain, covering:

- renewable energy generation;
- energy conversion and storage;
- components and infrastructure for supporting systems.

Together, they underpin both the decarbonisation of the energy system and the industrial transformation envisaged under the CID.

Of the 19 technologies identified by the NZIA as central to the EU's industrial transformation and climate transition, eight are considered key for meeting the 2030 deployment target. These are:

- onshore and offshore wind;
- batteries and storage;
- solar PV and solar thermal technologies;
- heat pumps and geothermal energy;
- hydrogen technologies (electrolysers and fuel cells);
- sustainable biogas and biomethane;
- carbon capture and storage (CCS);
- grid technologies.

Other net-zero technologies are also supported by the measures in the act. These include: technologies related to sustainable alternative fuels, advanced technologies to produce energy from nuclear processes with minimal waste from the fuel cycle, small modular reactors and related best-in class fuels (5).

Based on an assessment of their economic significance and growth patterns, employment relevance and solid data foundations, four focus technologies were selected for in-depth analysis in this report:

- onshore and offshore wind energy technologies;
- solar PV technologies;
- heat pumps;
- batteries.

These technologies, described in Table 3.1, combine high relevance to the energy transition with sufficient data for focused analysis. They are either commonly deployed already or have substantial future growth potential. Box 3.1 provides examples of other technologies that play a central role in the clean energy transition in Europe.

The four technologies differ substantially in their purpose, maturity and economic characteristics. They range from utility-level electricity generation (e.g. wind, solar) to decentralised heating and efficiency solutions (e.g. heat pumps) and energy storage (batteries). However, there is good data coverage for all of them, which makes them suitable for the modelling approach adopted in this report. The data enable a detailed examination of their industrial structures and related employment and labour market trends.

Table 3.1 Overview of selected clean energy technology sectors

Technology	Definition
Onshore and offshore wind technologies	Wind technologies generate electrical power from the kinetic energy of atmospheric wind. They are classified as onshore or offshore systems. Onshore wind refers to turbines installed on land. Offshore wind refers to turbines located in marine environments.
Solar PV	Solar PV technologies generate electricity by converting sunlight directly through solar cells.
Heat pumps	Heat pumps are systems (machines, devices or installations) that transfer heat from natural sources such asair, water or the ground to buildings or industrial processes. They use electricity to move heat from a lower-temperature source to a higher-temperature destination. Reversible heat pumps can also provide cooling by transferring heat in the opposite direction.
Batteries	Batteries are devices that deliver electrical energy through the direct conversion of chemical energy (6). They consist of one or more non-rechargeable or rechargeable battery cells, modules or battery packs. Types of batteries include electric vehicle batteries (designed to provide electric power for traction) and stationary battery energy storage systems (industrial batteries that store and supply electricity to the grid or end users). These large-scale grid systems help to balance the grid, store excess energy, provide back-up power and manage peak electricity demand.

Source: Authors' own elaboration.

(5) 'Best in class fuels' refers to advanced nuclear fuels that represent the most environmentally and technologically advanced options available.
(6) This report focuses on electric — not thermal — batteries. Thermal batteries store energy in the form of heat rather than electricity and release it later when needed.

Wind energy plays a pivotal role in the EU energy transition. It is a mature technology and is already widely deployed across Europe. It continues to have potential for growth in energy production. In 2024, onshore wind was the renewable source that made the largest contribution to gross electricity production, followed by hydropower, as illustrated in Figure 3.1.

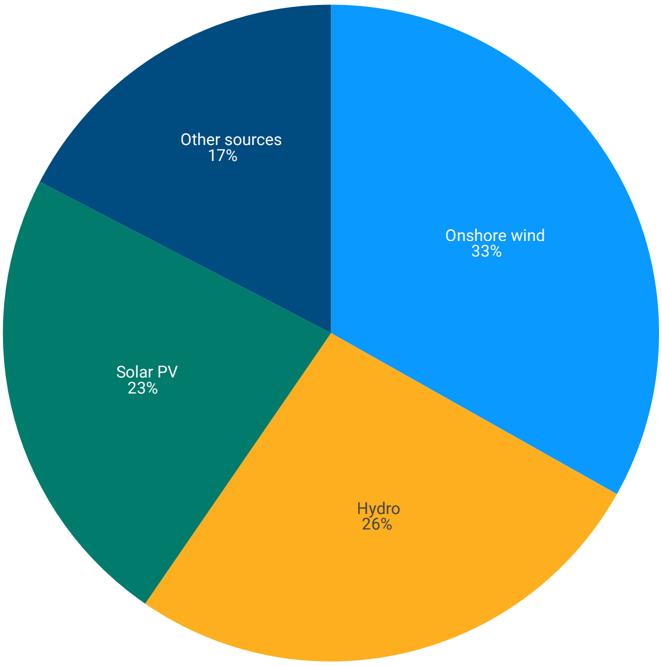
The EU has reaffirmed its commitment to accelerating wind energy manufacturing across Europe through the EU wind power package, presented by the European Commission (EC) in October 2023. As part of the package, the European wind power action plan sets out measures to support EU companies in the wind sector and improve their competitiveness. Examples of the measures included are increased predictability and faster permitting, as well as improved access to finance and development of the necessary workforce. Alongside the action plan, the EC communication on achieving the EU's offshore wind ambitions highlights the need to accelerate investment in offshore wind and ocean energies.

Solar PV also has a high technology readiness level (TRL) [7]. This translates into competitive energy production costs and reflects that it is already widely deployed in the EU energy market. Despite its maturity, solar PV still has considerable potential for increased capacity, improved efficiency and further cost reductions.

The main challenge in this sector lies in manufacturing; the EU remains heavily dependent on external producers, particularly China, as discussed more extensively later in this chapter. The EU solar energy strategy, launched in May 2022, sets out a comprehensive vision for solar PV and proposes targeted initiatives to accelerate the rate of uptake of solar energy. These include the European solar rooftops initiative. This aims to unlock the underutilised potential of rooftops for solar generation and includes a mandatory requirement for rooftop solar installations across several building categories.

(7) The TRL is a nine-point measurement system developed to assess the maturity of technologies. The scale ranges from 1 (basic principles observed) to 7 (system prototype demonstration in operational environment) and up to 9 (actual system proven in operational environment).

Figure 3.1 **Gross electricity production from renewables and biofuels in the EU in 2024**



Source: Eurostat, 2026h.

From a technological perspective, heat pumps are particularly relevant as they represent a key solution for reducing emissions in the building sector. The technology has a very high TRL and there is significant manufacturing capacity in Europe. Currently, heat pumps remain under-deployed across the EU, indicating significant growth potential. The Heat Pump Accelerator Platform, launched in January 2025, aims to identify barriers to the deployment of heat pumps across the EU. It also suggests targeted policy measures to address them.

As announced in the Electrification Action Plan in July 2026, the Commission will explore ways to mobilise public demand for heat pumps. It will also adopt a Cooling and Heating Action Plan, including to address the growing need for efficient cooling for EU citizens and economy.

Batteries are expected to play a crucial role in an energy market increasingly shaped by renewables. Although significant progress has been made in recent years, there is scope for further development and innovation. Manufacturing capacity in the EU is still limited, while China continues to dominate the market.

Electric mobility is becoming increasingly relevant, and in January 2026, battery-electric vehicles (BEVs) represented around 20% of all new passenger car registrations (EC, 2026d). At the same time, batteries are rapidly becoming a crucial pillar of Europe's energy system, increasingly used to store renewable electricity for the grid. This indicates that they are being deployed far beyond their traditional role in electric vehicles (Petrovich, 2026).

The Battery Booster strategy presented in December 2025 is the new overarching framework to strengthen the entire European battery value chain. It is built on six pillars:

- unlock investment;
- develop a resilient upstream value chain;
- align foreign investments with Europe's strategic interests;
- stimulate demand for EU-made batteries;
- accelerate research, innovation and skills for the battery value chain;
- coordinating action to maximise impact across Europe.

Under the first pillar, the Battery Booster facility aims to mobilise up to EUR 1.5 billion from the Innovation Fund to support European Battery cell producers, with support provided in the form of interest-free loans.

In the field of energy production, decarbonisation and energy storage technologies, the four technologies selected for analysis in this report represent dynamic and strategically significant segments of the EU's net-zero industry. This study focuses on exploring their industrial and labour market structures in greater depth.

Box 3.1

Other key clean energy technologies

While this study focuses specifically on wind technologies, solar PV technologies, heat pumps and batteries, it is recognised that other technologies play a central role in the clean energy transition in Europe. This box provides some examples of the technologies that have relevance in the current EU industrial policy framework.

Grid technologies are receiving increasing attention. In the past decade Europe has demonstrated that a successful energy shift is possible but greater interconnectivity and integration of the electricity system is essential to develop renewables further (EEA, 2025b).

In November 2023, as part of the European Green Deal, the EC published a grid action plan to speed up the deployment of electricity grids, which are considered the backbone of the European energy system. Building on this, in December 2025, the EC launched the European grids package. This aims to modernise the grid infrastructure to deliver cheaper and cleaner energy to citizens and businesses. However, several Member States remain off track to achieve the 15% interconnection target by 2030 (EC, 2026b) and interconnected grids are essential for building a true energy union.

Carbon capture and storage (CCS) technologies also have a key role to play in clean energy transitions. They have gained momentum through the industrial carbon management strategy (European Commission, 2024b). This establishes clear obligations for infrastructure development and storage capacity.

CCS technologies are unique: they contribute to reducing emissions in hard-to-abate sectors and also remove carbon dioxide (CO_2) from the atmosphere (IEA, 2020). However, CCUS technologies are still at an early stage; mostly they are still being developed. Carbon capture investments are increasingly economically viable, but there are limited CO_2 storage sites in operation in the EU. This constitutes a key bottleneck. The NZIA sets out an EU target of achieving at least 50 million tonnes of annual CO_2 injection capacity by 2030.

Hydrogen also plays a central role in decarbonising the EU energy system, particularly in hard-to-abate sectors where electrification is not yet a viable option, as recognised in the CID. There is already an advanced and structured policy architecture for hydrogen, anchored in the EU hydrogen strategy and the EU hydrogen and gas decarbonisation package, in the form of Directive (EU) 2024/1788 and Regulation (EU) 2024/1789, adopted in May 2024.

Bioenergy continues to represent a valuable — though minor compared to other renewable sources — contributor to the EU electricity market. Bioenergy involves the conversion of natural resources into energy carriers that can be used to generate electricity and heat, as well as to produce biofuels.

Unlike many other net-zero industries, energy production from bioenergy sources offers greater flexibility, since biomass can be stored and used when needed. In November 2025 the EC published the bioeconomy strategy (European Commission, 2025c). The bioeconomy encompasses biomass production and the conversion of biomass into food, materials and products, as well as the production of bioenergy.

3.2 Economic significance and market growth

3.2.1 Gross value added

Since 2010, the EU clean energy technology sector has become increasingly significant economically, as shown in the recent assessment of the competitiveness of clean energy technologies prepared for the EC's Climate, Infrastructure and Environment Agency (CINEA).

Gross value added (GVA) [8] for the EU clean technology sector has grown by an average of 8.3% per year in the period 2010-2023, reaching EUR 138 billion in 2023 [9]. This compares with a GVA in agriculture of around EUR 216 billion in 2020 (Eurostat, 2026e). Of the clean energy technologies, wind and solar PV energy rank highest in terms of GVA, at EUR 51,100 million and EUR 29,400 million respectively (Figure 3.2). These sectors have also experienced the highest growth in GVA, growing annually by 13.5% and 14.4% respectively over the 2010-2023 period (EC, 2025a).

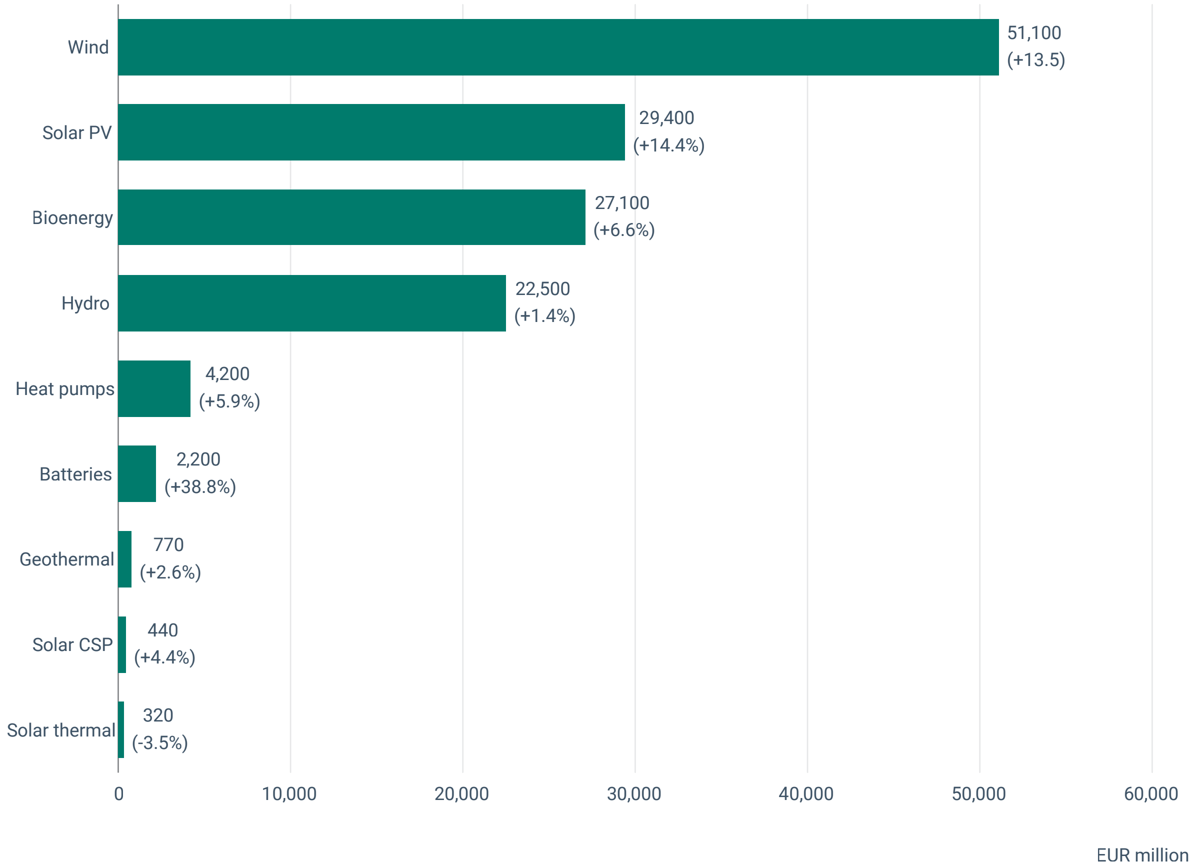
Despite being of lower economic significance in terms of GVA, heat pumps and — to an even greater extent — batteries have also shown strong growth. The GVA from heat pumps doubled between 2010 and 2023, reaching EUR 4,200 million in 2023; this corresponds to average annual growth of 5.9%.

The battery market has shown the strongest upward trend, unmatched by any other clean energy sector. The sector's GVA increased from nearly zero in 2018 to EUR 2.2 billion in 2023; the average annual growth rate was 35.8 % over the 2010-2023 period — the highest of all the clean technologies. This trend confirms the emergence of batteries as one of the EU's fastest-growing and most strategically significant net-zero industries (EC, 2025a).

(8) Gross value added (GVA) is defined as output (at basic prices) minus intermediate consumption (at purchaser prices); it is the balancing item of the national accounts' production account.

(9) Including GVA from: wind energy, PV energy, bioenergy, hydropower, heat pumps, batteries, geothermal energy, concentrated solar power (CSP) and solar thermal energy.

Figure 3.2 GVA of selected clean energy technologies in the 27 EU Member States (EU-27) in 2023



Notes: GVA is given in EUR million and the average annual growth rate between 2010 and 2023 is given in brackets. Data refer to the EU-27 excluding Cyprus, Luxembourg and Malta due to limited data availability. Annual growth is calculated as compound annual growth rate (CAGR). The results are presented as nominal values reflecting the respective annual price level.

Source: Prognos 2025 based on EC, 2025a.

The expansion of GVA in the EU clean energy technology sectors has been supported by a growing number of enterprises. Battery-related enterprises increased the most in number (17% annual growth in the 2010-2023 period), followed by enterprises related to wind energy (+12.9%) and solar PV (+8.7%). In absolute terms, in 2023 solar PV and wind energy had the largest number of enterprises: 42,600 and 39,000 respectively (EC, 2025a).

Recent analysis on clean tech in Europe highlights the pivotal yet uneven role of small and medium-sized enterprises (SMEs) in clean-tech manufacturing across batteries, solar PV and wind technologies (Bianchini et al., 2025). While SMEs account for around 95% of firms in the economic sector concerned with manufacturing the three technologies, they are primarily engaged in the upstream and low value-added segments, such as the production of subcomponents and components; they currently contribute less to the value of exports. In contrast, large enterprises dominate final manufacturing and assembly and contribute to most net job growth.

When comparing GVA across Member States, Germany is the country with the highest absolute GVA for the wind energy (EUR 21,800 million) and solar PV sectors (EUR 11,700 million). Sweden leads in the heat pump sector (EUR 930 million), followed by Germany (EUR 570 million). In the battery value chain, Hungary has the highest GVA (EUR 990 million in 2023), again followed closely by Germany

(EUR 940 million) (EC, 2025a). The extent to which these geographical disparities in GVA translate into differences in relation to job creation will be discussed in Chapter 4.

3.2.2 Capacity, deployment outlook and investment

The NZIA has set non-binding manufacturing capacity benchmarks for the technologies being analysed in this study:

- 30 gigawatts (GW) for the PV sector;
- 36GW for wind energy;
- 31GW for heat pumps;
- 550 gigawatt hours (GWh) for batteries.

The EC staff working document 'Investment needs assessment and funding availabilities to strengthen EU's Net-Zero technology manufacturing capacity' presents a comparison of EU manufacturing capacity in 2022 with the respective targets for 2030 (EC, 2023b). It also assesses the investment needs associated with boosting EU manufacturing capacity for selected net-zero technologies. The analysis shows that about EUR 87.5 billion will be needed to achieve the NZIA objectives for wind, solar PV, heat pumps and battery cell production over the 2023-2030 period, as illustrated in Table 3.2. Even greater investment would be required for a scenario where EU manufacturing covers 100% of the EU's deployment needs, rather than relying on imports.

Manufacturing capacity will need to be rapidly scaled up across all four technologies in the coming years to meet the NZIA 2030 targets. However, it remains difficult to track manufacturing capacity consistently. The Net-Zero Europe Platform is intended to help monitor progress towards the NZIA targets, but an integrated public dataset or dashboard was not available at the time of writing.

A 2025 study commissioned by the Directorate-General for Energy (DG ENER) reports on Member States' operational manufacturing capacity for selected net-zero technologies and their components in 2023 (European Commission and ECORYS, 2025). In addition, Bruegel's European Clean Tech Tracker compiles economic information on clean technologies. It provides data on manufacturing capacity as a share of demand for selected technologies and their main components.

For example, the tracker shows that in the fourth quarter of 2025 the European operational manufacturing capacity for solar module assembly, solar cells and solar ingots and wafers only ranged between 14% and 3% as a share of demand. In contrast, for wind energy, European manufacturing capacity far exceeded the demand for wind nacelles and blades (417% and 311%, respectively). This is consistent with a relatively strong EU trade position in wind components and a continued high dependence on China for solar PV. This is discussed in more detail in the following section.

Importantly, significant labour and skills are required to ramp up the production of clean technologies. This is a key focus of this report and will be explored in detail in the following chapters. The EC has assessed the investment needs related to attracting, reskilling, upskilling and maintaining the net-zero industry workforce.

Based on the manufacturing capacity discussed above, the investment required to retrain, reskill and upskill workers would range between EUR 1.7 and EUR 4.1 billion for the period up to 2030. In addition to these specific investments in human capital in particular manufacturing sectors, the workforce must be expanded further to install and operate these technologies.

Table 3.2 Manufacturing capacity and NZIA targets

Technology	Manufacturing capacity in 2022	Manufacturing capacity — 2030 targets based on NZIA	Manufacturing capacity investment needs for the 2023-2030 period (EUR billion)
Wind	13GW	36GW	6.1
Solar PV	1GW AC	30GW	7.6
Heat pumps	14GW	31GW	5.6
Battery cell	75GWh	550GWh	68.2
Total			87.4

Notes: In the solar industry, AC refers to alternating current. When the capacity is specified as GW AC, it refers to the usable electrical power after conversion by inverters, reflecting what can actually be delivered to the grid.

Source: EEA based on EC, 2023b.

More recent and complimentary evidence on the current deployment and outlook for specific technologies is provided by industry-level analysis. An overview of this is presented in Table 3.3.

Wind energy data for Europe show that the EU-27 had 236GW of installed wind power capacity — 215GW onshore and 21GW offshore — in September 2025 (WindEurope, 2025c). WindEurope expects the EU-27 to build new wind farms with a total capacity of 22GW each year on average over the 2025-2030 period and to have 344GW of wind capacity installed by 2030 (298GW onshore; 46GW offshore).

While the EU Renewable Energy Directive 2023/2413 (RED III) sets out a binding EU-wide target for at least 42.5% of all energy consumed to be provided by renewables by 2030, it does not indicate any technology-specific targets. The European wind power action plan indicates that installed wind capacity would need to grow from 204GW in 2022 to more than 500GW in 2030 in order to reach this target (European Commission, 2023). The calculation is based on the MIX policy scenario for delivering the European Green Deal.

Notably, industry analysis from WindEurope refers to 425GW as the approximate wind capacity required to meet the RED III target. The expansion in capacity is supported by financial investment. In 2024 this returned to the pre-pandemic level in the EU and has continued to accelerate. Wind farm investment totalled EUR 34 billion in Europe in the first six months of 2025, surpassing the entire total for 2024 (WindEurope, 2025c).

Meanwhile, the latest data from the 'EU Solar Market Outlook 2025-2030' indicate a decade of continuous growth in the EU solar market, including rapid expansion between 2021 and 2023 (SolarPower Europe, 2025b). However, this was followed by a sharp slowdown in 2024, when annual growth dropped from double-digit rates to just 2.8%. The market is now at a turning point, with a further decline in newly installed solar PV recorded in the EU in 2025 (a 0.7% contraction from 65.6GW installed in 2024).

Despite the market decline, it is estimated that total EU solar capacity was 406GW by the end of 2025, surpassing the target of 320GW set out in the EU solar energy strategy. Capital investment in EU solar PV climbed steadily from roughly EUR 19 billion in 2020 to about EUR 60 billion in 2023. However, this upward trend changed markedly in 2024 (SolarPower Europe, 2024a).

Looking ahead, additions to EU solar capacity are expected to slow in the period to 2027, after which it is predicted that the sector will begin to grow again. However, under the current policies and conditions, the industry-backed 2030 benchmark of 750GW total installation capacity is unlikely to be met with projections indicating that it will only reach 718 GW (SolarPower Europe, 2025b). The latter number is above the target of 600GW by 2030 set out in the EU solar energy strategy.

Table 3.3 Current deployment and outlook

Technology	2025 status	2030 outlook	Notes
Wind	236GW installed capacity (215GW onshore, 21GW offshore)	344GW expected (298GW onshore, 46GW offshore)	Strong investment; ~22GW/year additions
Solar PV	406GW installed capacity; EU solar energy strategy target of 320GW exceeded but market slowing	On track to achieve EU solar energy strategy target of 600GW, but industry-backed benchmark of 750GW more challenging.	Slowdown is set to continue in 2026 and 2027
Heat pumps	2.31 million sales in 19 countries; 25.5 million heat pumps installed	Up to 4 million units/year installed	Market declined post-2022, but sales up in first quarter of 2026;
Batteries	251GWh cell production capacity; 4.6 million electric vehicles per year being manufactured	1.2 TWh to 1.7 TWh by 2030	FDI-driven; rapid growth of BESS

Notes: BESS, battery energy storage systems; FDI, foreign direct investment; GW, gigawatts; GWh, gigawatt hours; TWh, terawatt hours.

Source: EEA compilation based on industry-level analysis in Section 3.2.2 and Bruegel, 2026, and Fraunhofer Institute for Systems and Innovation Research ISI, 2025.

For heat pumps, deployment is commonly assessed using the number of installed units; this figure serves as a proxy for installed capacity. The heat pump industry also faced a difficult year in 2024. While 2.8 million heat pump units were installed in 2022, this slowed to 2.7 million in 2023 and fell to 2 million in 2024, as reported by DG ENER. The 2025 European heat pump market report published by the European Heat Pump Association (EHPA) indicates that heat pump sales across 19 European countries [10] fell to about 2.31 million units — 22% below 2023 levels (EHPA, 2025a).

Overall, the market expanded for a decade, peaked in 2022 and has since fallen back to earlier levels. The 2022 record in annual sales was largely driven by Russia's invasion of Ukraine, which sent gas prices soaring and prompted governments to boost subsidies, making heat pumps a more attractive option for residential heating.

In 2022 REPowerEU envisaged a doubling of the pace of deployment of heat pumps, resulting in an additional 10 million units by 2027. In terms of overall installed capacity, the latest figure from the EHPA market data indicates a total stock of

(10) These countries are Austria, Belgium, Czechia, Denmark, Estonia, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom.

around 28 million installed heat pumps. The EU is estimated to have the capacity to manufacture 1.2 million hydronic heat pumps (11) per year, rising to 1.4 million once supply chain constraints ease. Planned investment could boost the current production capacity to 7.8 million units annually by 2030 (Eunomia, 2024). In 2023 the total investment announced for heat pumps and components production in Europe came to nearly EUR 7 billion (EHPA, 2023).

Importantly, the energy crisis triggered by the war in Iran and the closure of the Strait of Hormuz on 2 March led to an average 17% increase in sales of residential heat pumps across 11 European countries over the period from January to March 2026, compared to the same period in 2025 (EHPA, 2026a).

The Electrification Action Plan includes the specific objective to increase the installation rate of heat pumps to around 4 million per year in 2030.

Finally, the battery sector covers both electric vehicle batteries and stationary battery energy storage systems (BESS). Electric vehicle batteries currently dominate policy attention and industrial investment; however, stationary BESS represent a rapidly expanding segment.

Smaller storage units — such as those used in combination with residential solar PV installations — are already widely deployed (Coccato et al., 2025). Evidence from SolarPower Europe's EU market outlook for battery storage (2025-2029) shows sharply rising utility-scale installations and growing system integration and commissioning activity (SolarPower Europe, 2025c).

The latest market monitor from the Energy Storage Europe Association reports that Europe's total installed energy storage capacity reached approximately 89GW in 2024, covering all storage technologies (pumped hydro, and battery and thermal energy storage systems). While pumped-storage hydro still dominates the market, BESS are playing an increasingly important role. AccelerateEU notes that the EU needs to expand its storage capacity to 200GW by 2030, although SolarPower Europe reports that it lacks the dedicated financing mechanisms to achieve this target (Publicover, 2026).

In terms of production capacity, data from European clean tech tracker show that, as of September 2025, European factories could produce about 251GWh (12) of battery cells per year and 4.6 million electric vehicles, compared with demand for batteries with a storage capacity of 410GWh in 2024 (around 90% for electric vehicles and the rest for stationary batteries) and 2.3 million electric vehicles. This means that Europe has the capacity to produce about two-thirds of the battery cells it needs and to build roughly twice as many electric vehicles as it sells domestically (Jugé, M. et al., 2025). Looking ahead, a conservative estimate suggests that the EU will have the capacity to manufacture batteries with a storage capacity of between 1.2TWh and 1.7TWh by 2030 (Fraunhofer Institute for Systems and Innovation Research ISI, 2025).

However, considerable investment is needed to set up battery cell production. It is estimated that since 2017, companies have invested EUR 38 billion in European battery manufacturing facilities and a further EUR 34 billion in electric vehicle manufacturing facilities. In 2025 alone, the investment in battery manufacturing amounted to EUR 6.7 billion (Jugé, M. et al., 2025).

(11) Hydronic heat pumps are systems that use water to distribute heat from a heat pump through radiators, underfloor heating or hot-water systems inside a building. Hydronic heat pumps dominate the EU market, led by air-to-water models, which make up almost half of all units sold.
(12) GWh units express the energy storage capacity of batteries produced. One GWh of battery production equates to the production of approximately 15,000 electric vehicles.

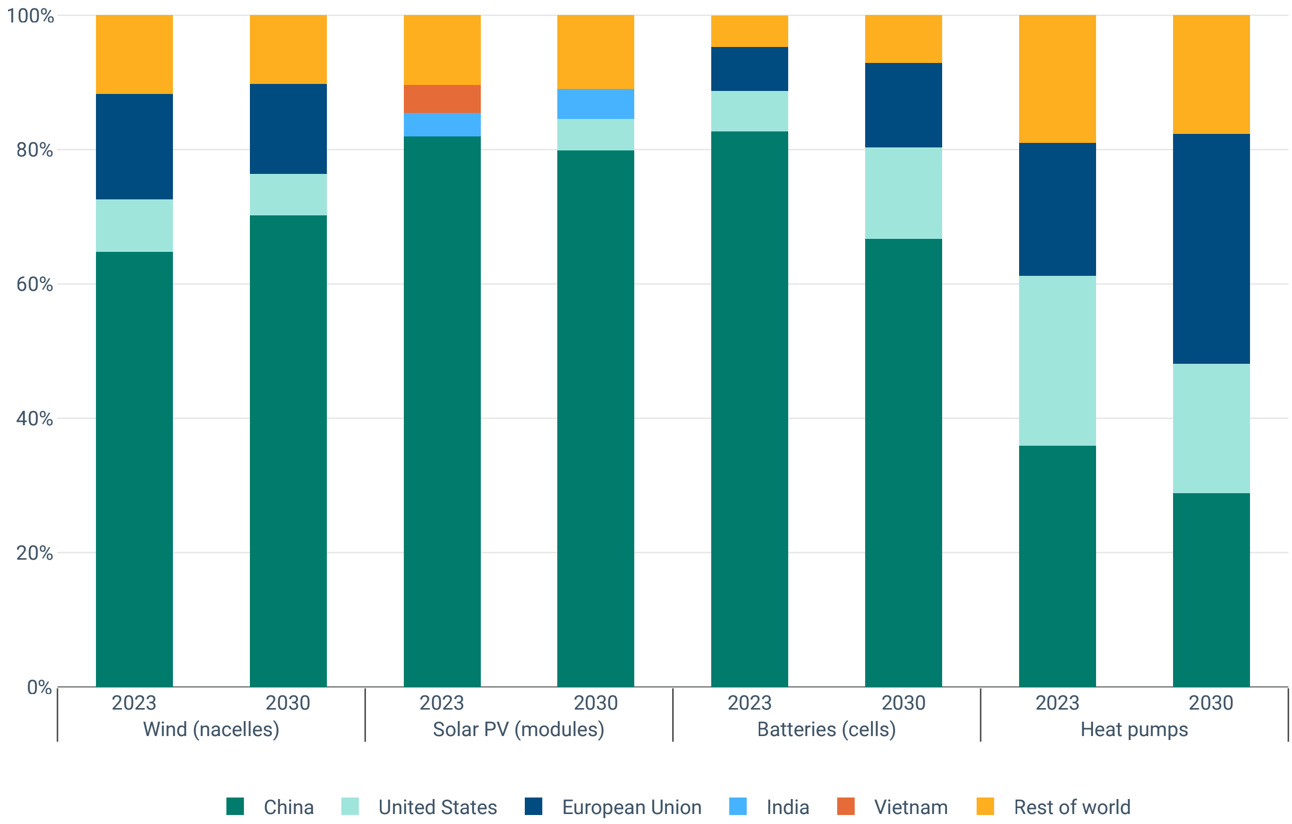
Foreign direct investment (FDI), especially from South Korea, has been central to building the EU's battery manufacturing base. Three leaders in lithium-ion (Li-ion) technology — LG Energy, SK Innovation and Samsung SDI — control about 80% of Europe's operative battery cell capacity. While investment from South Korea has slowed recently, Chinese investment is increasing (Jugé, M. et al., 2025).

3.3 Global market share and vulnerabilities

Over the past decade, the EU's position in the net-zero technology sector has evolved considerably. European companies have demonstrated strong capabilities while facing intensifying global competition that continues to challenge domestic manufacturers. At the same time, beyond cost-efficient and high-quality production, there is an increasing focus on considerations relating to economic resilience and strategic autonomy in Europe.

This section presents a summary of the EU market position and global market share for each technology, drawing on the Clean Energy Technology Observatory (CETO) reports 2025. Figure 3.3 provides an overview of the geographical concentration of manufacturing capacity in 2023. It also illustrates planned capacity up to 2030 for wind, solar PV modules, battery cells and heat pumps across different countries/regions globally.

Figure 3.3 Geographical location of manufacturing capacity of wind energy technology, solar PV modules, battery cells and heat pumps in 2023 and 2030



Note: The 2030 value includes all operational capacity in 2023 together with the capacity of announced manufacturing projects through to 2030.

Source: Adapted from IEA, 2024a.

The EU maintains a strong position in the global wind energy sector, particularly for offshore wind. It accounts for 38% of the global market for offshore wind turbines. Its trade performance is positive, with exports exceeding EUR 2 billion in 2024. However, competitive pressure is increasing as Chinese manufacturers continue to dominate the global onshore wind segment. While China remains the world's largest producer of wind turbines, European companies remain key players in the global offshore market (Tapoglou, E. et al., 2025).

In the PV sector, the EU continues to experience a negative trade balance, particularly with China. This is notably the case for PV modules, although this trade deficit has narrowed. The situation for inverters has improved significantly, with the EU recording a trade surplus in 2024.

In terms of PV installations, between 2015 and 2024 the EU's global market share declined by 60%, while China expanded its share by 130%, accounting for 46% of global PV capacity installed in 2024. Overall, higher production costs in the EU — combined with very low prices and oversupply from China — have placed significant pressure on European producers. As a result, several EU manufacturing companies are struggling to remain competitive (Chatzipanagi, A. et al., 2025).

In the global heat pump market, the EU is a major manufacturer of hydronic and large heat pumps for apartment buildings, district heating and industrial applications. Overall, the European heat pump industry is well positioned, with favourable prospects for continued growth and rising global relevance (Volt, J. et al., 2025).

It is expected that by 2030 the EU will have significantly expanded its heat pump manufacturing capacity to become the largest producer globally, with close to 40% of total worldwide production capacity (IEA, 2024a).

In terms of current installed capacity, in 2023 China still had the largest market share (35%), followed by the EU (27%) (Volt, J. et al., 2025). Industry estimates indicate that more than two-thirds of the heat pumps installed in Europe have been produced in Europe (EHPA, 2026b).

As for batteries, the dominant technology is currently Li-ion. However, sodium ion (Na-ion) batteries are becoming increasingly important, notably because they rely less on critical raw materials (CRMs) (Yao et al., 2025). China currently dominates the global trade in CRMs necessary for Li-ion battery production (EIA, 2025); it is also the market leader in the Na-ion segment, with a global market share of 99.4% in 2023.

This suggests that Europe's battery challenges are more complex than simply access to CRMs leading to reliance on third countries. High energy and labour costs as well as competition with well-established battery producers globally also pose significant challenges to the EU battery sector. The EU is not currently producing sufficient cost-competitive battery cells and components at scale and therefore relies heavily on imports of batteries from China, which accounted for over 85% of the total in 2024 (JRC, 2024; Bielewski et al., 2026). While the EU battery sector does enjoy strong support for its research and development (R&D) activities (Ragonnaud, 2025), the EU has lost its leadership in battery research (Bielewski et al., 2026).

Across technologies, Europe faces a set of common, structural and cross-cutting challenges that affect the extent to which production can be scaled up and deployment can be accelerated. These relate to, for example, higher energy and labour costs, which affect both capital-intensive manufacturing (e.g. of PV modules or battery cells) as well as more labour-intensive sectors (e.g. heat pumps). This makes it difficult to compete on price in global markets without scale or policy support.

Permitting, planning and infrastructure bottlenecks are also problematic. Lengthy and complex procedures for developing industrial facilities, renewable energy projects and grid connections continue to slow down both manufacturing expansion and deployment.

While the NZIA explicitly seeks to streamline procedures for clean-tech manufacturing and related projects, effective implementation — including by strengthening administrative capacity in Member States — is crucial for tangible outcomes (EPRS, 2025a). In addition, Europe remains structurally dependent on China and other countries for the import of key inputs such as CRMs as well as intermediate components that remain essential for meeting Europe's clean energy ambitions.

Alongside these vulnerabilities, the shortage of skilled labour in key technical and vocational occupations remains another persistent challenge to scaling up the EU clean-tech manufacturing base. Bottlenecks in workforce capacity are consistently identified as key limiting factors for achieving the EU's clean energy ambitions (Widuto, 2025; IEA, 2023a).

Workforce constraints are regarded as being just as critical as financing, permitting and supply chain issues. Although the situation improved slightly in 2024, shortages are expected to intensify as the EU workforce ages. This will affect industrial sectors critical to the clean transition.

Ensuring the availability of skilled labour will therefore remain a core challenge (European Commission, 2025i). As such, science, technology, engineering and mathematics (STEM) education is high on the EU agenda (Binder, 2025).

The implications of the clean energy transition for jobs, skills and workforce development represent a central theme of this report and are explored in depth in the chapters that follow.

4 Employment and the workforce in the EU clean energy sector

The European Union (EU) policy framework that supports the expansion of the clean-tech industry also aims to create jobs. This chapter presents evidence of how the shift towards net-zero technologies is reshaping labour markets in Europe.

First it examines how job creation is evolving across the selected technologies and the prospects for future growth. It then highlights geographical disparities between Member States in terms of aggregate employment trends. The analysis then further explores the workforce across the value chain and its gender composition.

The methodological approach primarily relies on Prognos envigos model for environmental goods and services. This model encompasses economic goods and services associated with net-zero technologies. It aligns them with established international classification systems such as the nomenclature of economic activities (NACE) and Prodcom. The analysis measures the direct effects of the economic activities under consideration along the defined value chain of the technology. Annex A.1.1 provides details on the model and input data.

4.1 Employment trends across clean technologies

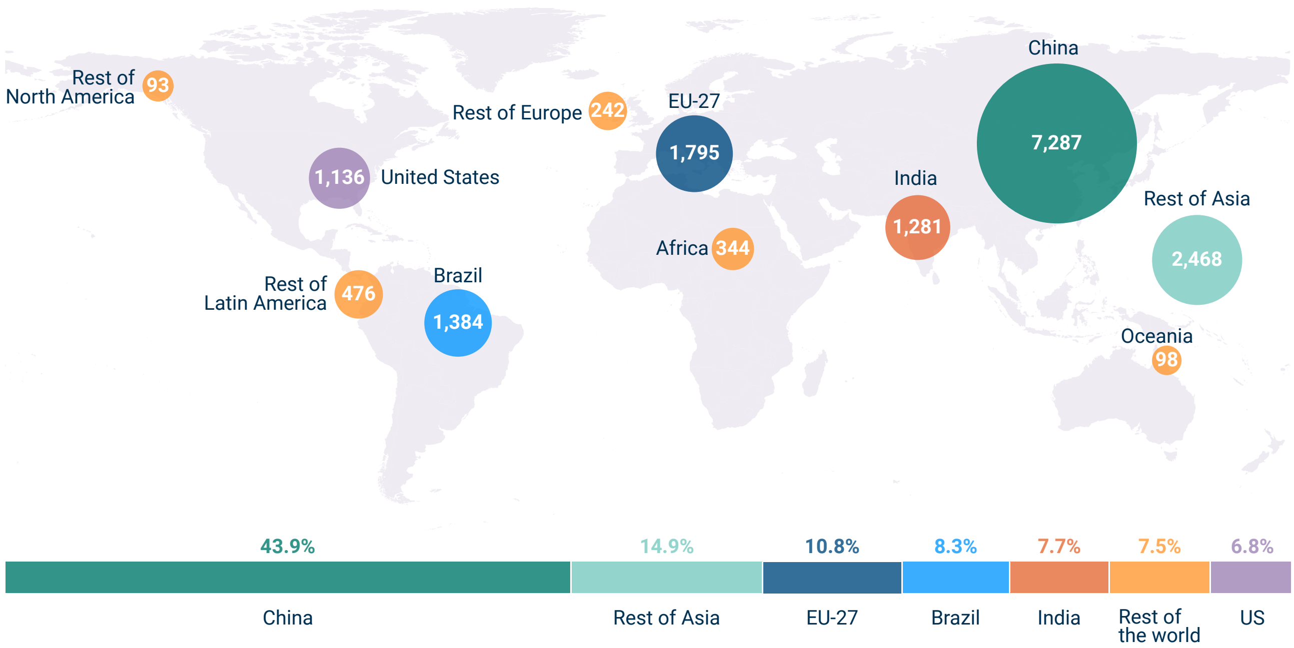
Recent data indicate that employment in the global energy sector is expanding at a rate that outpaces the broader economy. It grew by 2.2% in 2024 against 1.3% growth in employment across the economy as a whole (IEA, 2025).

According to the International Renewable Energy Agency (IRENA), jobs in the renewable energy sector globally totalled 16.2 million in 2024, up from 13.7 million in 2022. They have more than doubled over the past decade.

China is the region that has created the most employment in this sector, with just over 7 million jobs, primarily in solar photovoltaics (PV) (see Map 4.1). Chinese employees held 58% of global jobs in solar PV in 2024, although this was down from 65% in the previous year, due to job creation in India and Brazil (IRENA and ILO, 2024, 2026).

The EU ranks second after China, with a total of 1.8 million jobs directly or indirectly linked to renewable energy. In 2024, the EU was responsible for 18% of global employment in onshore and offshore wind and around 10% of solar PV jobs globally (IRENA and ILO, 2026).

Figure 4.1 **Renewable energy employment in selected countries and regions in 2024**



Notes: These figures account for direct and indirect jobs linked to renewable energy. Percentages may not total 100% due to rounding.

Source: Adapted with permission from IRENA and ILO, 2026.

Based on the modelling exercise undertaken for this report, an estimated 951,000 (13) people were directly employed in the EU clean energy sector in 2023, with employment growing at an average annual rate of 5.3% since 2010. When compared with total employment in the EU — based on Eurostat structural business statistics (14) — the clean energy sector accounts for a relatively modest share of jobs at 0.6% in 2023.

This is comparable, for example, to the workforce in the manufacture of chemicals and chemical products (NACE C20), which employed approximately 1.3 million people in 2023 (Eurostat, 2026b). However, while employment levels in NACE C20 have remained largely unchanged since 2010, jobs in the clean-tech industry have more than doubled across the EU over the same period, demonstrating strong growth dynamics.

Among the clean technologies, the wind energy sector employs the most people (273,000 jobs in 2023), followed by solar PV (227,300), as shown in Figure 4.1. The wind energy sector has continued to register steady employment expansion since 2010. However, solar PV experienced a temporary decline between 2010 and 2015, with volatile trends primarily caused by policy and market shifts (see Figure 4.2). Since 2015, the solar PV workforce has regained significant momentum and until 2023 was on a strong upward trajectory.

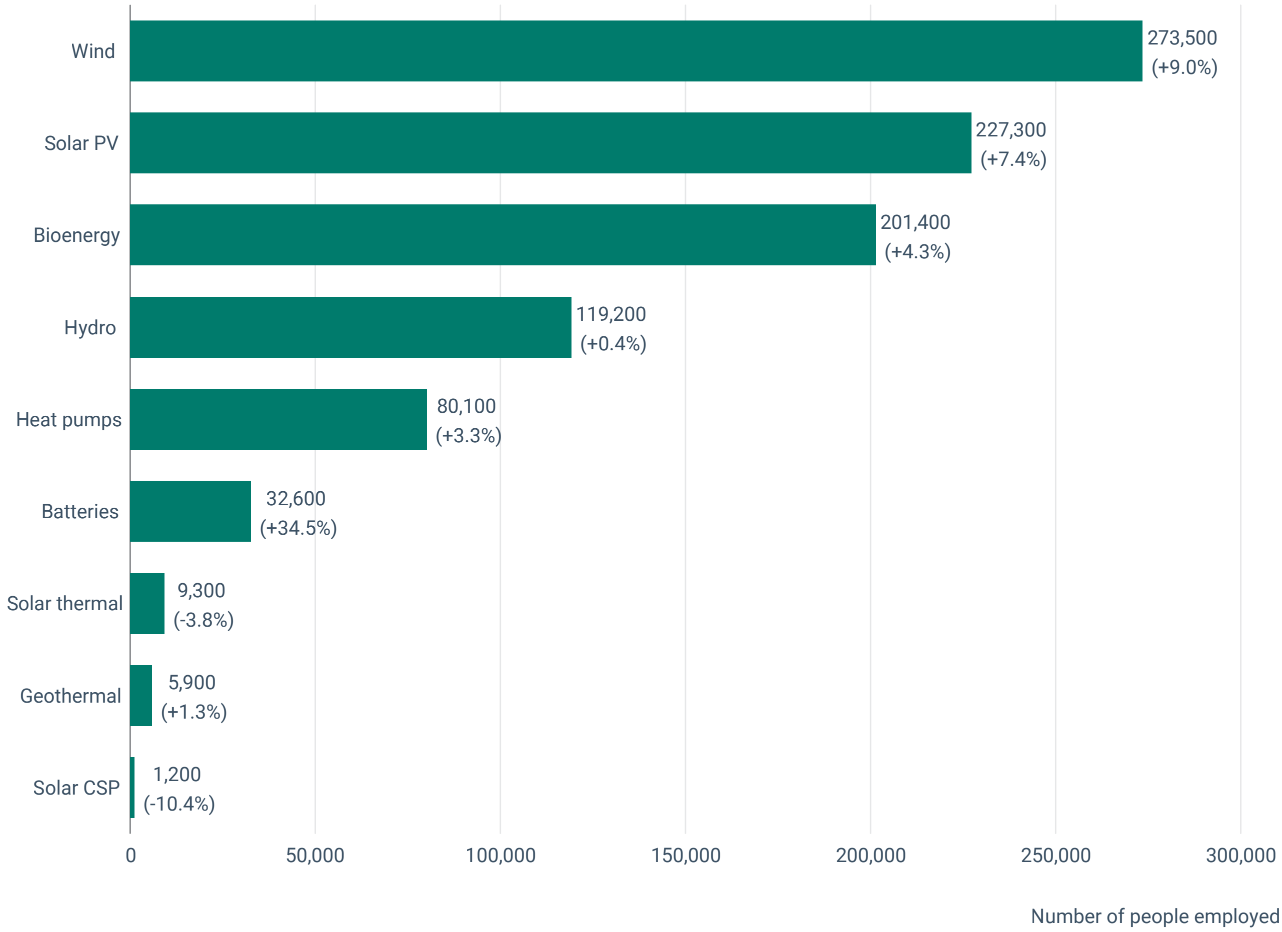
(13) The figure refers to direct employment, such as jobs in manufacturing solar PV converters or wind towers. Indirect employment includes jobs involved in supplying intermediate goods and services, for example producing the steel used in wind towers. For further information, see the Sustainable Energy Jobs Platform and IRENA (2024).

(14) Eurostat structural business statistics cover the economic activities of market producers within the business economy NACE Rev. 2 Sections B to N, P to R and Divisions S95 and S96. These include industry, construction and market services (except public administration and defence; compulsory social security; activities of membership organisations).

Among the four featured technologies, heat pumps rank third, with just over 80,000 people employed and a moderate growth rate of 3.3%. While the market is expanding, the heat pump energy sector is very volatile, potentially due to fluctuations in fossil fuel prices, which directly affect the competitiveness of heat pump systems. When fossil fuels like gas are inexpensive, heat pumps are less financially attractive, leading to reduced demand. Conversely, when fossil fuel prices rise, heat pumps become more competitive, potentially driving higher demand and job creation.

Batteries have the smallest workforce amongst the clean technologies assessed in this study, with around 33,000 people employed in 2023. Nevertheless, this is a very dynamic sector which has been growing by nearly 35% per year and accelerating fast between 2018 and 2023. Prior to 2018, the economic impact of the sector was minimal and difficult to quantify.

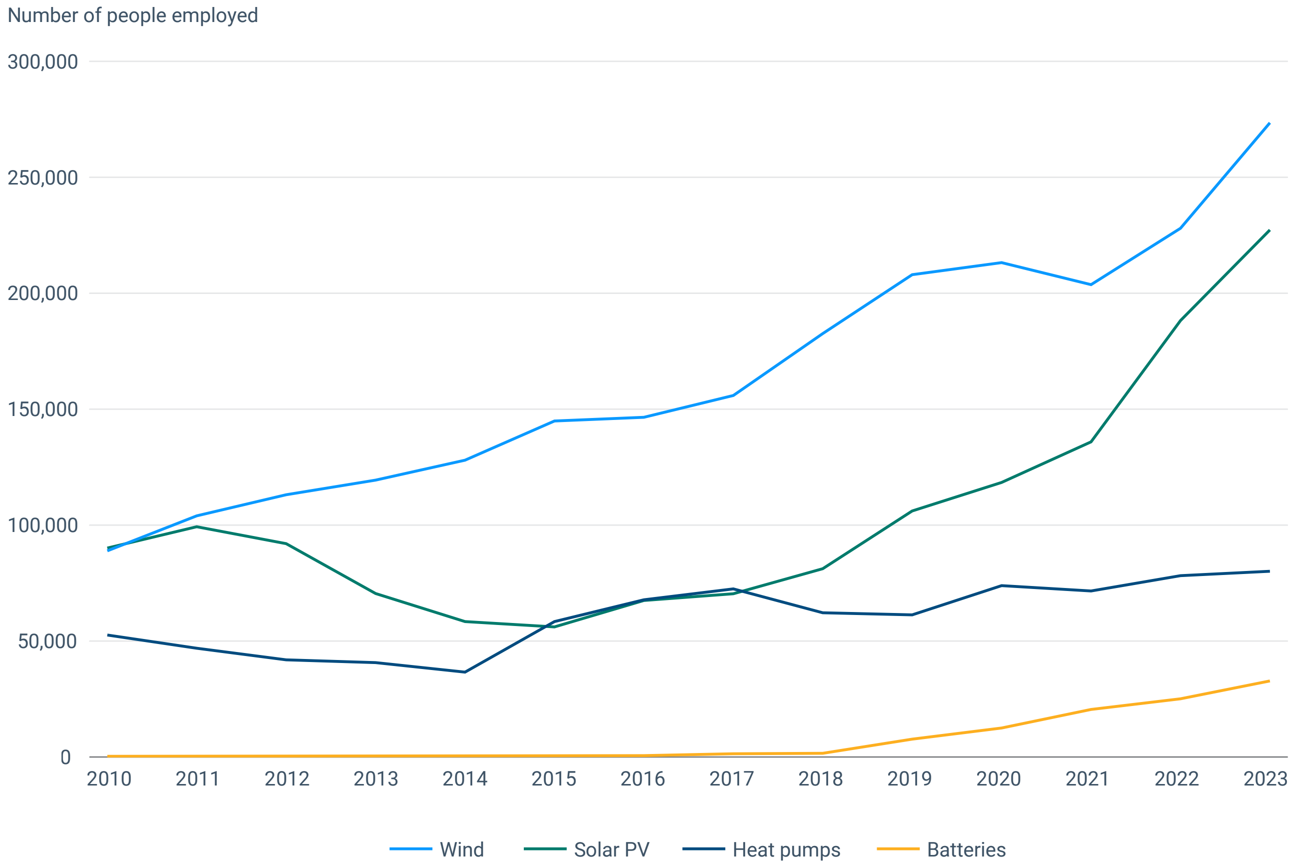
Figure 4.2 **Number of people directly employed in clean energy technology in the EU-27 in 2023 and annual growth between 2010 and 2023**



Notes: EU-27 excluding Cyprus, Luxembourg and Malta due to limited data availability. Annual employment growth is calculated as compound annual growth rate (CAGR).
CSP, concentrated solar power.

Source: Prognos 2025 based on envigos model and Eurostat Structural Business Statistics.

Figure 4.3 **Number of people directly employed in wind energy, solar PV, heat pumps and batteries in the EU-27 from 2010 to 2023**



Note: EU-27 excluding Cyprus, Luxembourg and Malta due to limited data availability.

Source: Prognos 2025 based on envigos model and Eurostat Structural Business Statistics.

Box 4.1

Employment estimates from other studies

The external evidence broadly supports the findings presented above based on the Prognos envigos model, although absolute employment estimates differ depending on the geographical coverage and whether indirect jobs are included.

EurObserv'ER provides comprehensive data on the EU's renewable energy sources, including employment figures. The 2024 edition of the *State of renewable energies in Europe* report provides estimates for total numbers of (direct and indirect) jobs in wind power; the estimate for the EU-27 was 333,800 jobs in 2023 (up from 273,500 in 2022) (EurObserv'ER, 2024).

The estimates suggest that EU-27 jobs in PVs totalled 560,300 (up from 346,900 in 2022) and that employment in the EU heat pump sector reached 432,900 jobs in 2023 — an increase of 16,700 jobs compared to 2022. However, EurObserv'ER does not publish separate figures for direct and indirect employment; this means that it is not possible to make a direct comparison with the numbers given in Figure 4.1.

The 2025 *European Wind Energy Competitiveness Report*, published by the European Technology and Innovation Platform on Wind Energy, indicates that there were around 350,000 jobs in wind energy in the EU in 2023. Half of these were direct employment. Direct jobs in the wind industry increased in 2024, reaching almost 180,000. Meanwhile, indirect employment contracted slightly (WindEurope, 2025a).

The *EU Solar Jobs Report 2024* by SolarPower Europe reported significantly higher figures. It stated that at the end of 2023, the solar sector had 826,000 full-time jobs in the EU. Of these, 362,000 full-time positions were direct jobs, accounting for 44% of the total. Meanwhile, the remaining 464,000 full-time positions (56%) were indirect jobs. Solar employment expanded by around 5% in 2024, compared with 0.8% growth across the wider EU labour market (SolarPower Europe, 2025a).

The European Heat Pump Association (EHPA) estimates that the heat pump sector provided close to 170,000 direct jobs in 2023. This number has been increasing over time (EHPA, 2024). However, heat pump sales fell by 21% in 2024 in 14 European countries, resulting in at least 4,000 job cuts (EHPA, 2025b).

In the batteries sector, according to data from the European Battery Tracker by New Automotive, there are approximately 62,000 total jobs (direct and indirect) across the European battery value chain. This estimate is based on around 30,600 identified jobs in gigafactories and 900 in battery recycling. New Automotive doubles this number to reflect additional employment in upstream and midstream activities, thereby approximating total value chain employment. The methodology thus combines identified gigafactory employment with multiplier assumptions. This helps to explain divergences from the stricter, direct-effects modelling used in the body of this report. Although the tracker does not specify the reference year or distinguish between direct and indirect jobs, it provides a useful order-of-magnitude estimate consistent with the strong upward trend indicated by the envigos model.

4.2 A look into the future — employment projections

The market for net-zero technologies is expected to expand in the coming years, along with associated employment effects. Based on scenarios developed in this study, drawing on existing targets and market outlooks, each of the four selected technologies is expected to experience absolute employment growth by 2030. The approach used for modelling direct employment projections is explained in detail in Annex A.1.2.

The projections reported in Figure 4.3 indicate that there could be over 500,000 people working in wind energy and the same number in solar PV by 2030. This highlights the critical role of the workforce in the energy transition and net-zero industry.

The long-term outlook published by WindEurope in the latest *Europe's Wind Energy Workforce Report* is similar. It estimates significant industrial potential for the wind energy sector, with total employment in the EU-27 projected to grow to 483,000 jobs by 2030, based on an average of 22 gigawatts (GW) of capacity being installed annually (WindEurope, 2025b). This includes 223,000 direct jobs.

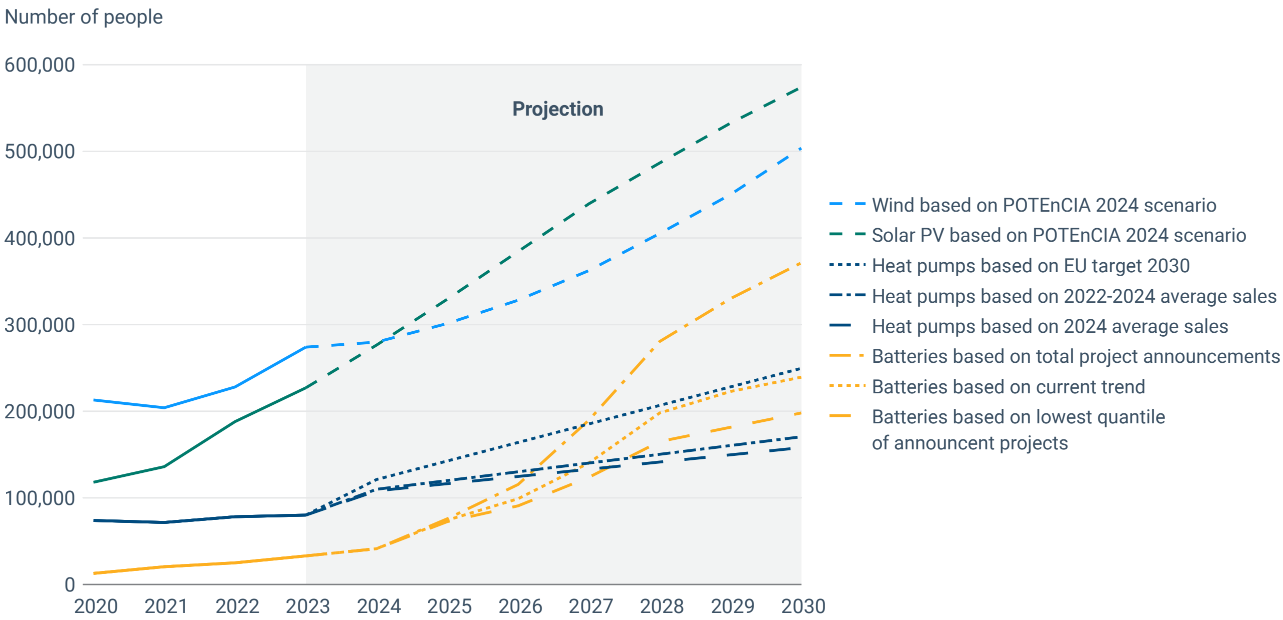
Projections from SolarPower Europe for solar PV are even more optimistic, ranging between 680,000 and 1.4 million (direct and indirect) jobs by 2028, depending on the scenario. The expectation is that jobs related to deployment activities will continue to dominate in absolute terms, but that they will be subject to annual fluctuations in the PV market. Moreover, they are projected to decrease as a relative share of all jobs in the sector. Conversely, roles in operations and maintenance are likely to be more stable. They are expected to continue to grow, expanding as a relative share of the sector from 7% in 2024 to 11% in 2028 (SolarPower Europe, 2024b).

A recent European Commission (EC) study by the Directorate-General for Employment, Social Affairs and Inclusion (DG EMPL) estimates that the installation of wind turbines and solar panels alone will require approximately 130,000 to 145,000 additional skilled workers in the construction, services and transport sectors by 2030 (Fulvimari et al., 2025). All of this evidence points to the likelihood of substantial labour demand linked to the expansion of renewable energy infrastructure.

In contrast, jobs related to heat pumps are expected to increase only moderately. On the basis of the data available — when the analysis was conducted in 2025 — the number of jobs in the heat pump sector was projected to range between 150,000 and 250,000 by 2030. While heat pumps are an efficient way to reduce the use of fossil fuels for heating, they face competition from fossil fuel systems, particularly gas. Because uptake relies heavily on consumer decisions to invest in domestic heating appliances, it is more challenging to predict employment trajectories.

However, the EHPA estimates that the EU will need at least 500,000 skilled workers in this sector by 2030 — an increase of more than 200% compared with current levels (EHPA, 2024). As previously noted, the energy crisis triggered by the Middle East crisis in March 2026 led to increased heat pump sales compared with the same period the previous year. The Electrification Action Plan published in July 2026 seeks to accelerate heat pump deployment through various policy and financial levers designed to support electrification and increase consumer uptake.

Figure 4.4 **Projections for the numbers of direct jobs in clean energy technology in the EU-27 up to 2030**



Note: EU-27 excluding Cyprus, Luxembourg and Malta due to limited data availability.

Sources: Prognos 2025 based on envigos model and Eurostat Structural Business Statistics; Neuwahl et al., 2024; Fraunhofer Institute for Systems and Innovation Research ISI, 2025; EHPA, 2025c.

Similar uncertainty applies to battery technologies. This is largely due to international competition and ongoing sector restructuring. The estimates for this sector suggest that the number of jobs will range from 200,000 to nearly 400,000 by 2030, depending on the assumptions applied.

Although employment in the battery value chain has grown rapidly in recent years and is expected to play a decisive role in the future energy system, it is difficult to pinpoint precise estimates. Employment outcomes will largely depend on whether the EU succeeds in securing domestic manufacturing and supply chains or whether production shifts to other regions.

Recent events, including the bankruptcy in March 2025 of Northvolt in Skellefteå (Sweden) — once a symbol of European battery ambition — have highlighted the fragility of progress in this sector. These setbacks, alongside stalled projects and workforce reductions in other major companies such as Automotive Cells Company (ACC), have introduced new layers of unpredictability (Eurofound, 2025).

While Europe's battery manufacturing capacity shows positive signs of growth, it has been supported primarily by foreign direct investment (FDI), notably from South Korea and China, with the construction in Hungary of what might become the largest battery cell facility in Europe (Jugé, M. et al., 2025). Employment outcomes will hinge on the EU's ability to stabilise and scale up its domestic manufacturing and supply chains.

Industry analyses based on the European Battery Tracker by New Automotive suggest that Europe's evolving battery supply chain could generate between 140,000 and 250,000 new jobs within five years. Total employment could exceed 300,000 by 2030 (Evison, 2025).

Overall, the projections presented in Figure 4.4 are considerably higher than those reported in the EC investment assessment linked to the Net-Zero Industry Act (NZIA). This estimates additional manufacturing jobs of around:

- 25,000-66,000 for solar PV;
- 31,000-40,000 for wind;
- 28,000-60,000 for heat pumps;
- 139,000-294,000 for batteries

by 2030, depending on the scenario.

The difference reflects scope: while the EC's calculations focus specifically on jobs created by expanding manufacturing capacity, the estimates for this report capture the entire value chain (see Section 4.4 for an in-depth analysis of employment creation along the value chain for selected clean technologies). The two perspectives are therefore complementary: the EC's figures highlight the scale of industrial manufacturing needs and related skills investment (EUR 1.7 to EUR 4.1 billion by 2030), while projections for this report reflect the broader labour market impact of deploying these technologies at scale.

A more recent study based on the POTEnCIA Clean Energy Technology Observatory (CETO) 2025 scenario gives an estimate for the total labour demand in the EU-27 associated with the deployment of decarbonisation technologies between 2026 and 2030. The estimates for the average yearly number of direct jobs in the EU, over the 2026-2030 period, associated with specific technologies of interest are:

- 205,000 for wind energy;
- 210,000 for solar PV (assuming a 10% EU manufacturing share);
- 475,000 for heat pumps (van Santen et al., 2025).

In summary, differences in future employment estimates result from the use of different methodologies. This limits how comparable the findings are, as some rely on industry workforce data while others use capacity-based estimates. There is also variation in what counts as a direct or indirect job. Estimates can differ further depending on which manufacturing steps or components are considered, how technologies are defined and assumptions about how much production takes place in the EU (van Santen et al., 2025). Yet, while absolute numbers may diverge, the overall trends towards employment expansion remain consistent.

Box 4.2

Employment in the solar thermal value chain

While solar PV technologies dominate the global solar sector, solar thermal technologies potentially remain relevant due to their specific use cases in heating. Based on estimates from the envigos model, the sector employs fewer than 10,000 people in the EU; more than half of them work in the construction segment — driven by the installation of solar thermal systems — followed by manufacturing (2,700 people). Other sources that include indirect jobs estimate a total of 23,600 jobs in the solar thermal sector in 2023 (EurObserv'ER, 2024).

The sector has faced negative employment trends since 2010; only the manufacturing segment has experienced a slight resurgence since 2020. Greece stands out as the EU Member State with the highest level of employment in this sector and also one of the few Member States with a positive employment trend for solar thermal energy. In contrast, nearly all other EU countries have experienced a steady decline in employment in this sector since 2010, reflecting its small role in many national energy systems.

Looking ahead, the solar thermal segment is expected to provide an additional 250,000 jobs by 2030 (Solar Heat Europe, 2024). This signals significant long-term potential if supported by favourable market conditions. Recent analysis from Solar Heat Europe reinforces this outlook; it highlights that solar thermal remains a predominantly EU-made technology, with a manufacturing base capable of meeting most European demand and retaining strong export activity.

The report also notes that solar thermal is increasingly relevant for district heating and industrial heat decarbonisation. Both of these areas are likely to have sizeable future labour needs. For instance, more than 260 towns and cities in Europe already operate solar-assisted district heating systems. At the same time, the number of projects under construction continues to grow. This points to an emerging pipeline of installation, engineering and operational roles (Solar Heat Europe, 2025).

The Electrification Action Plan recognises solar thermal as part of Europe's clean electrification value chains, highlighting its contribution to reducing fossil fuel use in heating alongside heat pumps, for instance.

4.3 The geography of clean-tech jobs in Europe

The relative contribution of clean energy technologies to employment varies significantly between EU Member States. In some countries, the workforce is largely dominated by a single technology — for example, bioenergy in Latvia or wind energy in Denmark. In contrast, other Member States — such as Sweden and the Netherlands — have a more diversified employment landscape, with multiple technologies contributing to job creation.

Overall, the net-zero industry accounts for a relatively modest share of employment. This is typical for a specialised sector. The relative contribution of clean energy technologies [15] to total employment, based on Eurostat structural business statistics (Eurostat, 2026c), per Member State ranges from 0.3% (employment in

(15) The technologies included are batteries, bioenergy, concentrated solar power (CSP), geothermal energy, heat pumps, hydropower, solar PV, solar thermal energy and wind energy.

countries such as Belgium, Ireland, the Netherlands and Slovakia) up to the highest employment shares, which are observed in:

- Denmark (1.1%, mainly driven by wind and bioenergy);
- Lithuania (1.2%, also primarily due to bioenergy and wind);
- Austria (1.2%, where hydropower and solar PV are the main contributors).

This indicates a more prominent role for clean technologies in their respective labour markets.

Looking more specifically at how employment in the four technologies featured in this report is distributed across Europe, Germany records the highest number of jobs for each individual technology, except for heat pumps (see Map 4.1).

Germany leads the EU in wind energy employment, with around 125,000 people directly employed in the sector and an annual growth rate of 12% since 2010. As the country also records the highest gross electricity production among EU Member States, more than 80% of its wind workforce is concentrated in the operations segment.

France and Poland have also demonstrated strong growth, with average annual increases of 13% and 15%, respectively; however, their total wind workforce ranges between only 22,100 and 19,300. Spain and Denmark also maintain relatively robust employment figures (18,900 and 14,900 respectively); however, their recent growth dynamics have been less pronounced compared to other Member States.

Denmark is a key hub for wind equipment manufacturing, particularly for offshore wind technologies, with more than 40% of its wind energy workforce located in the manufacturing segment. Spain, by contrast, has benefited from significant gross electricity production from wind energy in recent years, ranking second in the EU in 2023 (Eurostat, 2026d). This has resulted in a workforce which is almost evenly divided between the manufacturing and the operations segment.

As a proportion of total employment in the business economy of the country, as measured by Eurostat structural business statistics (Eurostat, 2026c), Denmark has the highest employment share in wind energy technology (at 0.7%). This is twice as high as Germany, which ranks second on an equal footing with Lithuania (at 0.3%).

Germany also continues to be the Member State with the highest number of jobs in the solar PV sector (83,800) and a modest growth rate (7%). The country also has the highest net maximum electricity production capacity for solar PV of any EU Member State (Eurostat, 2026a).

Other large countries such as Spain, Italy and Poland follow in terms of absolute employment numbers (from 25,800 to 16,700). Poland and Spain have positive growth rates. Italy, in contrast, experienced a negative trend between 2010 and 2023.

Recent market data from Italy confirm that installation rates have continued to decline during 2023-2025. This has been driven in part by the phase-out of residential incentives and a broader European slowdown (Solar Vision, 2025; Il Sole 24 Ore, 2025).

In relative terms, Austria, Bulgaria, Greece and Hungary have the highest employment share for solar PV (at 0.3%). Germany, Lithuania and Spain follow (at 0.2%).

Portugal leads the EU in terms of jobs in the heat pump sector, significantly driven by the construction segment. The country has both the highest absolute number of workers, the highest employment share relative to the total economy (0.3%) and the strongest growth between 2010 and 2023 (23%). While Portugal does not lead the EU in terms of the number of installed or sold heat pumps, it still has robust demand; it is one of only two Member States not to experience a decline in sales between 2023 and 2024 (EHPA, 2025d).

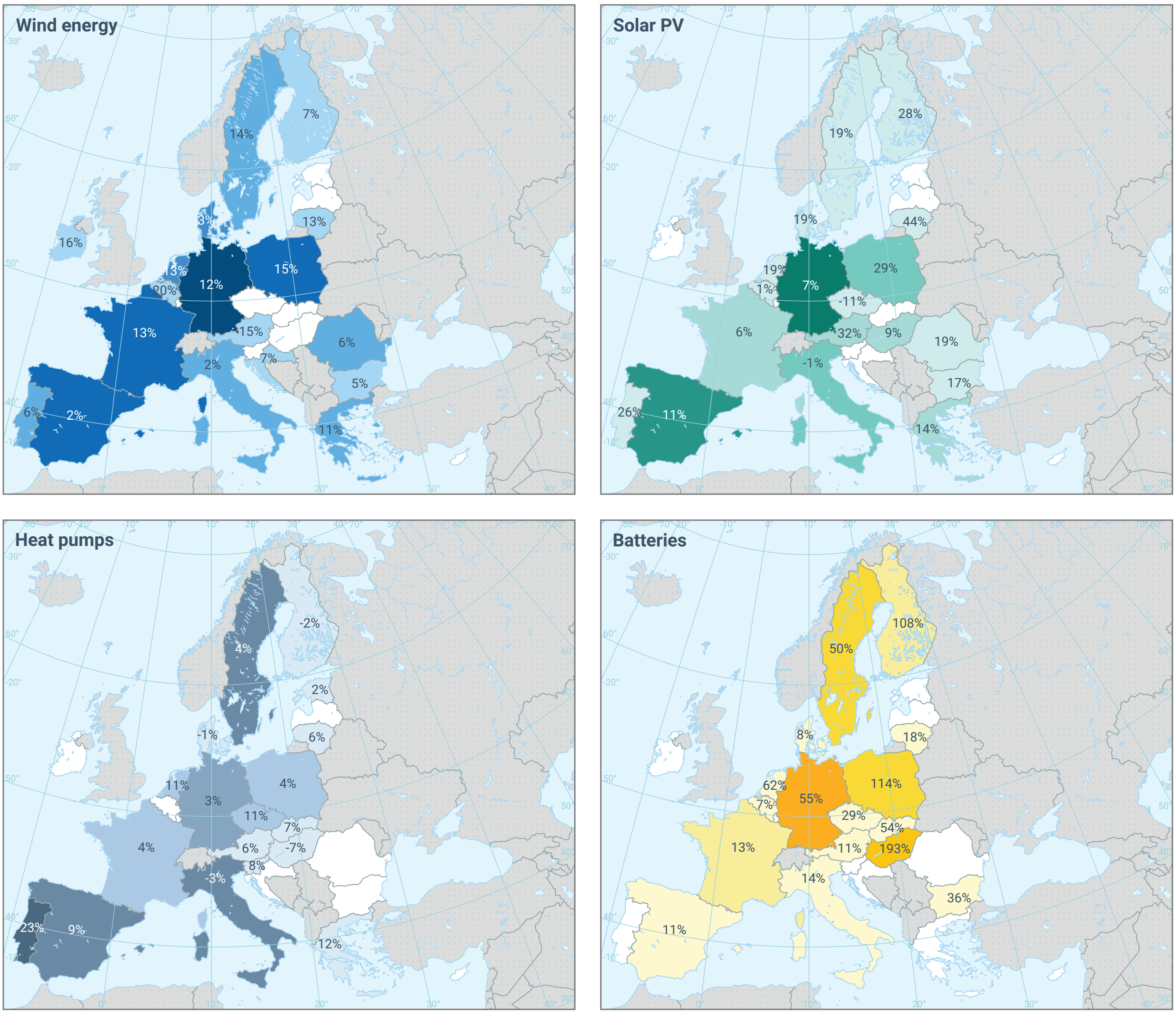
At the same time, there is relatively low labour productivity — measured as gross value added (GVA) per person employed — in Portugal. Consequently, the construction segment in Portugal supports a substantial workforce for heat pump installation and construction activities.

Italy and Spain follow in terms of absolute employment figures, although their recent trends diverge. Spain continues to record solid growth, whereas Italy — despite having the third largest workforce in the EU heat pump sector — has seen a slowdown in the number of people employed.

This is consistent with independent evidence from the European Trade Union Institute (ETUI), which reports that Italy employed around 85,000 workers in the heat pump sector in 2022, but had already lost around 6,000 jobs compared with 2017. This reflects a weakening trajectory in recent years (ETUI, 2025). It mirrors the broader dynamics observed in the Italian solar PV sector, where deployment and employment have also decelerated.

In relative terms, Estonia and Sweden have a higher employment share (0.2%) than Italy and Spain (0.1%).

Map 4.1 **Number of people directly employed in selected clean energy technologies in the EU-27 in 2023 and annual growth between 2010 and 2023**



Reference data: © EuroGeographics, © FAO (UN), © TurkStat Source: European Commission – Eurostat/GISCO

Number of people directly employed in selected clean energy technologies in the EU-27 in 2023 and annual growth between 2010 and 2023

Thousands of people employed in wind energy: 0-5,000; 5,000-10,000; 10,000-15,000; 15,000-30,000; ≥30,000

Thousands of people employed in solar PV: 0-7,500; 7,500-15,000; 15,000-25,000; 25,000-35,000; ≥35,000

No data

Outside coverage

Thousands of people employed in heat pumps: 0-2,500; 2,500-5,000; 5,000-7,500; 7,500-12,000; ≥12,000

Thousands of people employed in batteries: 0-1,000; 1,000-3,000; 3,000-5,000; 5,000-10,000; ≥10,000

0 500 1,000 1,500 km

Note: EU-27 excluding Cyprus, Luxembourg and Malta due to limited data availability Annual growth is calculated as the compound annual growth rate (CAGR) over the 2010-2023 period.

Source: Authors' elaboration based on Prognos 2025 envigos model and Eurostat Structural Business Statistics.

In the battery value chain, Germany leads again in terms of absolute employment numbers, with around 12,300 jobs. It is followed by Hungary with 8,100 jobs and Poland with 4,100. The most dynamic growth is observed in Hungary, which has experienced average annual growth of 193% in employment since 2010, followed by Poland with 114%. These two Member States host some of the largest battery cell manufacturing capacities in the EU. In terms of total workforce, they are followed by Sweden (3,600) and France (1,600).

In Hungary, an additional 128GWh of manufacturing capacity is under construction. This promises significant growth and reinforces the country's leading position within the EU battery industry (Jugé et al., 2024). Hungary is also the country with the highest employment share in this sector as a proportion of total employment (at 0.2%). It is the only Member State with a share above 0.1%.

4.4 The workforce across the value chain

The technologies analysed in this report can be mapped across comparable segments of the value chain. This approach captures the main economic activities related to:

- research and project development;
- manufacturing;
- construction;
- operations.

The types of goods and services within each segment of the value chain are summarised in Figure 4.4. The framework serves as the foundation for assessing the economic impact and trends of clean technologies. It offers essential context for understanding labour market developments and workforce dynamics.

While waste treatment and recycling of components and circular materials is not explicitly included in this modelling exercise, it is acknowledged that it plays a pivotal role in the transition to a more circular economy. Beyond recycling, the integration of circularity principles in the traditional value chain is also a key aspect of efficiency gains and a more sustainable use of resources.

Box 4.3

The circular economy as a key enabler of clean technologies and job creation

Circularity is increasingly recognised as a core enabler of the clean-tech transition; the two are mutually reinforcing from both an environmental and a strategic perspective. The large-scale deployment of renewable energy technologies and energy storage systems is driving a rapid increase in demand for critical raw materials (CRMs), but the supply chains for CRMs are often highly concentrated and exposed to geopolitical and market risks. Strengthening circularity through recycling is therefore essential to reduce reliance on primary extraction and imports.

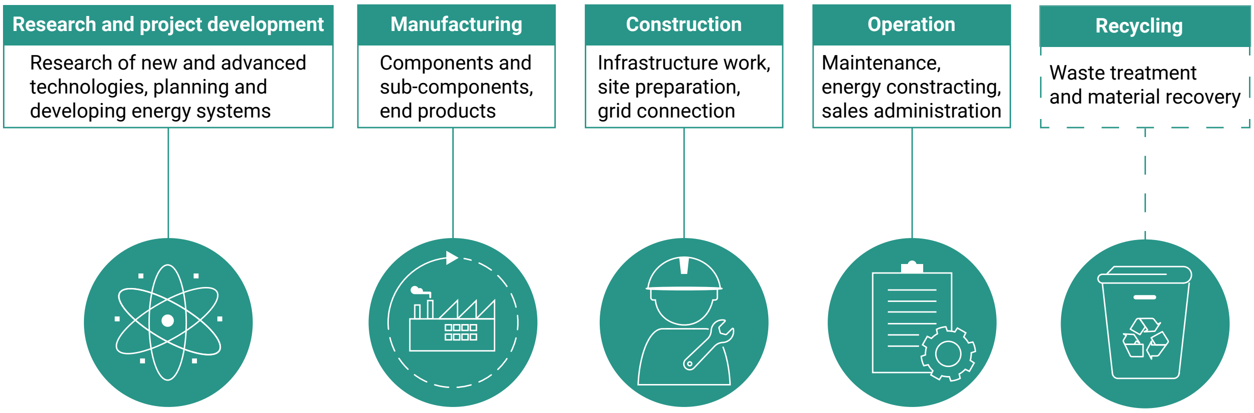
The International Energy Agency (IEA) estimates that increased recycling could reduce the need for new mining activity by around 25-40% for key battery and energy transition minerals by the middle of the century (IEA, 2024b). At the same time, the clean energy transition itself is generating new and rapidly growing waste streams. Decommissioned wind turbines, end-of-life solar PV panels, batteries and heat pumps are expected to produce large volumes of complex, material-rich waste over the coming decades. For example, IRENA estimates that cumulative global solar PV waste could exceed 200 million tonnes by 2050. This points to attractive opportunities to recycle critical materials (IRENA, 2022).

The European Environment Agency (EEA) likewise highlights that waste from renewable energy infrastructure could increase up to thirty-fold between 2020 and 2030. This will present both a resource challenge and a major opportunity to reinject valuable materials into clean-tech value chains through improved design, reuse and recycling (EEA, 2021).

Reflecting these dynamics, EU policy is increasingly embedding circularity into its industrial strategy. The upcoming Circular Economy Act constitutes a central pillar of the Clean Industrial Deal (CID). It is due to be adopted in 2026. While annual investment in the circular economy has reached around EUR 120 billion, this is driven primarily by the private sector and there is a significant investment gap (European Investment Bank, 2026).

Besides the environmental benefits of a transition to a circular economy, there is also potential benefit in terms of job creation — although the job quality outcomes may vary and skill requirements may change (Van Opstal et al., 2026). It is estimated that currently between 121 million and 142 million people are employed in sectors that contribute to the circular economy globally (Circle Economy et al., 2025). Eurostat estimates indicate that there were around 4.4 million circular jobs in the EU in 2023 (Eurostat, 2026f).

Figure 4.5 **Goods and services in the net-zero value chain segments**



Notes: For a detailed overview of the goods and services included in the statistical analysis for each technology and value chain segment, see Appendix 2 of the recently published *Assessment of the competitiveness of clean energy technologies* (EC, 2025a). Please note that waste treatment and recycling of components and circular materials is not explicitly included in the modelling exercise used in this report. However, its key role in the transition to a more circular economy is acknowledged and discussed in Box 4.3.

Source: Authors' own elaboration.

From a value chain perspective, operations represent the most important segment for wind and solar technologies. This reflects their substantial economic relevance due to widespread deployment across EU energy markets. In 2023, around 211,000 people were working in the operations segment of the wind energy sector. That number corresponds to around 77% of the total workforce (see Figure 4.5). In the same year, there were approximately 109,000 jobs in the operations segment of solar PV.

In the case of solar PV, the construction phase is also a major source of employment. It currently provides jobs for around 80,800 people (36% of the total solar PV workforce). This number is driven by continued growth in installed PV capacity, which increased from 30GW in 2010 to over 240GW in 2023 (Eurostat, 2025).

Between 2010 and 2015, employment in the manufacturing segment of the solar PV sector saw a measurable decline, but since then the segment has shown signs of gradual recovery. In contrast, manufacturing employment has remained broadly stable for wind energy, reflecting a consolidated industrial base.

For heat pumps the construction sector also plays a central role in supporting technology roll-out within the EU and related job creation. Around 51,900 people are employed in this segment (65% of the total heat pump workforce).

Manufacturing accounts for around a third of total heat pump employment, underpinning the industrial base within the EU. In contrast, the operations segment plays only a minor role, since heat generation and consumption primarily occur at the domestic level and are not integrated into broader energy market operations.

In the case of batteries, manufacturing is currently the most significant segment, employing over 31,000 people out of a total of 32,600 in the sector.

Although the workforce in the batteries research and development (R&D) segment is relatively small in absolute terms, it plays a crucial role in enabling the EU to keep pace with rapid technological developments in this field. Around 6% of the workforce in the battery sector is employed in R&D, compared to 2-3% in the other technologies. Europe is positioning itself as a global innovation hub for next-generation batteries by 2030, as envisioned in the strategic research and innovation agenda (Batt4EU, 2024), although not without challenges (Bielewski et al., 2026).

In contrast, the construction and operations segments of the battery value chain are still in an earlier development phase, although they may follow the upward dynamics already observed in the manufacturing segment. As a result, these segments are currently not significant enough from an economic perspective to be measured using the applied methodological approach.

Overall, employment dynamics across the value chain broadly mirror the trends in GVA. Operational activities largely determine the overall GVA in the EU wind energy sector as well as in the solar PV sector, although construction has become increasingly significant for the latter in recent years.

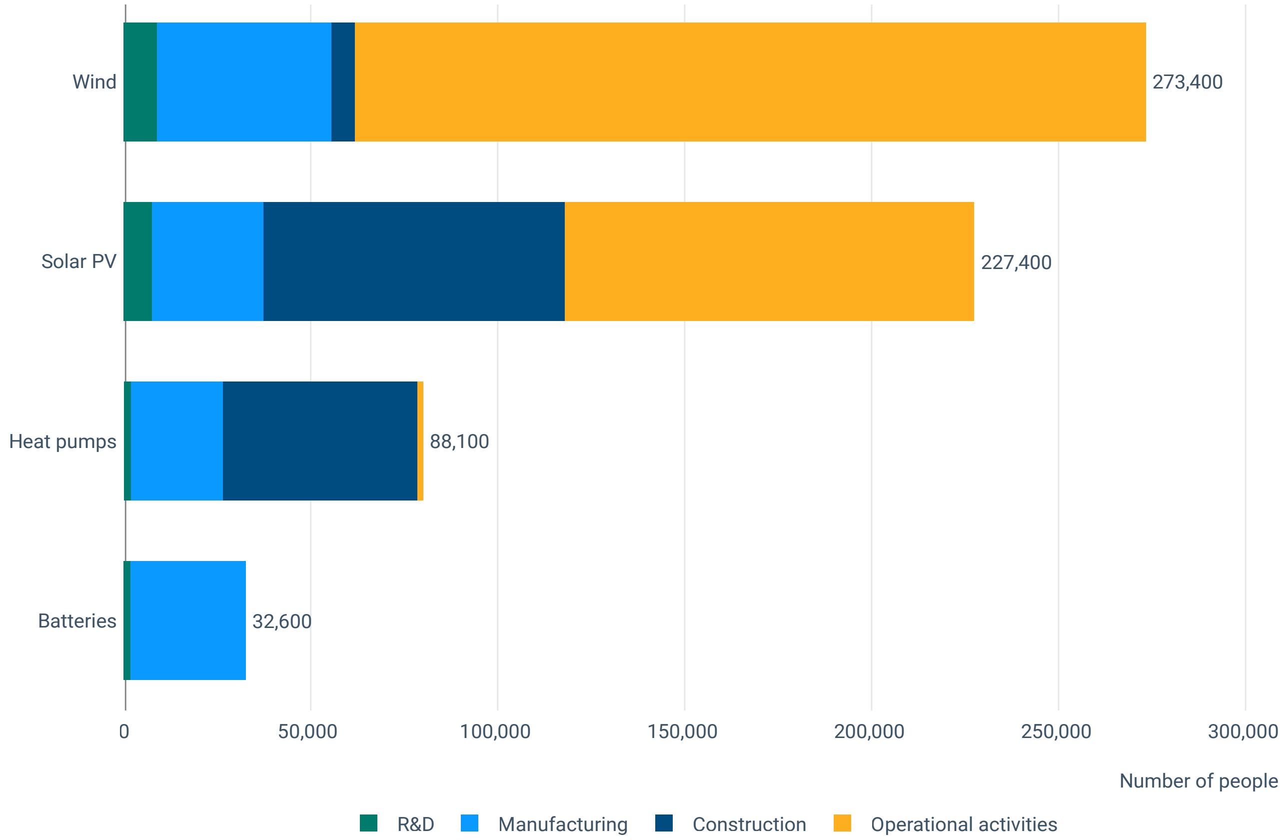
For heat pumps, the largest contribution in economic terms consistently comes from the construction segment, followed by manufacturing which show stable growth. Meanwhile, manufacturing is the most economically significant segment for the expanding EU battery sector (EC, 2025a).

In summary, the distribution of employment across segments in the value chain highlights important structural differences between clean energy technologies. Wind and solar PV are dominated by operational activities, consistent with their widespread deployment. Meanwhile construction has become an increasingly important driver of jobs and economic value for solar PV as installed capacity continues to expand.

For heat pumps, employment and value creation are primarily concentrated in construction and manufacturing. This reflects the central role of installation activities and equipment production in driving market uptake within the EU.

Batteries, by contrast, remain concentrated in manufacturing and R&D, underscoring their earlier stage of development and strategic relevance for future industrial competitiveness. These differences suggest that as technologies scale up, economic activity tends to shift downstream toward operations. Meanwhile, emerging technologies continue to rely on industrial capacity and innovation.

Figure 4.6 **Number of people employed per selected clean energy technology in the EU-27 in 2023, by value chain segment**



Note: EU-27 excluding Cyprus, Luxembourg and Malta due to limited data availability.

Source: Prognos 2025 based on envigos model and Eurostat Structural Business Statistics.

4.5 Women in the clean-tech industry

While tracking employment numbers can be helpful, more evidence is required to ensure quality jobs and a just transition. It is also necessary to understand which social groups are participating in — and benefiting from — the growth in net-zero technologies.

Particular attention needs to be paid to the inclusion of women and young workers, both of whom are explicitly prioritised in initiatives such as the NZIA. Their active involvement is essential not only to ensure equity, but also to address occupational shortages and build a resilient workforce.

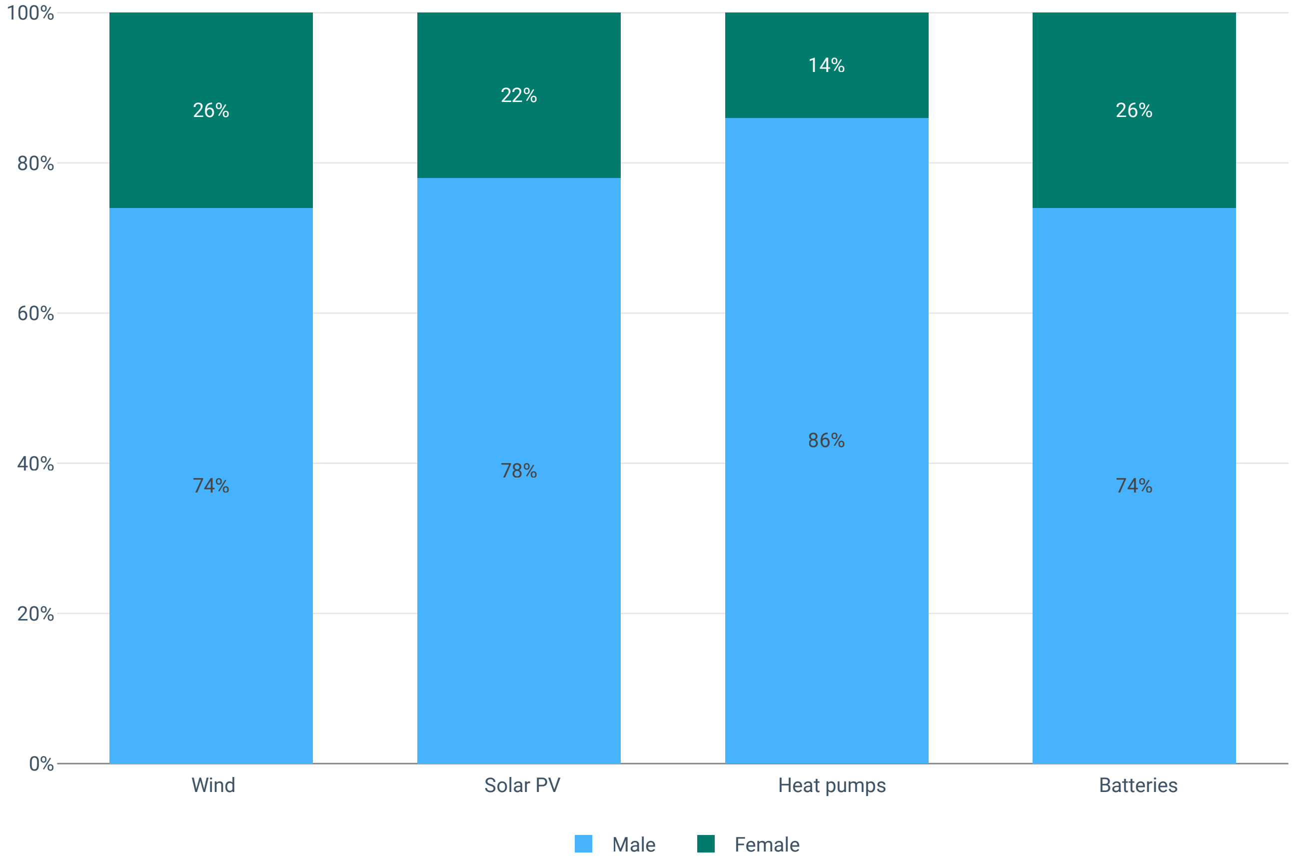
Migrant workers are an equally important part of the picture. They are particularly vulnerable to precarious working and living conditions, limited contract security or barriers to full participation. These challenges stand in contrast to the principles of a just transition and call for targeted support.

Against this backdrop, the new evidence presented in this and the following section focuses on the gender and age dimension of the clean-tech industry. This has been made possible by the availability of more detailed data to support robust quantitative analysis [16].

(16) Although the EU Labour Force Survey (LFS) provides employment data disaggregated by nationality — classifying people as 'Nationals', 'EU Nationals' and 'Non-EU Nationals' — the data gaps are too significant to apply the existing analytical framework.

Gender disparities remain a persistent feature of the net-zero workforce, as Figure 4.6 shows. In 2023, the heat pump value chain recorded the lowest share of female employees, at only 14%. The other technologies featured in this report are also far from achieving gender balance, with women representing 22% of the workforce in solar PV and around 26% in batteries and wind energy.

Figure 4.7 **Employment share by gender and clean technology in the EU-27 in 2023**



Note: EU-27 excluding Cyprus, Luxembourg and Malta due to limited data availability.

Source: Prognos 2025 based on envigos model, Eurostat Structural Business Statistics and European Labour Force Survey data.

These gender disparities are consistently apparent and become more obvious when looking at employment patterns across different segments of the value chain. When disaggregated by segment, the data show that women are least represented in construction; they made up just over 10% of the workforce in 2023. This mirrors broader gender gaps within this segment.

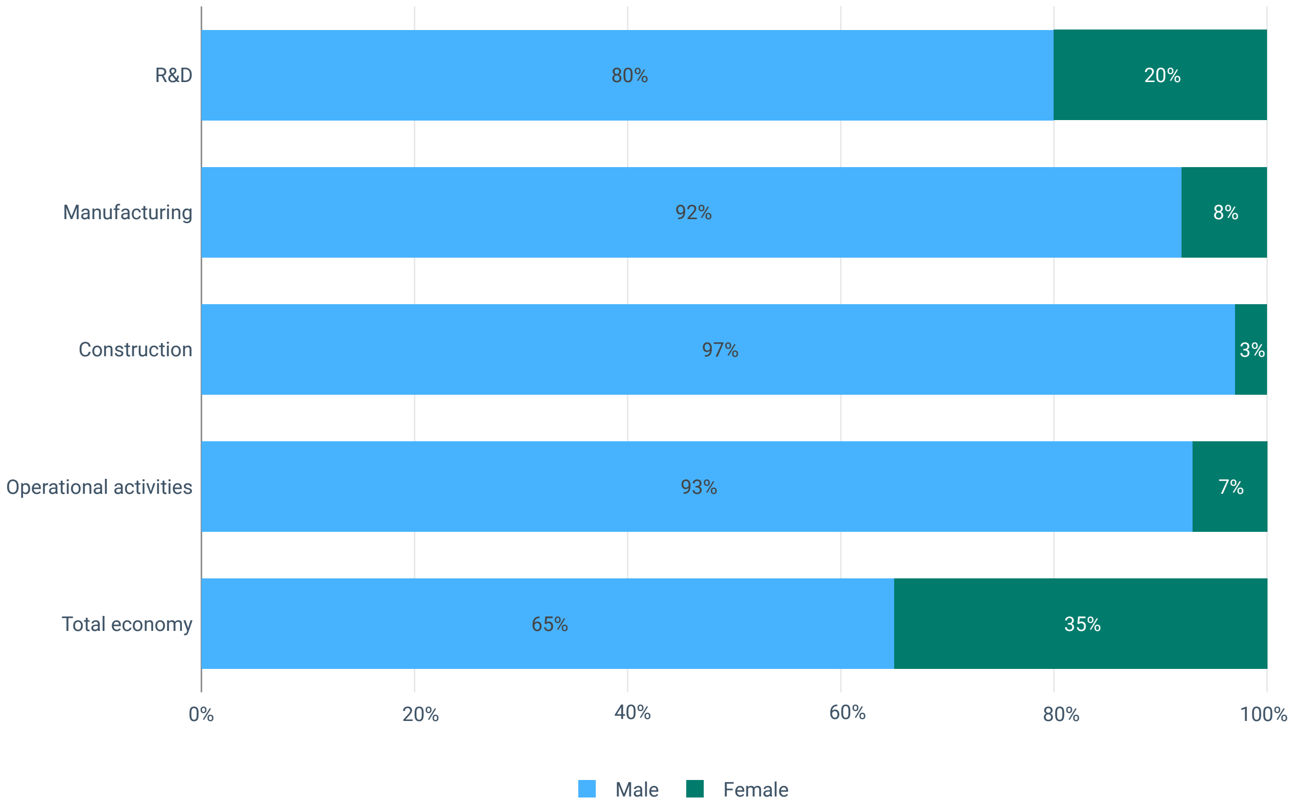
The highest share of female participation is in the R&D segment — particularly in scientific R&D, where women make up nearly half of the workforce at around 47%. However, scientific R&D represents only part of the segment and in R&D overall, women are employed in just over one-third of jobs.

In manufacturing and operations, women are employed in roughly one-quarter of all jobs, although this average masks significant variation: for example, women make up around 40% of the workforce in the manufacture of electronic components and boards, but only 14% in structural metal products. Compared with the total economy average of 46% female employment, the net-zero industry continues to lag behind in achieving gender balance.

Gender imbalances persist not only in overall employment, but also in leadership positions, as shown in Figure 4.7. Findings from the 2024 European Working Conditions Survey (EWCS) (Eurofound, 2026) reveal a particularly low share of women with roles as immediate supervisors in male-dominated sectors: just 3% of respondents in construction, 7% in operations and 8% in manufacturing report working with a female supervisor.

R&D has a much higher share (20%) of workers having a woman as their immediate manager or supervisor; however, this remains far below the total economy average of 35%. This under-representation suggests that there are ongoing and pronounced gender barriers to advancement across technical and industrial occupations. This situation limits women's access to decision-making and managerial pathways.

Figure 4.8 **Gender of immediate boss for the featured clean energy technologies in the EU-27 in 2024**



Notes: The net-zero technologies included are solar PV, wind, heat pumps and batteries. Data were accessed and analysed in February 2026.

Source: European Working Conditions Survey 2024 (Eurofound, 2026).

Recent analyses show a consistent global pattern: women hold about one-third of jobs in the renewable energy workforce, a higher share than in the fossil or nuclear sectors, but still below the share for overall participation in the economy. Their presence is uneven across roles, with women concentrated in administrative positions (45%). They hold only 28% of science, technology, engineering and mathematics-related (STEM-related) jobs, for example as technical specialists, data scientists and engineers (IRENA, 2025a).

National studies reinforce this picture. In Spain, for example, women held 38% of energy transition jobs created between 2015 and 2021. However, they held fewer than 20% of high- and medium-skilled technical positions (Naturgy Foundation, 2023).

Vertical segregation persists as well. EU data show that in the electricity and gas sectors, only 20% of women hold supervisory roles. This is compared with 34% of men (EIGE, 2023). Globally, women occupy just 19% of senior management positions in renewable energy (IRENA, 2025a).

These disparities are rooted in systemic workplace, cultural and educational barriers. When it comes to the latter, for example, gender gaps persist in STEM pathways. These disciplines equip students and graduates with the knowledge and skills necessary for employment in the energy sector or to pursue research careers in energy-related fields. However, while 54.8% of all tertiary graduates in the EU in 2023 were women, almost twice as many men as women graduated in STEM fields (Eurostat, 2026g).

The under-representation of women in science and technology is not driven by differences in ability. It is related to several other factors, including gendered self-perceptions, limited access to mentoring and a shortage of female role models during secondary education (Santero-Sánchez et al., 2025).

Existing initiatives co-funded by the EU — such as the Women4AGreenEU (2025/2028) consortium — directly address female under-representation in technical vocational education and training (VET) roles essential for deploying renewable energy projects. The project brings together nine organisations from seven different Member States. The aims are to:

- integrate gender-focused initiatives within existing educational and workforce development frameworks;
- develop a mentorship initiative to attract women to green technologies and retain them;
- develop a policy assessment framework to increase women's participation in clean technology sectors.

Looking ahead, it is estimated that 200,000 more women need to enter the energy sector in the EU-27 to reach a minimal gender balance of 40% female participation by 2050 (European Commission, 2026a). Governments, employers, workers' representatives and society at large are all critical actors in breaking down some of the systemic barriers that women still face. Measures that can support women in the energy transition include:

- ensuring gender mainstreaming in energy and climate policies;
- ensuring gender mainstreaming in labour market and education policies;
- promoting gender-sensitive workplace practices;
- challenging existing cultural biases.

4.6 Age composition of the clean-tech workforce

Demographic change and an ageing workforce are key factors shaping the resilience and capacity of the net-zero industry. It is essential to ensure participation across all age groups to address labour shortages, close skill gaps and sustain sector growth.

As a relatively young and rapidly evolving field — particularly in emerging areas such as battery production — the clean-tech industry has significant potential to attract younger workers, whose education and training can be aligned directly with technological needs in the industry. In contrast, older workers may face higher barriers to training opportunities and find it harder to transition into these emerging sectors (EPRS, 2025b).

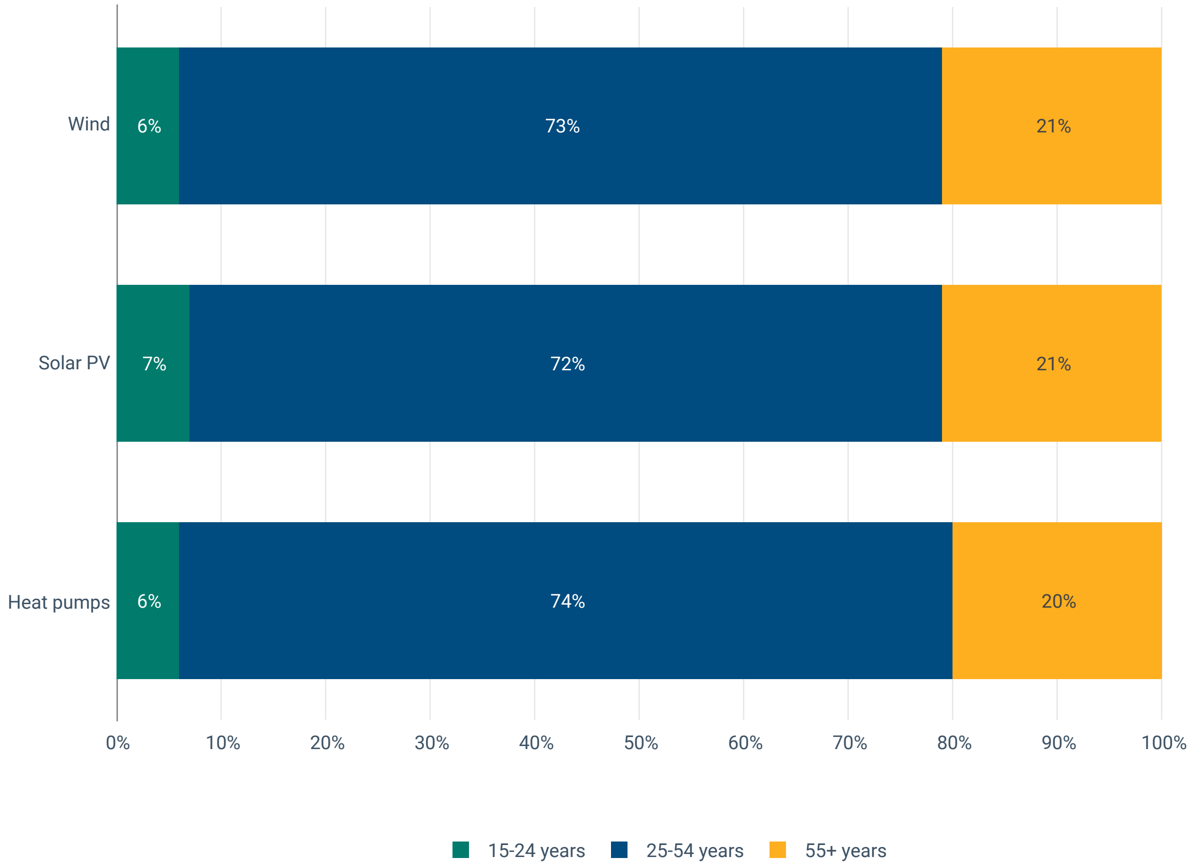
However, there is growing concern that young people — and notably those not in employment, education or training (NEET) — are being excluded from access to job opportunities linked with the green economy (Cedefop, 2025). Anecdotal evidence from offshore wind developments on England's east coast suggests that, despite rapid sectoral growth, many local young people are struggling to access clean-tech jobs (Shipley, 2026).

Technology-specific evidence on the age of the workforce in net-zero industries remains limited; most studies focus on the energy sector as a whole rather than individual technologies. Understanding the age composition of the clean-tech workforce is therefore a key input for policy measures that aim to address labour shortages, support skills development and ensure a resilient and inclusive net-zero transition.

The quantitative assessment presented in this section indicates that workers aged 15-24 currently account for only 6-7% of the workforce across the wind energy, solar PV and heat pump value chains. Despite clean tech's growing potential and opportunities for new entrants, younger generations remain under-represented. Over two-thirds of jobs are held by workers aged 25-54 and around one-fifth are held by people aged 55 or above.

As illustrated in Figure 4.9, age distributions are broadly similar across all four of the technologies analysed in this report. This reflects the wider demographic challenge of an ageing energy workforce in Europe: many workers are approaching retirement and insufficient younger entrants are joining the sector.

Figure 4.9 **Employment share by age group and clean energy technology in the EU-27 in 2023**

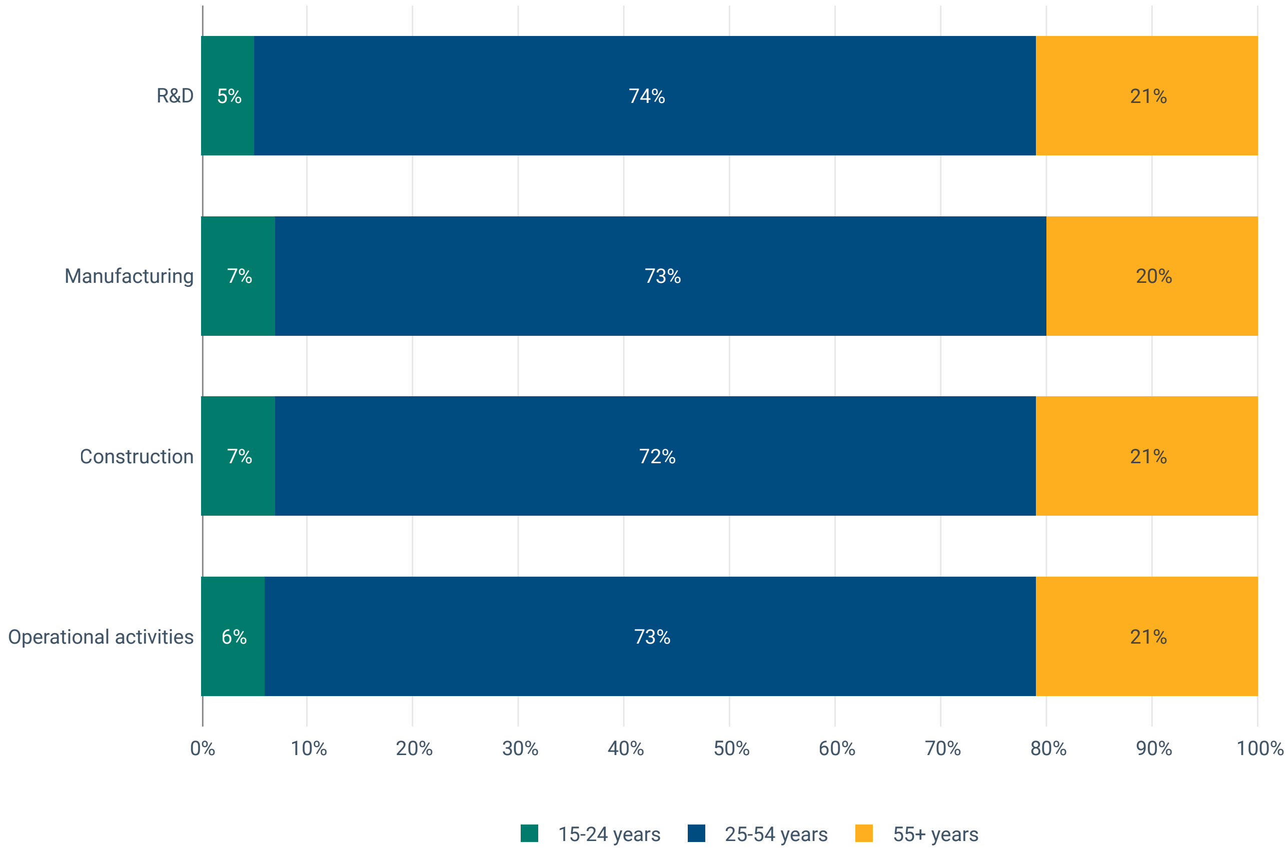


Notes: The figure excludes batteries due to significant data gaps. Data relate to the EU-27 excluding Cyprus, Luxembourg and Malta due to limited data availability.

Source: Prognos 2025 based on envigos model, Eurostat Structural Business Statistics and Eurostat Labour Force Survey.

This pattern is consistent across segments in the value chain. Here the workforce is similarly dominated by those aged 25-54, with a stable 20% share of workers aged over 55. These trends highlight that the net-zero industry faces the same ageing challenges observed in nearly all economic sectors; young workers aged 15-24 represent around 5-7% of employment, mirroring the average in the total economy (8%). The age composition is also remarkably consistent across EU Member States.

Figure 4.10 **Employment share by age group and value chain segment in the EU-27 in 2023**



Notes: The net-zero technologies included are solar PV, wind and heat pumps. Data relate to the EU-27 excluding Cyprus, Luxembourg and Malta due to limited data availability. The figure exclude batteries due to significant data gaps.

Source: Prognos 2025 based on envigos model, Eurostat Structural Business Statistics and Eurostat Labour Force Survey.

Taken together, the analysis of workforce age highlights that the wind, solar PV and heat pump sectors face the same demographic challenges as the broader economy. Young workers remain under-represented, older workers make up a substantial share of the workforce and the bulk of jobs are held by workers in the 25-54 age group.

This reinforces the need for targeted measures to attract younger cohorts into technical and industrial roles. At the same time, it is necessary to support upskilling and reskilling among older workers to facilitate smoother intergenerational transitions.

The distribution of jobs is consistent across the selected technologies, value chain segments and EU Member States. This indicates that demographic pressures are systemic rather than isolated. Given the growing demand for skilled labour and the technical requirements of clean energy technologies, these demographic trends could directly impact the green transition and the expansion of renewable and low-carbon industries in the EU.

5 Occupational profiles, skills and job quality

This chapter sheds further light on labour market dynamics in the four clean technologies featured in this report, that is wind energy, solar photovoltaics (PV), heat pumps and batteries.

The chapter provides insights into the current occupational structure of the net-zero workforce in the European Union (EU) by value chain segment, and highlights the roles most critical to the development of the sector. The analysis is complemented by a detailed examination of the skills and knowledge associated with these occupations. It is then followed by an assessment of occupational shortages that may pose challenges to scaling up net-zero technologies. Factors relating to job quality are also assessed through selected indicators, with a particular focus on wages and the physical working environment.

Together, these elements provide a multidimensional view of employment in net-zero technologies. They also inform how Europe's clean-tech transition is reshaping work, skills and job quality across the EU.

5.1 Key job roles in the featured technologies across value chains

Delivering the EU's net-zero transition will depend on the capacity of labour markets to provide enough workers with the right skills, training and experience across relevant occupations. The deployment of clean technologies is accelerating. As such, it is becoming increasingly important to understand which occupations are most relevant across the value chain to anticipate labour market needs and guide workforce development strategies.

Studies consistently point to persistent bottlenecks in vocational and technical roles (Jansen, 2023; Widuto, 2025). In particular, there is a shortage of installers, technicians and engineers (InnoEnergy, 2025). This makes it challenging to achieve the EU's deployment targets under the Net-Zero Industry Act (NZIA) and the Clean Industrial Deal (CID). For example, shortages of installers can quickly translate into deployment slowdowns, creating knock-on effects for upstream manufacturing and investment.

As shown in Chapter 4, clean-tech value chains comprise a range of different economic activities. There is significant diversity in the occupational structure within each part of the value chain. Identifying the different types of occupation along the value chains of the four featured technologies provides insights into the demand for labour. It also means that changes in demand and possible future labour shortages can be anticipated as the market for each technology grows.

This section quantitatively maps employment according to occupation across the featured technologies. It analyses the data based on value chain segments. For every value chain segment, the 15 occupations with the largest number of workers — equating to at least 50% of employment in the segment — were selected. These occupations are regarded as the key occupations in each respective value chain segment for the four featured net-zero technology sectors. The Prognos skilled-worker model was used to identify the most common occupations, building on highly granular German labour market data. Annex A.1.4 provides further details on the methodological approach used to identify the key occupational profiles.

5.1.1 Research and project development

The employment distribution across the 15 key occupations in the R&D segment reflects a relatively specialised set of roles. These are generally less physically demanding and emphasise higher-skilled, knowledge-based activities.

In this segment engineering professionals represent the occupation with the highest number of jobs (2,000). This reflects the crucial role of broad technical expertise in the development of innovation and technology. Secretaries (1,600) and draughtspersons (1,000) represent the next two largest professions, the latter supporting design and prototype development processes.

Other important roles include mechanical engineers (900), office supervisors (800) and production clerks (800). This indicates that both technical and organisational functions are needed in R&D phases. In total, the 15 key occupations in this segment account for 52.5% of all employment in research and project development for the four featured technologies. The figure equates to approximately 10,000 workers.

If the figure is split according to the technology, wind energy has the largest number of people employed in the 15 occupations (4,600), closely followed by solar PV with 3,800. Consistent with their lower levels of employment generally, the battery and heat pump sectors employ between 700 and 1,000 people each in the 15 key occupations.

Figure 5.1 **R&D jobs in the 15 key occupations for the featured clean energy technologies in the EU-27 in 2023**

Note: The data relate to the 27 EU Member States (EU-27) excluding Cyprus, Luxembourg and Malta due to limited data availability.

Source: Prognos 2025 based on envigos model and ISCO correspondences derived from the German Federal Employment Agency.

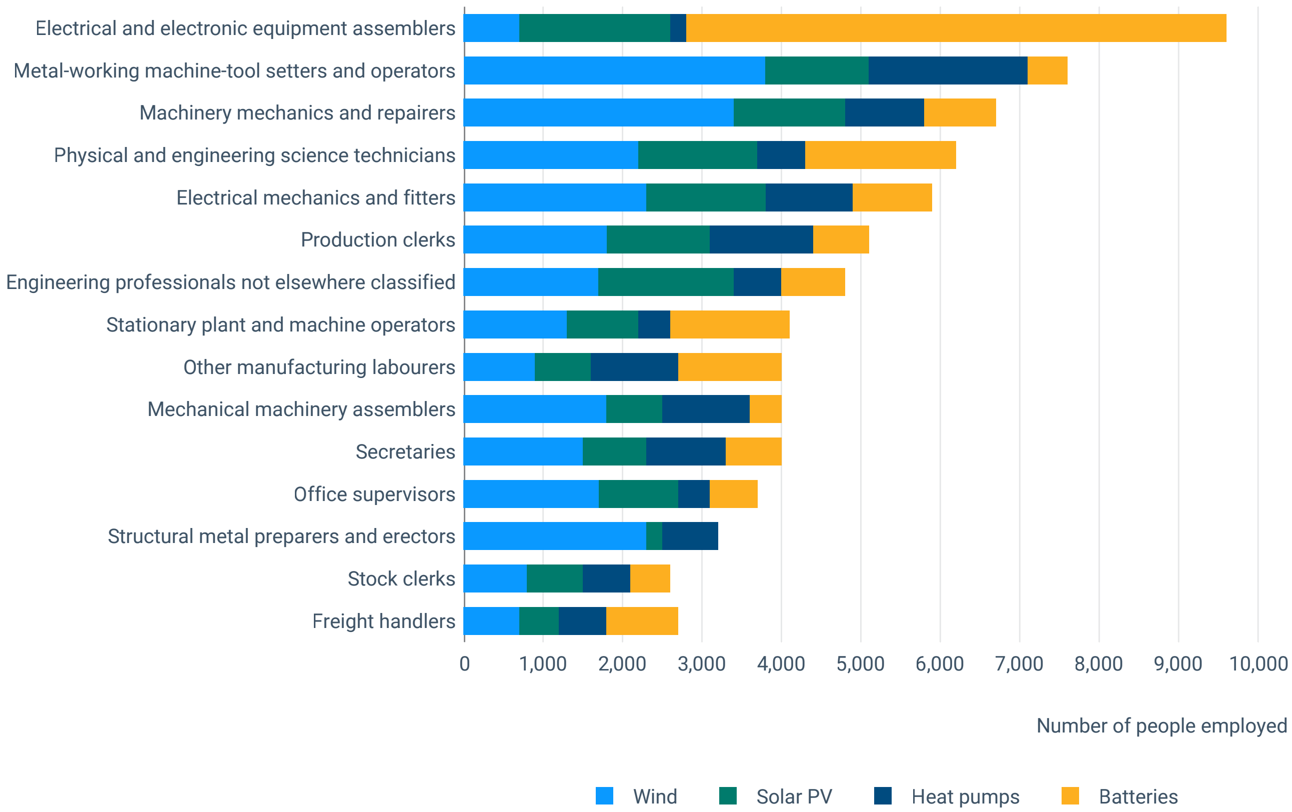
5.1.2 Manufacturing

Employment distribution across the 15 key occupations in the manufacturing value chain segments reflects a manufacturing workforce that is highly technical, production-oriented and broadly similar across technologies. Most occupations (e.g. assemblers, fitters, machine operators) are directly involved in manufacturing processes or handling machinery. Clerical and supervisory roles do exist. but represent a smaller share of jobs compared to the occupational structure across all value chain segments, as illustrated in Figure 5.2.

Electrical and electronic equipment assemblers account for the largest number of jobs (9,600), primarily driven by the batteries sector. Other significant occupations include metal-working machine-tool setters and operators (7,600) and machinery mechanics and repairers (6,700). These are engaged across multiple technologies.

In total, the 15 key occupations in the manufacturing segment account for nearly 75,000 employees across the featured technologies. Wind energy has the largest number of jobs with almost 27,000, followed by batteries with 18,500, solar PV with nearly 16,000 and heat pumps with just under 13,000. These substantial numbers across all four technologies indicate that the 15 occupations are relevant throughout the sector and that employment is broadly distributed across the different technologies for each occupation.

Figure 5.2 Manufacturing jobs in the 15 key occupations for the featured clean energy technologies in the EU-27 in 2023



Note: The data relate to the EU-27 excluding Cyprus, Luxembourg and Malta due to limited data availability.

Source: Prognos 2025 based on envigos model and ISCO correspondences derived from the German Federal Employment Agency.

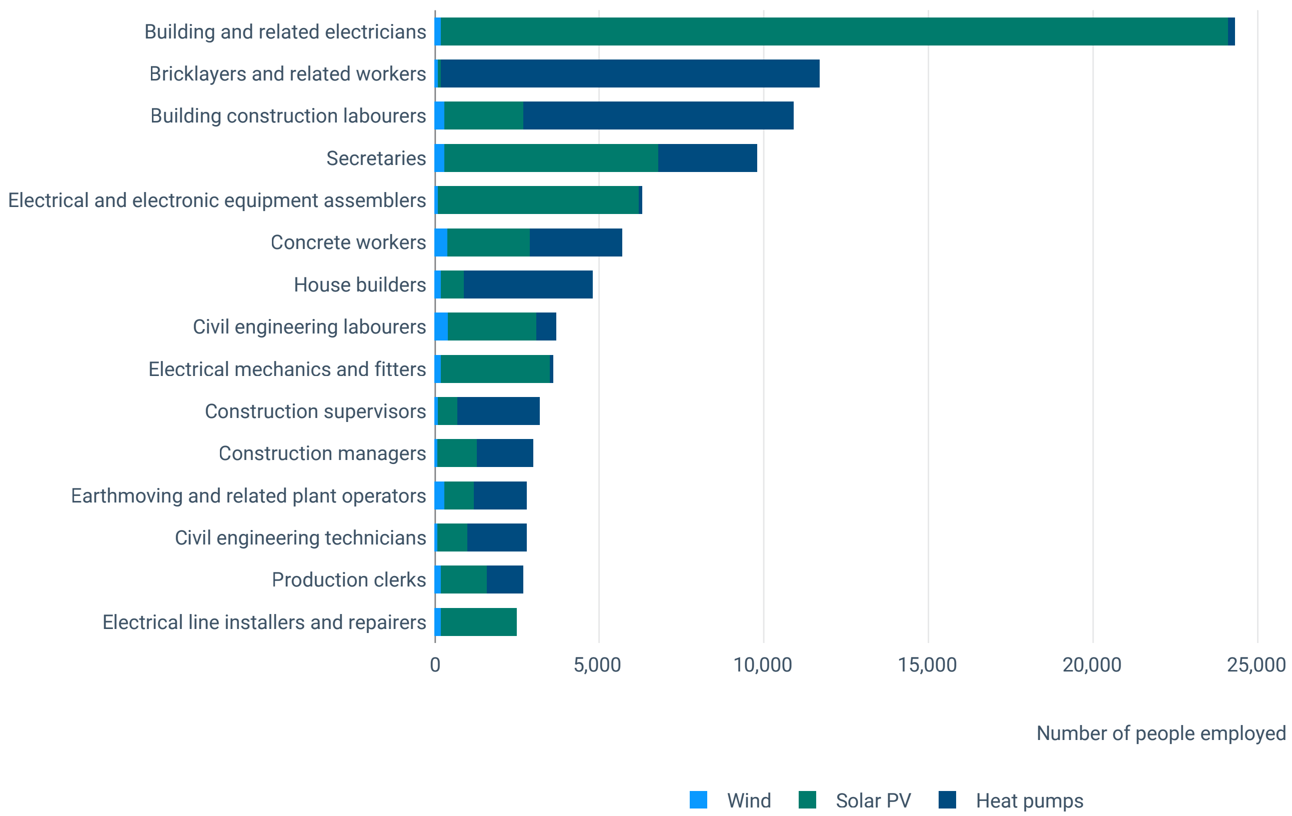
5.1.3 Construction

The construction value chain segment is relatively diverse; employment across the 15 key occupations is distributed between pure construction and electrical occupations. This points to the mixed skill demands of the construction phase. Analysis of this segment only includes solar PV, wind energy and heat pumps, as construction activities for batteries are not currently significant enough for the measures used in the applied approach.

The largest number of jobs within the construction segment are held by building and related electricians (24,300), a group primarily working on installing solar PV. Bricklayers and related workers (11,700) and building construction labourers (10,900) are the next most significant occupations. Both are central to heat pump installation in housing construction. Secretaries (9,800) also account for a notable share of jobs, reflecting essential administrative support functions.

Together, there are nearly 100,000 employees in the 15 key occupations. There is a clear distinction between solar PV, which accounts for 55,500 jobs, and heat pumps, with almost 40,000 jobs. This highlights the particular importance of construction activities for these two technologies. In contrast, employment in wind energy is not strongly represented in the key occupations in this segment.

Figure 5.3 Construction jobs in the 15 key occupations for the featured clean energy technologies in the EU-27 in 2023



Note: The data relate to the EU-27 excluding Cyprus, Luxembourg and Malta due to limited data availability.

Source: Prognos 2025 based on envigos model and ISCO correspondences derived from the German Federal Employment Agency.

5.1.4 Operations

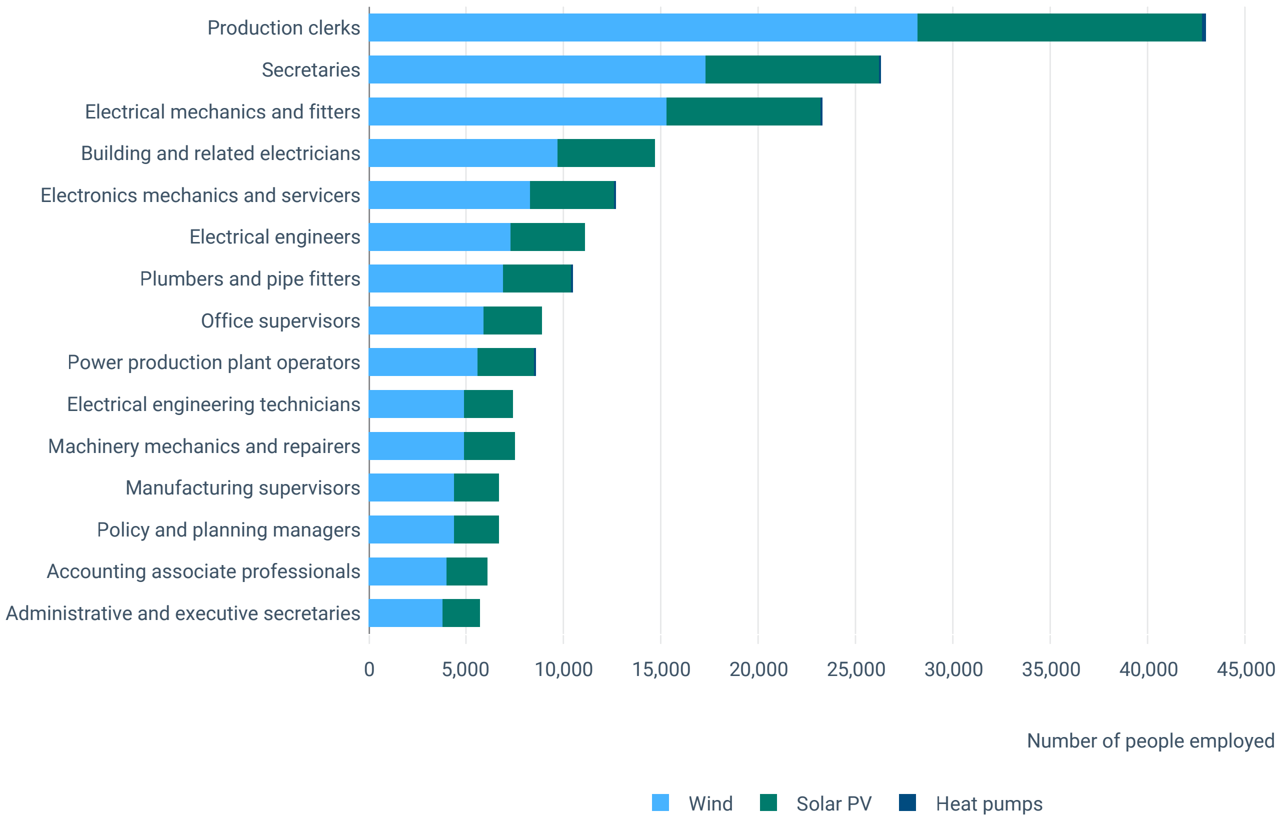
The 15 key occupations in the operations value chain segment can mainly be characterised as supportive, clerical and technical service roles rather than involving physical site or assembly work. Production clerks (43,000) make up the largest number of workers, strongly represented in both the wind energy sector (28,200) and solar PV (14,600). This points to the importance of administrative, coordination and process monitoring tasks in operations. The next largest number of jobs is held by secretaries (26,300), further underlining this central message.

There are also many people employed as electrical mechanics and fitters (23,300) and building and related electricians (14,700). This demonstrates the importance of technical support and maintenance in this segment.

The operations segment — driven primarily by the wind energy and solar PV value chains — employs the largest number of workers, with nearly 200,000 jobs in the 15 key occupations. Many of these roles are related to coordination, documentation and process oversight. Occupations related to electrical and mechanical services are also highly relevant.

From a technological perspective, it is not currently possible to measure employment in the batteries sector using the methodology applied in this report. Equally, only a few occupations in the heat pump sector are represented, such as production clerks, secretaries, and electrical mechanics and fitters. The remainder of the workforce in these key occupations is distributed between wind energy and solar PV.

Figure 5.4 **Operations jobs in the 15 key occupations for the featured clean energy technologies in the EU-27 in 2023**



Note: The data relate to the EU-27 excluding Cyprus, Luxembourg and Malta due to limited data availability.

Source: Prognos 2025 based on envigos model and ISCO correspondences derived from the German Federal Employment Agency.

In general, the occupational analysis presented in Section 5.1 shows that technical and vocational roles are central to the net-zero workforce. Key occupations such as electrical and electronic equipment assemblers, machinery mechanics and repairers form the foundation for employment across the sector. Alongside these specialised roles, there are many more generalist positions like production clerks and secretaries, notably in the operations segment.

Viewed collectively, the analysis confirms that labour demand is highly differentiated across the value chain. As such, a mix of professional, technical, vocational and clerical occupations are required to support innovation, production and deployment in net-zero technologies.

Box 5.1

An industry-level analysis of key job roles

Findings from one industry-specific report offer complementary evidence on the most common roles across various technologies. Engineers from all disciplines are crucial for the future of the wind energy industry, together with skilled labour for installation (EUREC, 2024). Examples of the most common jobs in the wind energy industry include physical and engineering science technicians, engineering professionals (especially electrotechnology engineers), assemblers and welders. Field engineers and a variety of specialised technicians are also critical jobs across multiple project phases (WindEurope, 2025b).

In addition, other more generalist workers are also likely to be in demand. These include project managers, information technology specialists for digital technologies, legal advisors, health and safety officers, quality control officers and environmental specialists.

For offshore wind energy, meteorological and oceanographic specialists, geophysicists, geotechnicians, naval architects and marine warranty surveyors are examples of specialists likely to be in demand, together with operations and maintenance (O&M) technicians able to operate and maintain offshore assets (EUREC, 2024).

The solar PV value chain also requires workers in a broad range of occupations across all qualification levels. A large share of employment is concentrated in deployment and O&M activities. For rooftop solar installations, for instance, two main types of professional are needed: construction workers (especially roofers) for mechanical work and electricians qualified in design, grid connection and project supervision (SolarPower Europe, 2024b). Accelerating training for both these professions is key to meeting the growing demand for solar projects.

The largest number of roles for the heat pump workforce is in on-site technical and installation jobs. Notably, these include plumbing and heating as well as heat pump technicians, who carry out the full installation of the unit itself, as well as specialists for the electrical work required for heat pump installation (Heat Pump Association, 2024). Beyond these technical roles, workers are needed for sales and administration to support the growth of the sector.

A report by the European Institute for Innovation and Technology (EIT) InnoEnergy Skills Institute provides a detailed analysis of job profiles required in the battery value chain. These range from raw materials and processing to battery recycling (EIT InnoEnergy, 2023). Batteries are a multidisciplinary field. As such, they require workers with a solid foundation in:

- extraction of raw materials;
- developing and processing new active materials;
- producing, integrating and assessing cell and battery packs for both mobility and stationary applications;
- assessing sustainability/circular economy/life cycles;
- safety;
- process digitalisation;
- recycling and second life (EUREC, 2024).

5.2 Labour shortages

Growing labour shortages in the EU have constrained the ability to meet the growing demand for clean technology jobs. This section provides new evidence about occupational shortages for the technologies featured in this study. Annex A.1.6. provides details on the approach and data used for the analysis.

Most Member States are currently reporting shortages in all 15 key occupations for the featured clean energy technologies, based on evidence from the European Employment Services (EURES) report *Labour shortages and surpluses in Europe 2024* (European Labour Authority, 2025). These gaps highlight structural constraints in the workforce that could slow the deployment of net-zero technologies.

The biggest shortfall is in building and related electricians, with 21 Member States reporting a shortage. More specifically, Greece, Ireland and Luxembourg are reporting a balanced position for this job, while Finland, Portugal and Spain are reporting a surplus.

Overall, 20 Member States are reporting a shortfall in the number of plumbers and pipe fitters. Here, Denmark, Latvia and Luxembourg are reporting a balanced situation. Meanwhile, Finland, Greece, Portugal and Spain are reporting a surplus. Both roles are particularly critical for the installation and maintenance of wind energy and solar PV systems. As such, the current situation is affecting the pace of renewable energy deployment.

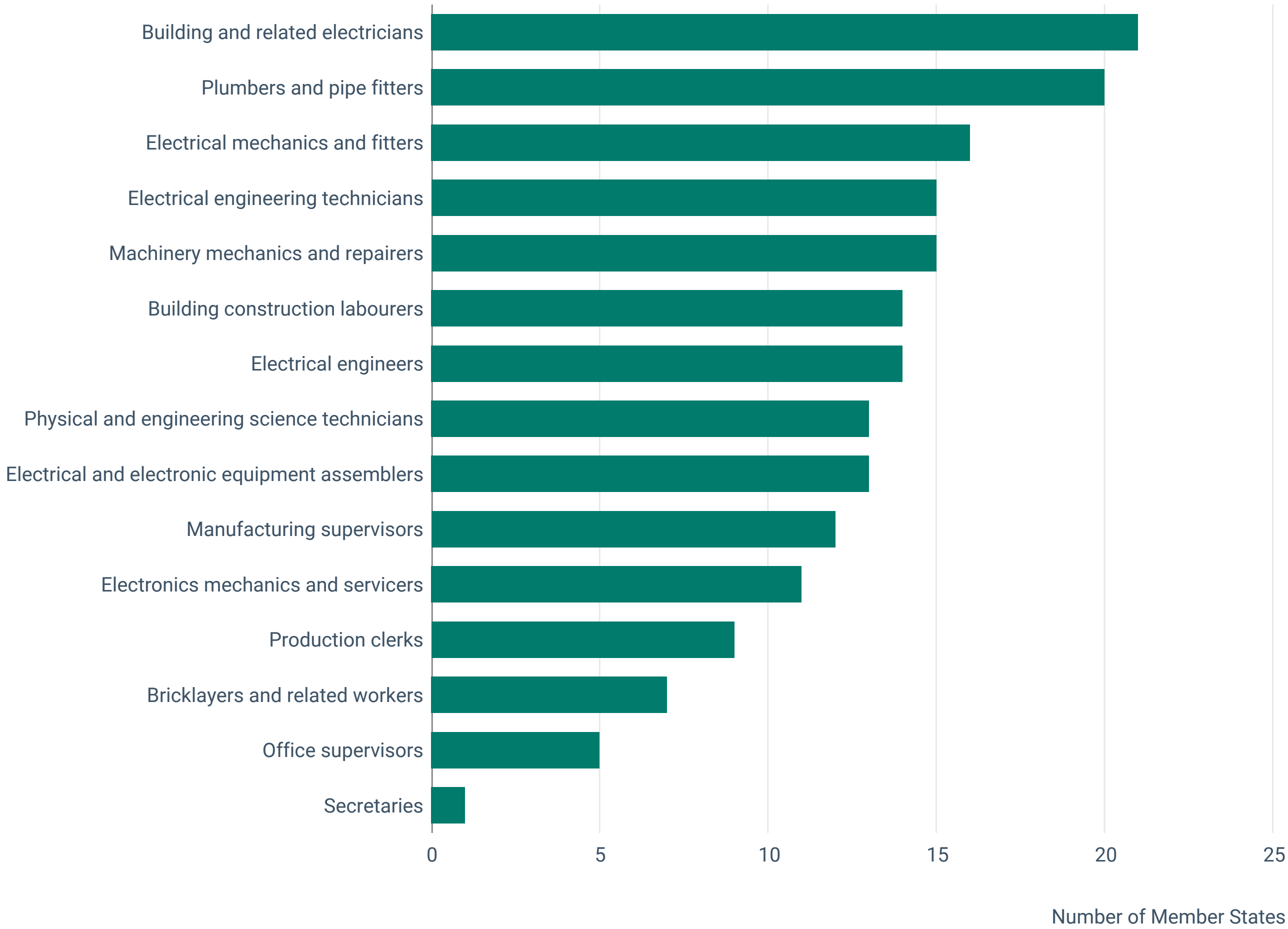
Other occupations facing notable shortages include electrical mechanics, technicians, engineers and various types of mechanics, reflecting the high demand for specialised technical skills across multiple net-zero sectors.

In contrast, there is less shortfall for office-based roles such as supervisors, clerks and administrative staff. Fewer Member States are reporting shortages in these categories. Such roles are less specialised and require relatively similar skills across different sectors. Overall, where shortages do occur, they are concentrated in occupations linked to construction, installation and engineering, while roles in operations or R&D are comparatively less affected.

From a Member State perspective, Finland, Portugal and Spain only have a shortage in one key occupation each; simultaneously they are reporting the highest numbers of surpluses, ranging from 9 in Spain to 10 in Finland and 14 in Portugal.

In contrast, Bulgaria (13 occupations), Malta (12) and both France and Italy (11 each) are reporting the greatest number of shortages in key occupations. Figure 5.5 provides a visual summary of the findings for the reported shortages for key occupations.

Figure 5.5 **Number of EU-27 Member States reporting shortages in key occupations for the featured clean energy technologies**



Note: The net-zero technologies included are solar PV, wind, heat pumps and batteries.

Source: Prognos 2025 based on European Labour Authority, 2025.

Industry-specific studies provide further evidence on job gaps. They highlight areas where the existing labour force does not meet growing demand. In the wind industry, critical shortages of blade technicians are expected by 2030 (with a deficit of 7,000 workers), field engineers (with a deficit of more than 6,000) and pre-assembly support technicians and commissioning technicians (with a gap of around 5,000 workers each).

Other occupations with the greatest shortages include engineering consultants, assembly technicians, surface finishers, scaffolders, electricians and electrical technicians (WindEurope, 2025b). In addition to skills shortages related to installation, a deficit is also expected in skilled labour for manufacturing components (EUREC, 2024).

The solar industry also faces major challenges in terms of labour shortages; companies are continuing to report persistent difficulties in recruiting electricians, roofers, engineers and manufacturing specialists with the appropriate skill sets (SolarPower Europe, 2025a). Rooftop solar installations require two main categories of professionals: qualified electricians (responsible for system design, grid connection and project supervision) and construction workers (particularly roofers) who carry out the mechanical work.

Meeting the rapidly growing demand for solar projects will depend on accelerating training for both these groups. Better-trained construction workers will be able to support large-scale deployment while ensuring high standards of quality and safety in this emerging subsector. Apprentice electricians should be encouraged to acquire solar PV skills during their studies, under the guidance of experienced professionals, to build the necessary competencies early on (SolarPower Europe, 2024b).

The EU is currently facing a substantial skills gap in the construction sector. In this context, the heat pump industry is no exception as it faces a shortage of skilled installers. This may hamper the rate at which this industry can grow in the medium term (Toleikyte, A. et al., 2024). In 2022 it was estimated that — to meet the REPowerEU targets by 2030 — the number of installers will need to increase by 50%. In addition, at least half of the current installer workforce will need to be reskilled to work effectively with heat pump technologies (European Heating Industry, 2022).

Labour shortages — both in technical and research roles — also pose a major risk to Europe's ability to develop a competitive, self-sufficient battery industry. The shortage of skilled workers is a barrier to innovation in Europe's battery ecosystem. Companies consider it to be an even greater challenge than innovation costs (Fraunhofer Institute for Systems and Innovation Research ISI, 2024).

Additional international evidence reinforces the severity of these shortages. The International Energy Agency (IEA) notes that the limited availability of adequately skilled workers has intensified competition both within and between energy industries — including renewables and oil and gas. As such, energy companies are responding by:

- increasing wages;
- expanding their efforts to reskill existing staff;
- relying more on external contractors and consultancies;
- in some cases, shifting their operations to regions with a deeper pool of technical labour.

These patterns mirror the shortages observed across Europe's net-zero value chains and underline the structural nature of skills constraints (IEA, 2023).

5.3 Skills and training

The European Skills, Competences, Qualifications and Occupations (ESCO) classification provides a robust foundation for understanding occupational profiles. It details the skills and knowledge associated with each occupation. Building on the key occupations identified above, specific ESCO profiles — that are directly relevant to the net-zero technologies considered in this study — were selected for analysis at a more detailed level. These profiles serve as representative examples of the skills and knowledge required across different technologies and value chain segments. Annex A.1.5 provides more details on the data and the methodological approach used.

The visualisations below (from Figure 5.6 to Figure 5.9) illustrate the complexity of requirements for jobs in the net-zero industry. A set of overarching skills — such as a solid understanding of renewable energy systems, energy efficiency practices, environmental legislation and health and safety procedures — is needed across all value chain segments and technologies; however, each technology also requires specialised technical and vocational skills.

Since onshore and offshore wind turbines operate on similar technological principles, engineers and technicians in both areas share many core skills and knowledge. This includes expertise in turbine components — such as blades — as well as understanding different types of turbines and electricity systems. However, there are notable differences. Offshore technicians require additional competencies in maritime operations and offshore safety protocols; in this sense, the job requirements differ significantly from those for onshore jobs.

Figure 5.6 Required skills and knowledge areas for selected occupations in wind energy

Technical skills

Onshore wind energy engineer

- ensure compliance with environmental legislation
- conduct engineering site audits
- test wind turbine blades
- ensure compliance with safety legislation
- perform data analysis
- record test data
- ensure compliance with noise standards
- adjust engineering designs
- research locations for wind farms
- perform scientific research
- use technical drawing software
- report test findings
- manage engineering projects
- provide information on wind turbines
- adjust voltage
- read engineering drawings
- promote innovative infrastructure design
- project management
- develop test procedures
- design wind turbines
- approve engineering designs
- design automation components

Offshore renewable energy technician

- inspect offshore constructions
- gather data
- maintain records of maintenance interventions
- provide first aid
- maintain electrical equipment
- manage emergency procedures
- inspect wind turbines
- install electrical and electronic equipment
- arrange equipment repairs
- use remote control equipment
- maintain sensor equipment
- install offshore renewable energy systems
- respond to electrical power contingencies
- test sensors
- analyse test data
- maintain hydraulic systems
- survive at sea in the event of ship abandonment
- maintain wind turbines
- maintain electronic equipment
- ensure equipment maintenance
- apply health and safety standards
- inspect tidal stream generators
- monitor electric generators
- inspect wave energy converters
- prevent marine pollution
- follow safety procedures when working at heights

Knowledge areas

Onshore wind energy engineer

- energy market
- engineering principles
- wind energy
- electrical discharge
- technical drawings
- electrical power safety regulations
- types of wind turbines
- engineering processes
- aerodynamics
- civil engineering
- meteorology
- data storage
- electric generators
- mining, construction and civil engineering machinery products
- renewable energy

Offshore renewable energy technician

- marine engineering
- wind energy
- electrical discharge
- electrical power safety regulations
- types of wind turbines
- electronics
- offshore contructions and facilities
- offshore renewable energy technologies
- maritime meteorology
- electricity
- electric generators
- marine energy
- marine technology
- mechanics
- renewable energy

Source: Authors' elaboration based on ESCO database (EC, 2026f).

In the solar energy sector, skill requirements differ across the value chain. Technicians mainly need expertise in materials, components and installation processes. Meanwhile, operators focus on the maintenance, monitoring and efficient functioning of solar facilities. Despite these distinctions, both roles share essential knowledge areas, including on solar products, electricity and electric generator systems.

Figure 5.7 Required skills and knowledge areas for selected occupations in the solar PV sector

Solar energy technician

Solar power plant operator

Technical skills

Solar energy technician:

- mount PV panels
- test procedures in electricity transmission
- work ergonomically
- install PV systems
- inspect electrical supplies
- check compatibility of materials
- comply with legal regulations
- transport construction supplies
- inspect construction supplies
- install electrical and electronic equipment
- install circuit breakers
- follow health and safety procedures in construction
- install concentrated solar power systems
- interpret 3D plans
- operate solar thermal energy systems for hot water and heating
- use measurement instruments
- interpret 2D plans
- follow safety procedures when working at heights

Solar power plant operator:

- maintain records of maintenance interventions
- install PV systems
- maintain PV systems
- maintain electrical equipment
- respond to electrical power contingencies
- maintain concentrated solar power systems
- install concentrated solar power systems
- apply health and safety standards
- monitor electric generators

Knowledge areas

Solar energy technician:

- solar energy
- alternative energy
- solar products
- electricity
- electrical wiring plans
- PV systems
- mechanics

Solar power plant operator:

- solar energy
- electric current
- electrical power safety regulations
- electricity
- electric generators
- PV systems

Source: Authors' elaboration based on ESCO database (EC, 2026f).

In the battery value chain, distinct skill sets are required for different roles. Battery assemblers need core assembly skills, such as aligning and fastening components. These must be complemented by technology-specific abilities such as adjusting voltage and ensuring safety. Battery system engineers, in contrast, focus on development, process optimisation and testing procedures.

Despite these differences, both roles share foundational knowledge of battery design and chemistry, with system engineers focusing on operational systems and programming, while assemblers concentrate on battery components and handling fluids.

Figure 5.8 Required skills and knowledge areas for selected occupations in the battery sector

	Battery system engineer	Battery assembler
Technical skills	• troubleshoot • perform product testing • develop new products • analyse test data • identify process improvements • define integration strategy • conform with production requirements • develop predictive models	• monitor machine operations • read assembly drawings • remove defective products • assemble batteries • ensure public safety and security • align components • wear appropriate protective gear • meet deadlines • adjust voltage • report defective manufacturing materials • fasten components • ensure conformity to specifications • operate soldering equipment • install low-voltage wiring • attach power cords to electric modules
Knowledge areas	• battery design • battery management systems • enginnering principles • embedded systems • computer programming • project management principles • vehicle electrical systems • electrical engineering • safety engineering • control systems • project management • computer science • battery chemistry • mechanical engineering	• battery fluids • battery management systems • electrical discharge • battery chemistry • battery components • quality standards • electricity • battery formation

Source: Authors' elaboration based on ESCO database (EC, 2026f).

One specific occupation is explicitly linked to heat pumps, as indicated by its title: refrigeration, air-conditioning and heat pump technician. This role spans multiple segments of the heat pump value chain, from installation and associated construction work to O&M. The technician's broad skill set is complemented by in-depth knowledge of hydraulics, thermodynamics and electronics. As a result, heat pump technicians must be versatile professionals, capable of mastering a wide range of technological and vocational competencies.

Figure 5.9 **Required skills and knowledge areas for a selected occupation in the heat pump sector**

Refrigeration, air-conditioning and heat pump technician

Technical skills

- install heat pump
- handle refrigerant transfer pumps
- ensure compliance with environmental legislation
- maintain records of maintenance interventions
- prepare copper gas-line pipes
- resolve equipment malfunctions
- measure electrical characteristics
- operate welding equipment
- record test data
- maintain electrical equipment
- perform test runs
- install electrical and electronic equipment
- lay pipe installation
- perform refrigerant leak checks
- conduct routine machinery checks
- use testing equipment
- install heating, ventilation, air-conditioning and refrigeration ducts
- perform maintenance on installed equipment
- install insulation material
- operate climate controls
- maintain air-conditioning systems
- consult technical resources
- install ventilation equipment
- interpret 3D plans
- install air-conditioning devices
- use measurement instruments
- maintain electronic equipment
- install refrigeration equipment
- test tightness and pressure of refrigeration circuits
- interpret 2D plans
- operate soldering equipment

Knowledge areas

- refrigerants
- hydraulics
- thermodynamics
- electronics
- heating, ventilation, air-conditioning and refrigeration parts
- electricity
- electrical wiring plans
- mechanics

Source: Authors' elaboration based on ESCO database (EC, 2026f).

This assessment highlights the complexity of skill requirements in the net-zero industry. While each technology demands specialised expertise tailored to its unique processes and applications, a common set of engineering, technical and project management competencies is necessary in all technologies and value chain segments. This overlap in the types of competencies in demand can result in strong competition for workers across clean energy technologies in a context where these sectors are all facing similar challenges (SolarPower Europe, 2024b).

Job vacancy rates doubled between 2020 and 2023 in sectors relevant to the energy transition such as manufacturing, energy supply, and scientific and technical activities. These shortages point to multiple technologies competing for the same limited pools of skilled technical workers (JRC, 2023). Cross-technology learning modules could help to reduce bottlenecks by enabling qualified workers to move between different technologies.

Some programmes to combine training or provide 'add-ons' for existing skills already exist. For example, a course offered by private training provider WBS in Germany allows installers to acquire the skills needed for the solar PV, heat pump and solar thermal sectors.

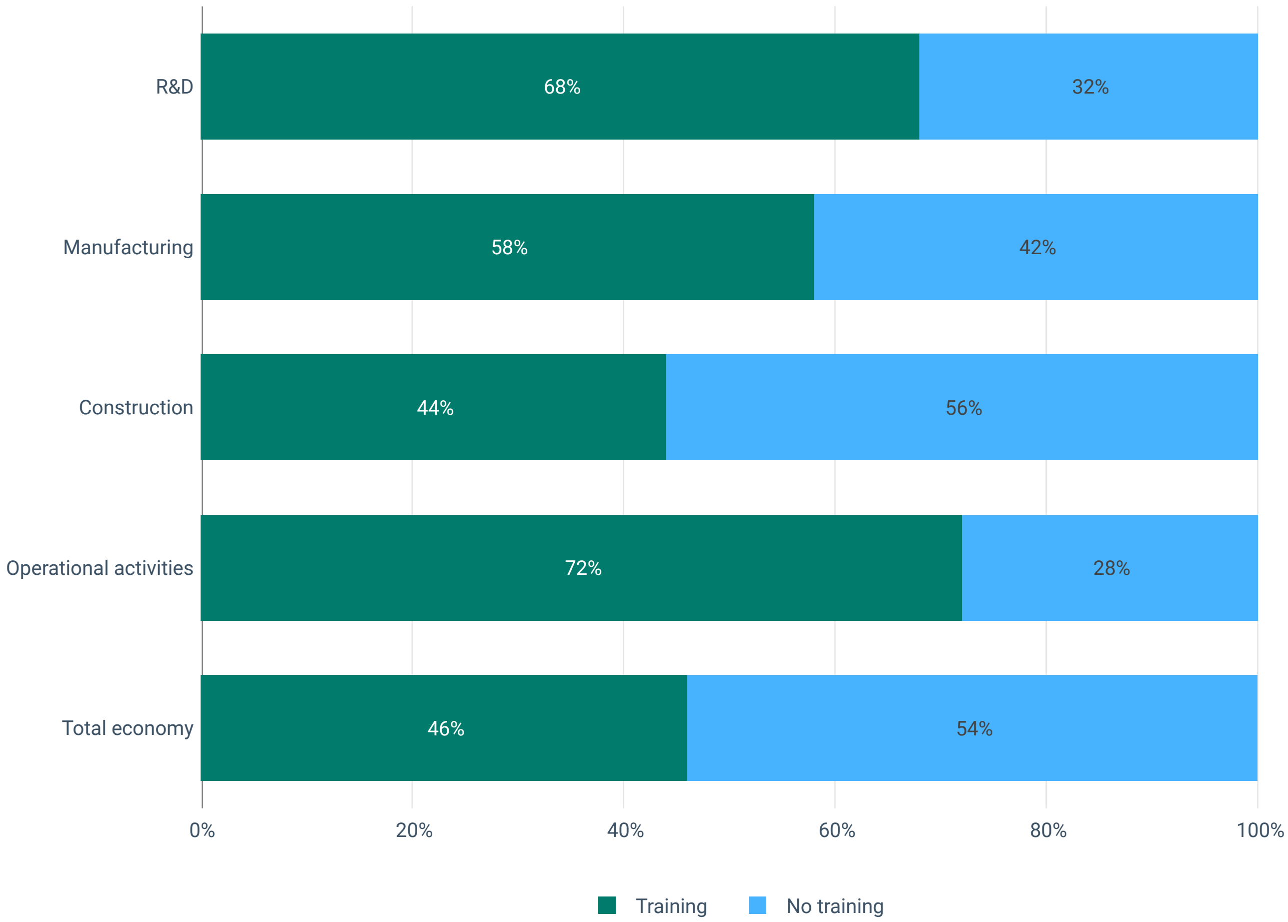
In this context, there are calls for European cooperation across industries to solve the skills gaps in the energy transition. The RESKILL4NETZERO project (see Section 2.2.1) is a good example of this kind of initiative. It aims to develop and test a scalable European framework to identify and support the critical job roles needed to overcome labour shortages in renewable energy industries.

As part of the project, industry associations and training experts will cooperate to develop a unified skills 'blueprint'. This will cover green, digital and safety-related competencies for transferable job roles shared across multiple renewable industries — including batteries, solar, wind, hydrogen, geothermal and critical raw materials (CRMs). This approach aims to create smoother pathways for reskilling and career transitions for qualified workers entering the rapidly expanding renewable energy sector.

Many of the technical roles required in the renewable energy sector can also be filled by workers from the declining fossil fuel industry and related fields. For instance, the skills used in offshore oil and gas operations are readily applicable to offshore wind and ocean energy. Meanwhile, gas boiler installers can be retrained to work with heat pump systems. It is essential to develop targeted training programmes — supported by EU-wide certification and mutual recognition of qualifications — to ensure an adequate supply of skilled labour (JRC, 2023). At the national level, concrete initiatives are already underway, such as Poland's Wind Academy. This is retraining coal miners as turbine technicians.

Overall, participation in training activities is very uneven across the value chain for the technologies featured in this report. Evidence from the European Working Conditions Survey (EWCS) indicates that only 44% of the people employed in construction have received training in the past 12 months. This compares with 72% of those in operations, 58% of those in manufacturing and 68% of R&D specialists having participated in training in the past 12 months. These figures are above the average for the economy as a whole (at 46%) (see Figure 5.10).

Figure 5.10 **Share of workers who undertook training by value chain segment for the featured clean energy technologies in the EU-27 in 2024**



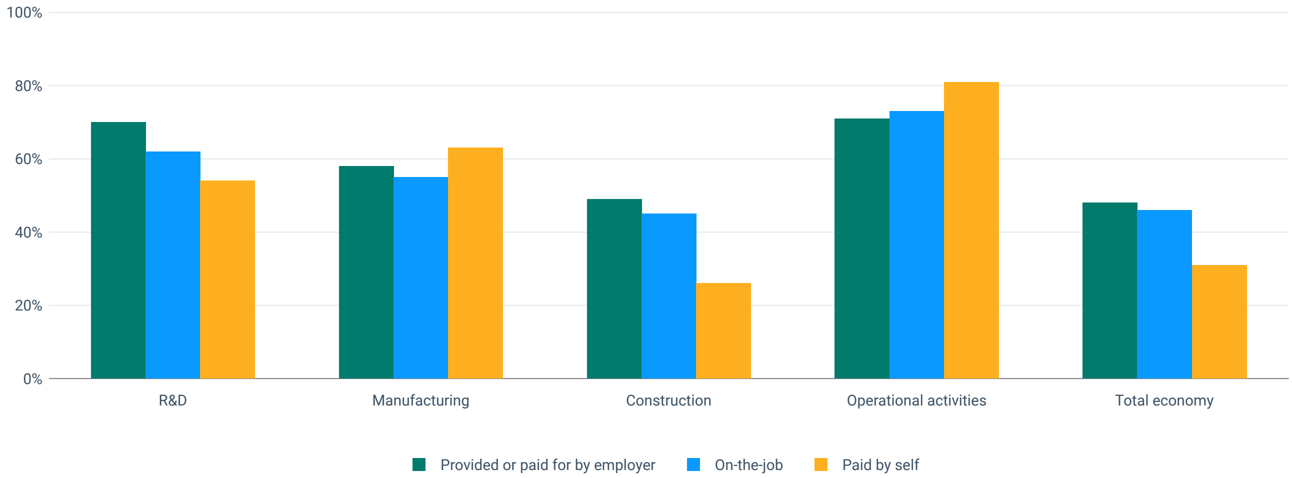
Notes: The net-zero technologies included are solar PV, wind, heat pumps and batteries. Data were accessed and analysed in February 2026.

Source: European Working Conditions Survey 2024 (Eurofound, 2026).

Figure 5.11 compares how much training is accessed by workers across different clean-tech value chains. It distinguishes between employer-provided or employer-paid training, on-the-job learning and training paid for by workers themselves. Workers in operational activities accessed the most training in 2024 across all training types. Meanwhile, workers in the construction segment accessed the least training, especially in the area of self-paid training. There was strong employer and on-the-job training in the R&D segment, while manufacturing was characterised by more balanced — but moderate — training levels.

Training remains a crucial component of lifelong learning and keeping pace with technological developments. However, a large share of workers still do not have access to it, as illustrated by Figure 5.10. Ensuring that workers can update and expand their skillsets is essential for maintaining workforce resilience, supporting the adoption of emerging technologies and securing the timely deployment of net-zero solutions across the EU.

Figure 5.11 Type of training to improve skills by value chain segment for the featured clean energy technologies in the EU-27 in 2024



Notes: The net-zero technologies included are solar PV, wind, heat pumps and batteries. Data were accessed and analysed in February 2026.

Source: European Working Conditions Survey 2024 (Eurofound, 2026).

Box 5.2

The digital transition, artificial intelligence (AI) and implications for the energy workforce

The energy transition is happening alongside the digital transition; this is changing job profiles and creating new ones. While the use of digital devices differs considerably between countries and by sector, education and occupation, it is estimated that an average of 90% of EU workers rely on computers, mobile devices and office software to perform their work. At the same time, one-third use AI tools, in particular AI chatbots powered by large language models (Gonzalez Vazquez et al., 2025).

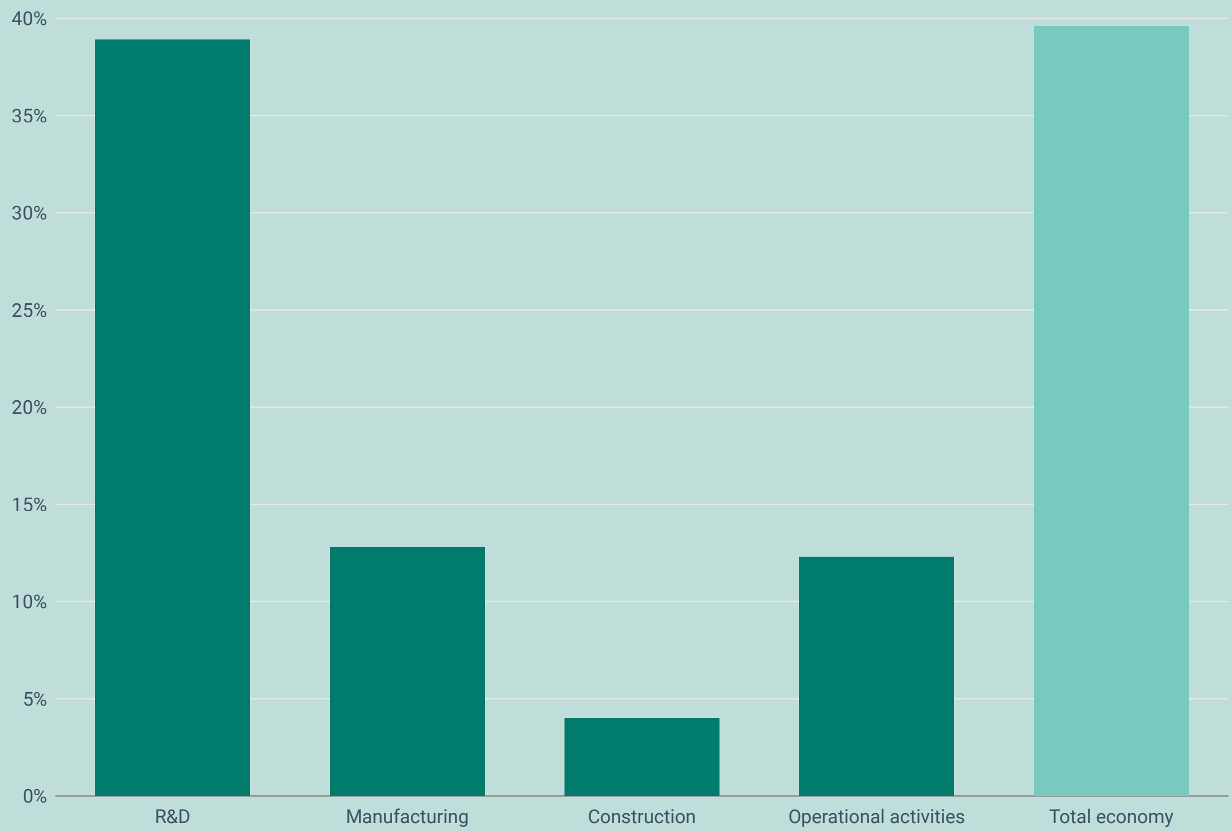
Technical skills remain central to the transition. As such, there is an increasing demand for workers to master digital tools and systems (EIT InnoEnergy, 2023; JRC, 2023; SolarPower Europe, 2025a). While the green and digital transitions are strictly interconnected, they are too often treated as separate phenomena rather than in an integrated manner (JRC, 2025).

However, a growing body of literature demonstrates that AI is becoming a critical enabler of the clean energy transition. This, in turn, has an impact on the labour force. Energy companies increasingly hire data scientists, AI specialists and digital innovators, alongside traditional engineers and project managers. These roles require expertise in both energy systems and advanced analytics and they are becoming central to renewable energy planning and grid operations (Dhaliwal, 2025). Field technicians and maintenance supervisors also need to develop their competencies in digitally enabled problem-solving. The ability to read sensor data and apply AI-driven insights to everyday decisions is quickly turning AI-literate professionals into high-value assets (Dhaliwal, 2025).

Existing evidence from the *World Energy Employment 2025* report (IEA, 2025) indicates that AI is primarily reshaping job roles, rather than solving the persistent shortage of skilled labour in the energy workforce. The adoption of AI leads to shifts in how work is organised, pushing companies to rethink roles that are most exposed to automation — particularly in administrative functions like procurement, permitting, compliance and documentation. At the same time, there is no evidence that AI is reducing the demand for key technical and vocational skills that are central to the energy transition. These depend on hands-on skills, real-time problem-solving and judgment in uncertain conditions — capabilities that AI cannot yet replace (IEA, 2025).

From a value chain perspective, the use of generative AI tools to simplify complex mental tasks or make recommendations on how work should be organised (e.g. ChatGPT, LLAMA, DALL-E, Midjourney, Jasper) is most prevalent in the R&D segment. Here 39% of workers make use of it, as shown by data from the EWCS 2024 in Figure 5.12. Manufacturing and operational activities follow at 13% and 12%, respectively.

Figure 5.12 Shares of workers using generative AI by value chain segment for the featured clean energy technologies in the EU-27 in 2024



Notes: The net-zero technologies included are solar PV, wind, heat pumps and batteries. Data were accessed and analysed in February 2026.

Source: European Working Conditions Survey 2024 (Eurofound, 2026).

Overall, experts emphasise that the role of AI in the energy workforce is to complement a well-skilled human workforce and unlock its full potential, rather than replacing workers (Saavedra, 2025). In addition, it is also important to equip the workforce with digital skills training for sustainable AI, which enables users to assess the ecological impacts of AI systems. Two recent European Environment Agency (EEA) briefings explore how digitalisation and AI can deliver measurable environmental benefits when aligned with sustainability objectives (EEA, 2026a; EEA, 2026b).

5.3.1 Targeted support for skills development

As anticipated in Chapter 2, net-zero industry academies are a flagship initiative under the EU's NZIA. These academies aim to provide coordinated, high-quality training aligned with industry needs. Their goal is to reskill and upskill workers for jobs in clean-tech manufacturing.

As of January 2026, academies focused on batteries, solar and hydrogen were already operational; initiatives for the wind and raw-material sectors were also under preparation (European Commission, 2024c). The European Solar Academy was the first net-zero academy to be launched in 2024. Managed by the InnoEnergy Skills Institute, the knowledge and innovation community of the European Institute for Innovation and Technology (EIT), this academy aims to upskill and reskill 100,000 workers across the solar value chain by 2027 (European Commission, 2024a). It delivers harmonised curricula and standardised credentials. This facilitates mutual recognition of skills and labour mobility across Member States. It also fosters a cohesive skills ecosystem.

As part of the European Solar Academy project, SolarPower Europe (the association for the European solar PV sector) and the InnoEnergy Skills Institute launched the European Installer Training & Credential Initiative. This addresses fragmentation in certification schemes and introduces common competency standards and learning pathways for PV installers. The pilot phase of the initiative includes a network of training providers from Finland, France, Germany, Poland and Romania.

The European Solar Academy follows the successful model of the European Battery Academy, which was launched in 2022 to provide high-quality training across Member States in the battery value chain. Europe's automotive industry — which employs around 13 million people — is undergoing a major transition; this requires large-scale reskilling and upskilling of the workforce to meet new technological demands in a rapidly evolving sector.

The Battery Academy was also implemented by EIT and InnoEnergy. It relies on a network of more than 4,000 local training providers to deliver courses across the EU. As of March 2024, its platform offered 60 courses and had trained over 67,000 learners (European Commission, 2024c).

A European net-zero academy for the wind sector is foreseen and in preparation. However, it has not yet formally launched at the EU-level. There is currently no EU level academy for the heat pump sector under the net-zero industry academies framework, but specialised training ecosystems and industry-led academies do already exist.

The European Heat Pump Association (EHPA) plays a key role in coordinating heat pump skills in Europe. Some Horizon 2020 and LIFE [17] projects focus specifically on skills development in the heat pump sector, such as the HP4ALL (2020-2023) and HeatCraftHP (2024-2027). There is also projects with a focus on health and safety in relation to handling highly flammable refrigerants (SKILLSAFE EU, 2024-2027).

In addition and complimentary to the initiatives listed above, Erasmus+ has been financing several key projects and initiatives in recent years with the aim of developing skills across different technologies. These are presented in Table 5.1.

(17) Programme for the Environment and Climate Action (LIFE).

Table 5.1 Examples of Erasmus+ funded initiatives to support skills development across different technologies

Technologies	Projects and initiatives
Wind energy and solar PV	The RES-SKILL project (2020-2023) aimed to facilitate the transition of coal workers into renewable energy jobs. The project focused primarily on wind energy and solar PV, identifying job profiles where coal workers' skillsets could be redeployed with short, targeted training, rather than lengthy full retraining programmes. Key outputs from the project were: • the development of a novel, modular curriculum and tailored training content for transitions from work in the coal sector to renewable energy sources; • guidance and tools for vocational education and training (VET) providers on the delivery and integration of improved VET-industry collaboration models supporting work-based learning and job placement. The project directly addresses coal phase-out impacts in specific regions and is closely aligned with just-transition objectives under EU cohesion and social policy.
Cross-technology (including solar and wind energy, heat pumps)	The ReSkill4NetZero project (2024-2028) complements the RES-SKILL project by scaling up skills provision across the renewable energy sector to meet rapidly growing labour demand driven by EU climate, energy and industrial policies. Rather than targeting a specific declining industry or particular regions, it focuses on how to build a large, futureproof renewable energy workforce at EU scale. ReSkill4NetZero is designed as a cross-technology skills initiative covering several renewable and net-zero energy technologies — notably solar and wind energy, heat pumps, biogas and biomethane — rather than a single technology or value chain. The project aims to develop a sector-specific skills strategy that maps career and qualification pathways within the renewable energy sector to provide clear routes for career progression. Under the project, tailored curricula are also being designed for key occupational profiles, offering structured pathways to acquire the green, digital and safety-related skills required across renewable energy technologies. RESkill4NetZero will actively support the EU Renewable Energy Skills Partnership, created as part of the Pact for Skills.
Wind energy sector	The SIMULWIND (2017-2019), VET WIND II (2018-2019) and WINd (2023-2025) projects focused specifically on the wind energy sector. They supported skills development, employability and workforce transition. The main outcomes of these projects were: • a wind turbine O&M simulator for training O&M personnel (SIMULWIND); • comparative mapping and analysis of wind energy VET programmes (VET WIND II); • a competence-based reskilling package for workers transitioning from conventional energy industries into wind energy (WINd).
Batteries	The Alliance for Batteries Technology, Training and Skills (ALBATTS) was funded under Erasmus+ in 2019-2024. It supported curriculum development, 'skill intelligence' and the validation of new occupational profiles. Its *Handbook of Battery Teaching* was designed to help develop teaching and training competence in VET. A complimentary project on Capacity Building for Battery Teachers in VET (CaBatt), running between 2023 and 2025, specifically focused on training and upskilling VET teachers for the battery sector. Additionally, the project on Vocational Training for Optimal Learning and Growth in the European Battery Industry (VOLTAGE) was launched in 2024. Its aim is to establish a network of Centres of Vocational Excellence across Europe, specifically for the battery industry. The project will run until 2028.
Heat pumps	The PUMP-UP project (2023-2026) focuses on upskilling heating, ventilation and air-conditioning (HVAC) technicians for heat pump technologies. Among the expected results are: • the development of a modular VET curriculum on heat pump technologies; • the introduction of micro-credential-based certification for heat pump skills; • updated HVAC occupational profiles to reflect electrification and decarbonisation needs; • the development of a blueprint with specifications for an EU-wide qualification for HVAC technicians.

5.4 Job quality

The expansion of net-zero technologies is creating large numbers of new jobs. However, the quality of these jobs is expected to vary widely across value chain segments and occupations. While evidence about job creation is increasingly available, there is still a significant lack of data and metrics on job quality in clean technologies (Hanna et al., 2024). This gap means that policymakers lack comprehensive information to ensure these jobs are high quality, secure and aligned with just-transition principles.

Recent analysis reveals that existing occupations — for which demand is expected to expand during the green transition — score below average on job quality indicators. This is notably in relation to physical risks and demands (Eurofound, 2024a). This factor shapes the overall attractiveness of the sectors and directly affects recruitment and retention in occupations that are already experiencing acute shortages. It is therefore essential to understand the factors that feed into job quality to assess whether the net-zero transition is delivering in line with the ambitions of the NZIA and the CID.

It is recognised that job quality is a multidimensional concept, which refers to the extent to which a job's characteristics support workers' health, well-being and sustainable participation in work over a period of time (Parent-Thirion et al., 2016). This section presents a focused analysis across technologies and value chain segments for selected indicators, including:

- wages;
- employment type;
- physical environment;
- health and safety.

5.4.1 Wages and salaries

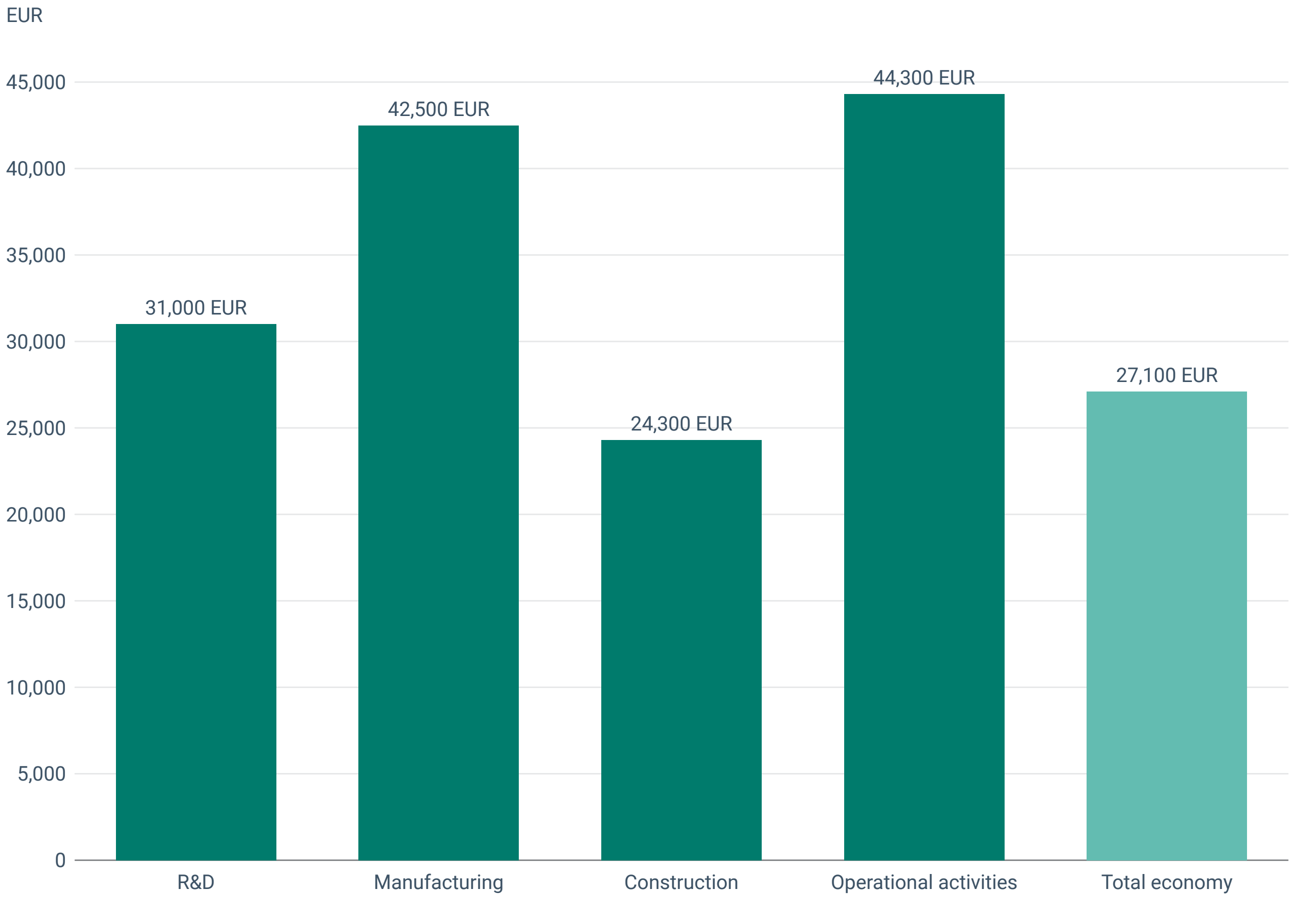
This section examines wage and salary patterns across the net-zero industry. It highlights differences between the technologies, value chain segments and EU Member States. The analysis shows that earnings vary considerably depending on the nature of the work and its position within the value chain. Annex A.1.7 gives a detailed explanation of the methodological approach used in this section.

The highest yearly average wages are found in the operations segment. Here roles in electric power generation, transmission and distribution tend to offer relatively high remuneration. This segment is followed by manufacturing, with average earnings exceeding EUR 40,000 per year per employee. This is largely driven by specialised activities such as the production of engines, turbines and electronic components.

R&D ranks third. While scientific research roles are generally well paid, the overall average is moderated by lower wages in other professional, scientific and technical activities, such as meteorology, safety consulting and environmental consulting.

The construction segment has the lowest average wages. This is particularly the case for specialised construction activities, where earnings fall below the EU-wide average for the economy as a whole, as shown in Figure 5.13.

Figure 5.13 **Yearly average wages and salaries per person employed by value chain segment for the featured clean energy technologies in the EU-27 in 2022**



Notes: The net-zero technologies included are solar PV, wind, heat pumps and batteries. The data relate to the EU-27 excluding Cyprus, Luxembourg and Malta due to limited data availability.

Source: Prognos 2025 based on envigos model and Eurostat Structural Business Statistics.

The average wage levels across net-zero technologies are shaped by the distribution of employment along the value chain. Wind energy has the highest average wages, at nearly EUR 45,000. This is largely due to the concentration of employment in higher-paying segments such as operations and manufacturing.

The batteries sector also has relatively high average earnings, at around EUR 38,000. This reflects the central role of manufacturing in this technology. In contrast, the heat pump sector, where most employment is concentrated in the construction segment, has lower average wages at approximately EUR 27,400. This is only slightly above the EU-wide average for the economy as a whole.

Table 5.2 Yearly average wages and salaries per person employed by technology in the EU-27 in 2022

Net-zero technology	Average wages and salaries
Wind	EUR 44,600
Solar PV	EUR 34,900
Heat pumps	EUR 27,400
Batteries	EUR 37,800
Total economy	EUR 27,100

Note: The data relate to the EU-27 excluding Cyprus, Luxembourg and Malta due to limited data availability.

Source: Prognos 2025 based on envigos model and Eurostat Structural Business Statistics.

Wage premiums within the energy industry are an important lever for securing a skilled workforce. Findings at the global level confirm that wages in the energy sector are typically higher than those in similar occupations, but that well-established industries such as oil and gas still pay more than the solar PV and batteries industries (IEA, 2023). This represents a potential barrier to shifting workers from the fossil fuel industry to clean energy sectors — especially for those who have already advanced in their career.

5.4.2 Employment status and contractual stability

Employment status varies considerably across the value chain for the technologies featured in this report. For example, existing data indicate a high incidence of self-employment in the construction sector in the EU (24%), the second highest proportion following agriculture (52%) (Eurofound, 2024b). Economically dependent self-employment is also mainly present in the construction sector (18). Subcontracting is widespread and structurally embedded in EU construction, with growing concerns about abusive practices (e.g. non-respect of working conditions, workers falsely declared as self-employed, illegal employment of third country-nationals, etc). This is a central issue in the effort to secure quality jobs (European Labour Authority, 2023; European Federation of Building and Woodworkers, 2025).

Data from the EWCS 2024 displayed in Figure 5.14 confirm that the construction value chain segment for the clean technologies featured in the report has the highest share of self-employed workers (22%). This is almost double the number for operational activities and R&D and higher than the average for the economy as a whole. Construction and installation roles in energy and clean technologies are inherently project-based; they occur during time-limited deployment phases. This results in contracts of a shorter duration (MacCallum, 2016). In this context, temporary workers provide a substantial contribution to construction projects in the energy sector (Kostic et al., 2020).

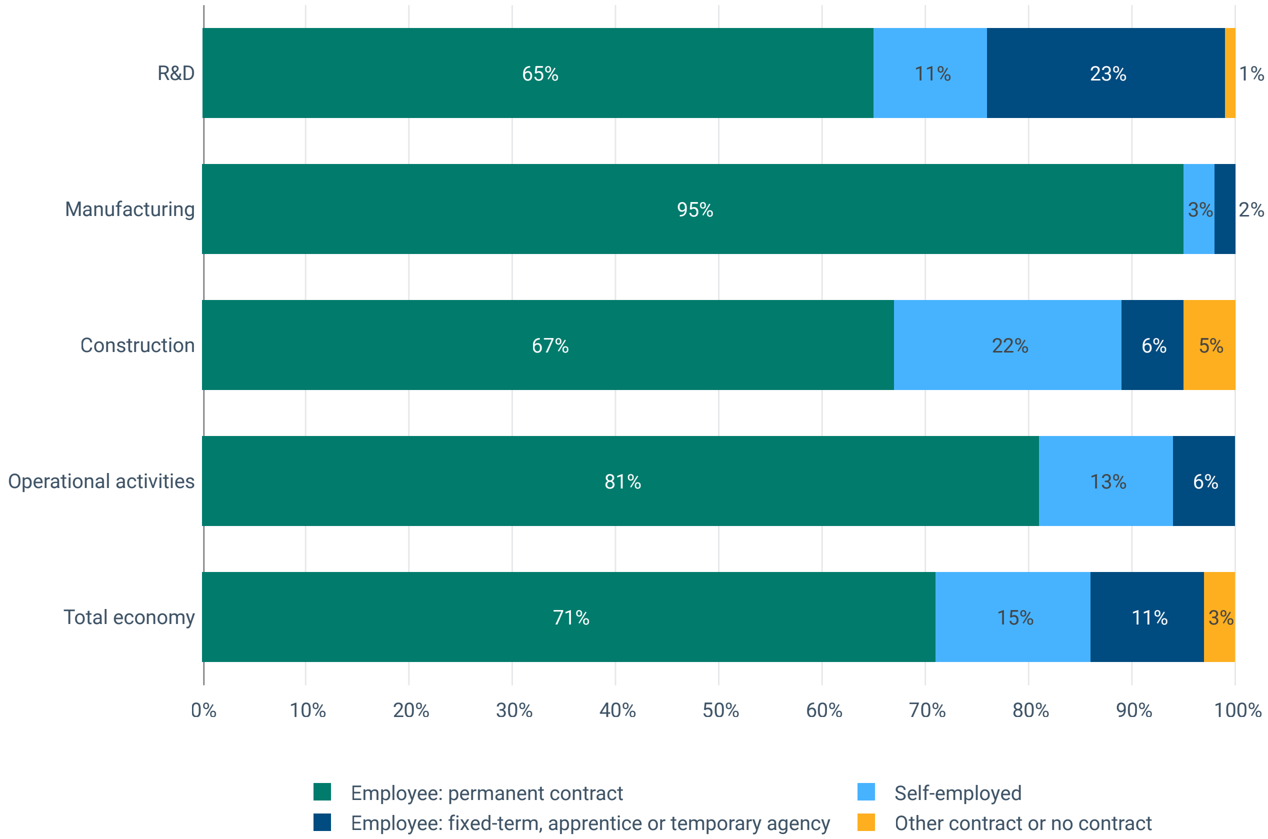
In contrast, in the manufacturing value chain, 97% of workers are employees. The majority of them (95%) have a permanent contract, indicating greater employment stability. The operations value chain segment has the second highest share of employees on a permanent contract (81%). Findings from the literature confirm that

(18) Economically dependent self-employed are defined as the self-employed without employees who worked during the last 12 months for only one client or for a dominant client, and this client decided about their working hours. Source: Self-employment statistics, Eurostat.

roles in O&M are most likely to offer more permanent employment, potentially lasting over the entire lifetime of the technology (Ram et al., 2022). For example, operations, maintenance and servicing are key activities on wind farms with a typical operational lifespan of 20-25 years.

R&D-related activities for the clean technologies featured in the report tend to offer the highest share of contracts of limited duration (23%). This is considerably higher than the figure for the economy as a whole (11%). While highly skilled engineering roles and some industrial R&D posts may offer competitive pay and career prospects, many research positions remain fixed-term and project-based. This is particularly true for roles in academic settings and early-stage innovation environments.

Figure 5.14 **Types of employment contracts in the featured clean energy technologies by value chain segment in the EU-27 in 2024**



Notes: The net-zero technologies included are solar PV, wind, heat pumps and batteries. Data were accessed and analysed in February 2024.

Source: European Working Conditions Survey 2024 (Eurofound, 2026).

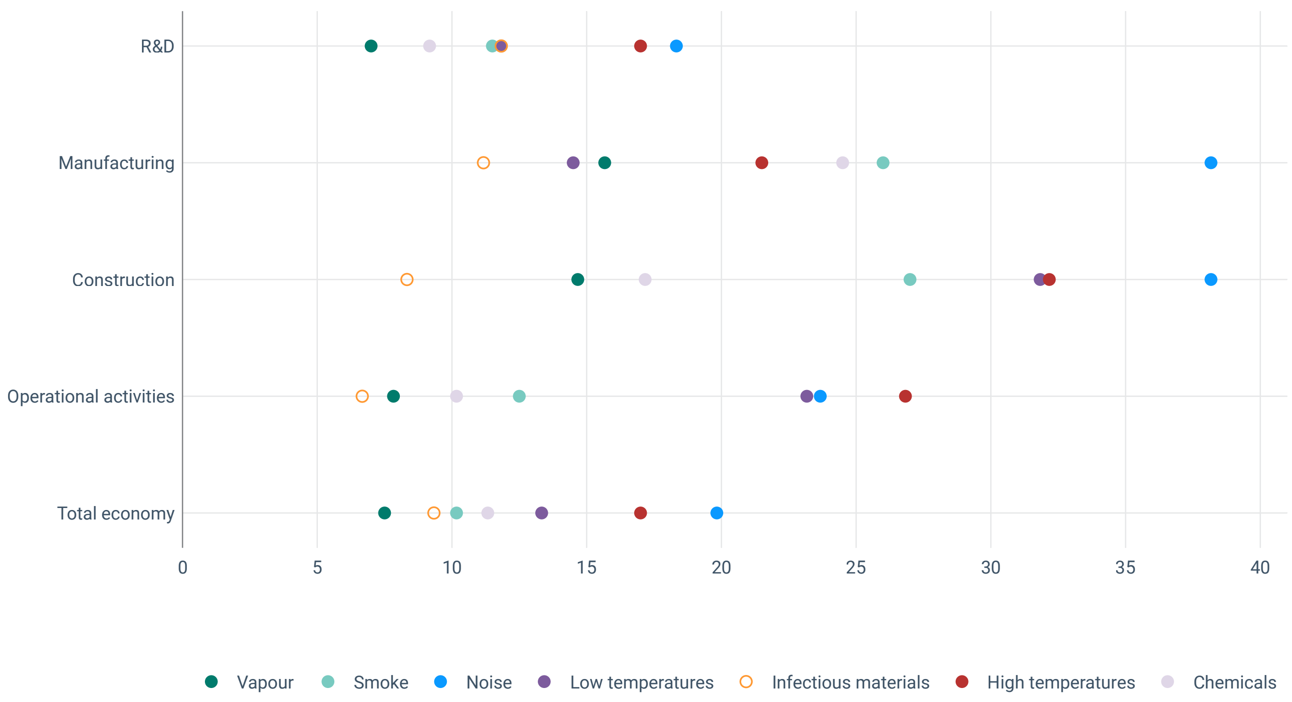
5.4.3 Physical environment and related risks

When examining physical working conditions, clear patterns emerge across the value chain segments. Construction and manufacturing consistently show higher levels of exposure to noise, smoke, vapours and chemicals compared with other value chain segments and the EU-wide average. The exposure to hazardous chemicals is particularly high in manufacturing; emerging evidence suggests that workers in the battery value chain are particularly at risk (see Box 5.3). Meanwhile, construction workers face the highest exposure to extreme temperatures — both low and high — reflecting the outdoor nature of many tasks in this segment.

In contrast, roles in R&D are typically office-based with minimal exposure to physical risks. The operations segment falls in between. It involves moderate exposure levels, especially during outdoor maintenance activities that require exposure to extreme temperatures and noise.

Overall, construction, followed by manufacturing and parts of operations, are most affected by physical risks, while R&D remains less affected.

Figure 5.15 Frequency of exposure to physical risks per value chain segment for the featured net-zero technologies in the EU-27 in 2024



Notes: Exposure to physical risks is measured on a scale ranging from 1 (all the time) to 7 (never). Values were standardised 0-100, with higher numbers indicating which specific physical risks workers are more often exposed to. Data were accessed and analysed in February 2026. The net-zero technologies included are solar PV, wind, heat pumps and batteries.

Source: European Working Conditions Survey 2024 (Eurofound, 2026).

Physical demands also vary considerably across the net-zero value chain. Figure 5.16 shows that construction and manufacturing face the highest exposure to physically demanding tasks. In particular, these include vibrations, lifting heavy loads, tiring positions and repetitive movements.

Manufacturing roles are often characterised by repetitive movements, particularly in assembly line settings. In contrast, R&D involves the highest share of sedentary work — which is notably higher in non-manual segments — with operations ranking second for this but slightly lower than R&D. These patterns highlight the need for tailored workplace measures that address the specific physical demands of each segment.

Figure 5.16 **How often jobs involve physical demands per value chain segment for the featured clean energy technologies in the EU-27 in 2024**

Notes: How often the job involves physical demands is measured on a scale ranging from 1 (all the time) to 7 (never). Values were standardised 0-100, with higher numbers indicating that the job involves performing physically demanding tasks more frequently. The net-zero technologies included are solar PV, wind, heat pumps and batteries. Data were accessed and analysed in February 2026.

Source: European Working Conditions Survey 2024 (Eurofound, 2026).

Existing studies highlight that working conditions related to the physical environment vary considerably between technologies. The operation of offshore wind farms, for example, poses unique health and safety challenges due to the harsh marine environment and remote location. It requires comprehensive risk assessments, stringent safety protocols and robust emergency response plans (Adekanmbi et al., 2024).

Workers in the solar energy industry face severe fall hazards (when working on pitched roofs or elevated ground-mounted structures), electrocution and other electrical hazards, and physical strain linked to lifting and carrying heavy solar PV (Occupational Safety and Health Administration, 2025; Wilson, 2025).

In addition, workers in the heat pump industry also face specific chemical hazards related to exposure to refrigerants (Hartnet, 2025). The battery industry also involves specific occupational health risks, as discussed more in detail in Box 5.3, due to exposure to hazardous substances.

Beyond sector-specific hazards, studies also highlight climate-related risks such as heat stress, ultraviolet (UV) exposure and extreme weather factors. These are expected to intensify for outdoor construction and installation work (EEA, 2025a). Ensuring a just and resilient transition also includes, among the other things, protecting outdoor workers from weather extremes. Measures to achieve this include appropriate legislation/regulation (EEA, 2025d).

Box 5.3

Battery value chain — workers' health and local environmental risks

Across Europe, the rapid expansion of the battery value chain is reshaping industrial work and creating new employment opportunities. At the same time, there are important concerns about workers' health and safety. This is particularly in relation to exposure to hazardous chemicals across the battery life cycle, from raw material processing and cell manufacturing to recycling and waste management. Workers may encounter metals, solvents, electrolytes and other substances that pose acute and long-term risks.

It is essential to address these risks through robust regulation, effective risk assessment, preventive measures and workers' participation to ensure that the growth of Europe's battery industry is aligned with high standards of occupational health and safety and supports a truly just and sustainable transition. At the EU level, for example, there is currently no specific binding occupational exposure limit for lithium.

Concerns about workers' and community health impacts are widespread in Hungary's battery value chain (Nelsen, 2023; Bodnár, 2022, 2024). A study by the SOMO Institute (Merk et al., 2024) documents demanding working conditions and occupational health and safety risks in Hungary's battery manufacturing sector, a key hub for EU production. The study reports:

- repeated breaches of regulations related to fire safety and hazardous materials;
- cases of worker exposure to elevated nickel levels;
- serious safety incidents in battery recycling facilities, including a fatal accident in 2023.

More recently, the BYD factory under construction in Szeged has also come under scrutiny following reports of violations of EU labour laws involving Chinese migrant workers (O'Carroll and Garamvolgyi, 2026).

Civil society organisations have also reported repeated fines for safety and permit violations, insufficient oversight and gaps in environmental monitoring. Greenpeace Hungary has pointed to fast-track licensing rules with limited local consultations, alongside evidence of N-Methyl-2-pyrrolidone (NMP) contamination in groundwater (Greenpeace Hungary, 2025). The Business and Human Rights Centre has highlighted allegations of hazardous 'black dust' emissions containing nickel and cobalt; it claims that over 170 workers have been exposed to levels above the permitted limits (Business and Human Rights Centre, 2025).

A major investment in Eskilstuna, Sweden has also sparked controversy after a Chinese-owned factory producing separator film for lithium-ion (Li-ion) batteries received a special permit to use methylene chloride — a solvent banned in Sweden since 1996 due to its carcinogenic and neurotoxic properties. The permit allows emissions of up to 900 tonnes annually, far exceeding typical industrial norms (Dagens Arbete, 2025).

Authorities argue that workplace exposure will remain within acceptable limits, yet local residents have expressed strong concerns, with some relocating due to perceived health threats. Experts warn that methylene chloride can cause cancer, neurological damage, reproductive harm and even acute fatalities upon inhalation.

The controversy underscores a regulatory gap: while occupational exposure is monitored, cumulative environmental and community-level risks are still poorly addressed. Furthermore, this case illustrates the tension between industrial competitiveness, green transition goals and public health safeguards (IVL Svenska Miljöinstitutet, 2024; Fagerudd, 2024; Sweden Herald, 2025).

In 2024, the European trade union IndustriAll launched a two-year EU-funded project, BatteryTUPower. This aims to build trade union capacity and negotiate collective agreements, as well as monitoring health and safety standards across the European battery sector.

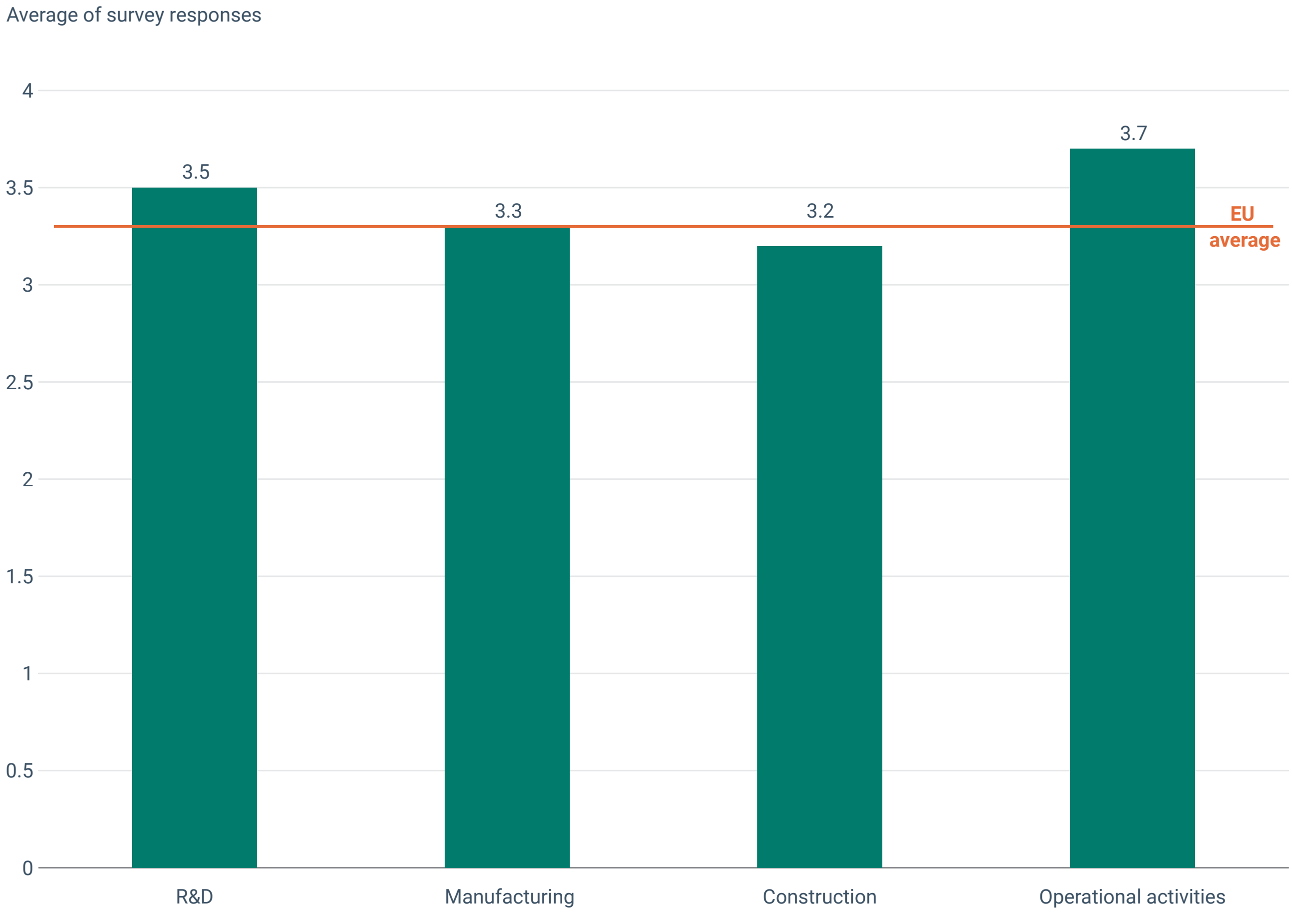
5.4.4 Health and safety

The findings from the EWCS 2024 data also point to gaps in health and safety awareness across segments of the net-zero workforce. Workers in construction and manufacturing report being relatively less informed about occupational risks.

Survey responses were based on a four-point scale, with 4 corresponding to 'very well informed', 3 to 'well informed', 2 to 'not very well informed' and 1 to 'not at all well informed'. The average score for the manufacturing segment was 3.3 and for construction it was 3.2. The average for the economy as a whole was 3.3.

In contrast, R&D (with an average score of 3.5) and operations (with an average score of 3.7) report higher levels of awareness (see Figure 5.17). These results indicate that the segments of net-zero technologies most exposed to physical risks — construction and manufacturing — are also those with comparatively lower health and safety awareness. This highlights the need for targeted information and training initiatives.

Figure 5.17 Health and safety awareness in the featured clean energy technologies by value chain segment in the EU-27 in 2024



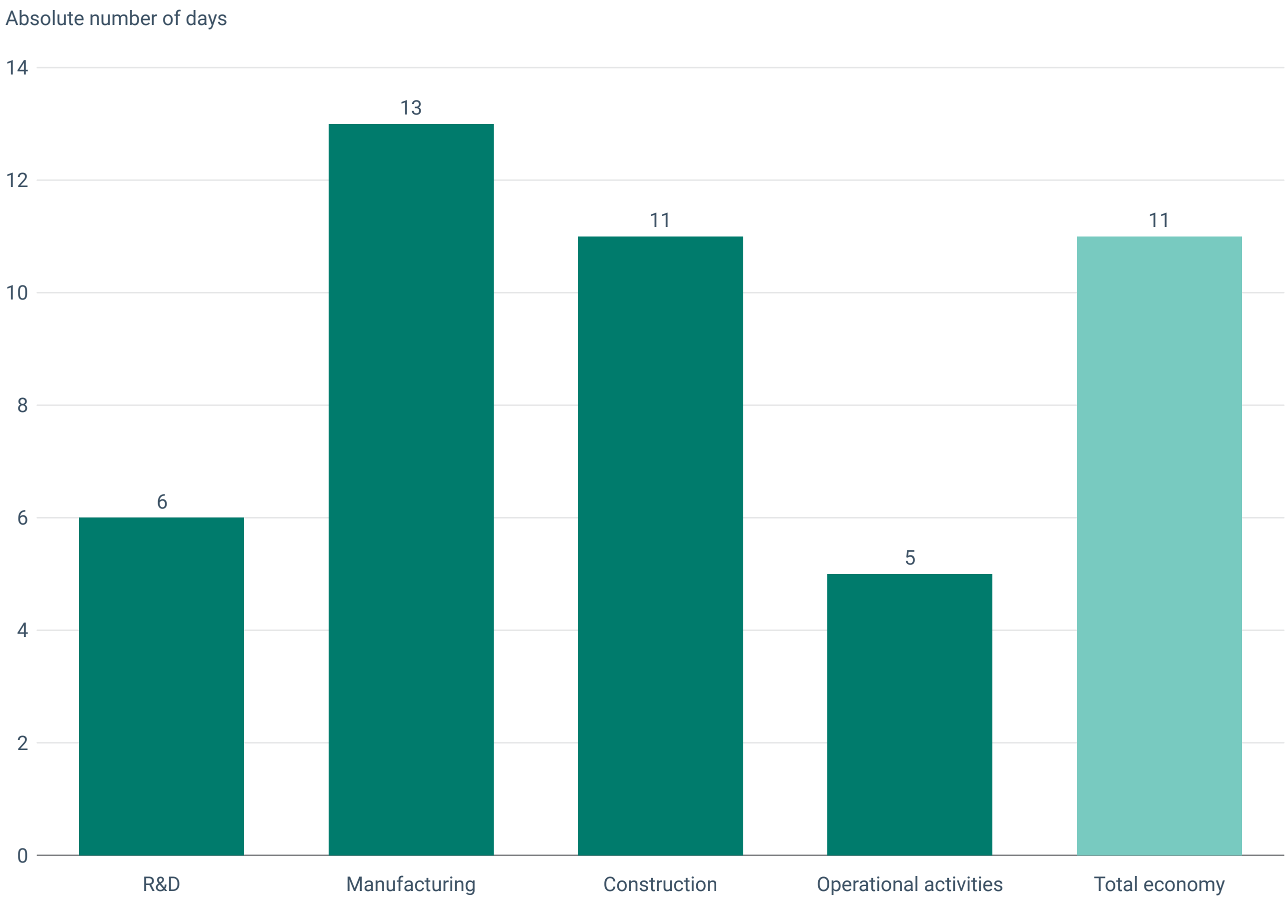
Notes: The net-zero technologies included are solar PV, wind, heat pumps and batteries. Data were accessed and analysed in February 2026. The higher the score, the higher the level of awareness.

Source: European Working Conditions Survey 2024 (Eurofound, 2026).

At the same time, as shown in Figure 5.18, employees in manufacturing and construction report higher rates of health-related absences. In manufacturing, workers reported an average of 13 days away from work due to sickness or health-related leave over the preceding 12 months. This segment was followed by construction with 11 days, in line with the average for the economy as a whole.

R&D and operations report fewer absences; this segment had the lowest number of sick days within the net-zero industry (an average of 6 days). Given that the findings indicate that manufacturing and construction face the highest physical risks and demands, it is likely that there is a correlation between health-related absences and exposure to occupational risks.

Figure 5.18 **Number of days absent from work due to sickness or health-related leave in the featured clean energy technologies by value chain segment in the EU-27 in 2024**



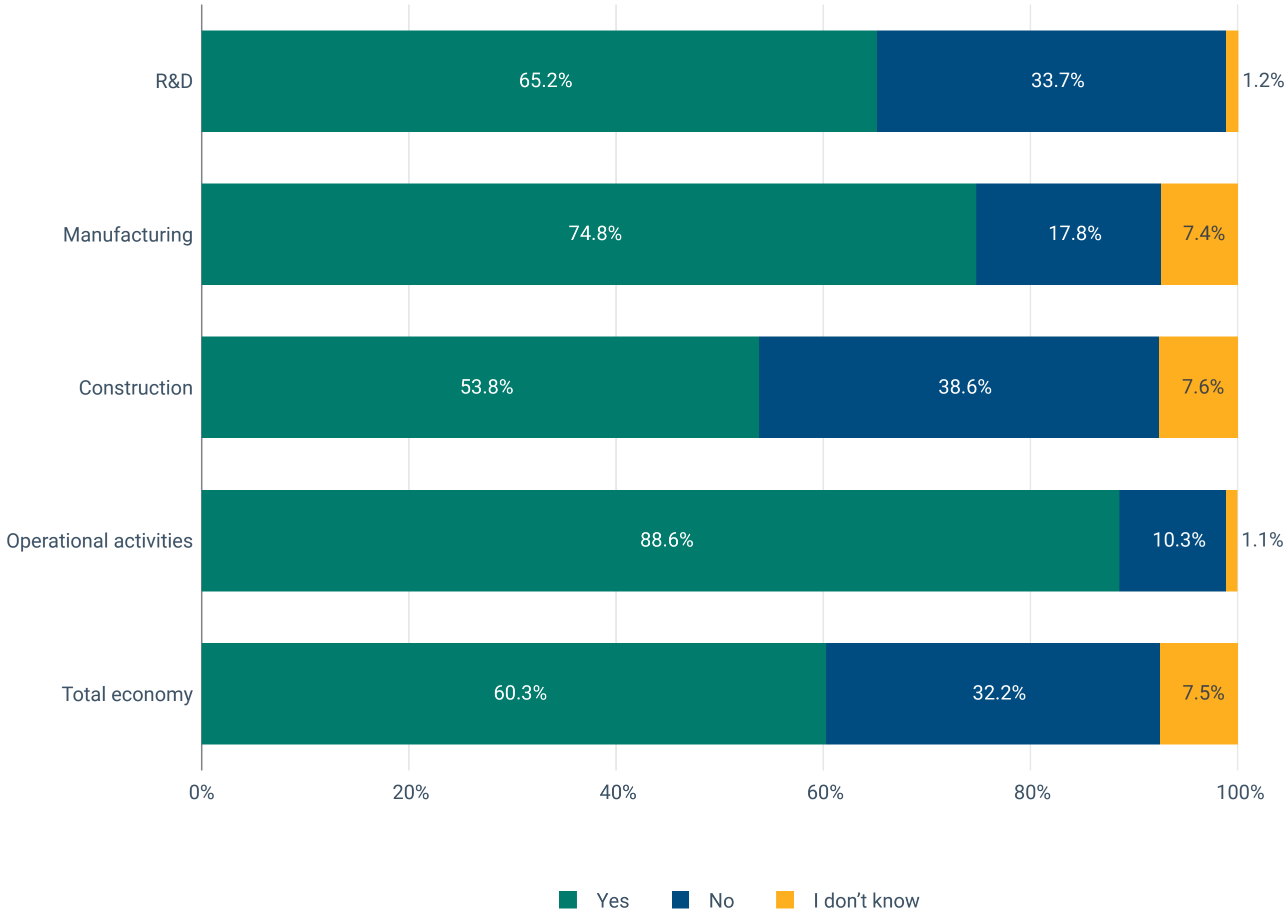
Notes: The net-zero technologies included are solar PV, wind, heat pumps and batteries. Data were accessed and analysed in February 2026.

Source: European Working Conditions Survey 2024 (Eurofound, 2026).

As shown in Figure 5.19, there are notable differences across segments in terms of whether a health and safety delegate or committee exists in the company or organisation. In the construction segment, only around half of workers responded positively, slightly below the average for the economy as a whole (at 60%).

In contrast, the operations segment reported the highest share, with 89% of workers confirming the presence of such structures. This was followed by manufacturing at 75%. These findings suggest that institutional support for health and safety is unevenly distributed across the net-zero value chain.

Figure 5.19 Presence of health and safety delegate or committee in the company or organisation for featured clean energy technologies in the EU-27 in 2024



Notes: The net-zero technologies included are solar PV, wind, heat pumps and batteries. Data were accessed and analysed in February 2026.

Source: European Working Conditions Survey 2024 (Eurofound, 2026).

6 Conclusions and way forward

Growth in clean tech is accelerating despite structural vulnerabilities

The European Union's (EU's) clean-tech energy industry has become a major and rapidly expanding segment of the European economy. It is characterised by increasing economic significance and represents a growing source of domestic employment. The spike in fossil fuel energy prices triggered by the situation in the Middle East in 2026 has reaffirmed the need to accelerate the transition to homegrown clean energy.

Manufacturing capacity and deployment have expanded across many clean-tech value chains, although progress remains uneven across technologies and competitive pressure is intensifying— particularly in solar photovoltaics (PV) and batteries. At the same time, several structural challenges continue to constrain the scale-up of clean-tech manufacturing and deployment. These include:

- high production costs;
- supply-chain vulnerabilities associated with critical raw materials (CRMs) and imported components;
- permitting and planning bottlenecks;
- labour shortages.

If these issues are not tackled systematically then Europe is likely to struggle to develop the resilient industrial base required to meet its climate targets, strengthen its strategic autonomy, support competitiveness and secure long-term, high-quality employment.

Against this backdrop, the EU has put in place an increasingly supportive strategic policy framework to strengthen clean-tech manufacturing, accelerate deployment and address key industrial bottlenecks. This includes the Net-Zero Industry Act (NZIA), the Clean Industrial Deal (CID), the proposed Industrial Accelerator Act, and AccelerateEU, as well as a range of financial instruments and targeted technology initiatives, such as the Battery Booster strategy aimed at supporting the scale-up of EU manufacturing capacity.

A transforming labour market — scale and structure

Europe's clean-tech transition is transforming labour markets in terms of both scale and structure. Between 2010 and 2023, employment has expanded across all four of the technologies considered in this report. Of these technologies, wind and solar are currently creating the largest number of jobs and employment in the heat pump sector is continuing to grow despite cyclical fluctuations. Meanwhile, batteries are emerging as the most dynamic and innovation-driven sector.

Employment growth has been particularly dynamic in the operational segments of wind energy and solar PV. This is due to widespread deployment of these technologies across the EU energy markets. The construction segment also contributes to significant job creation for solar PV and heat pumps, driven by the continuous expansion of installed capacity.

Batteries and heat pumps represent emerging growth opportunities in the manufacturing segment. Manufacturing employment constitutes the core of the current battery workforce — mirroring the industrial orientation of the battery value chain — and makes up almost one-third of heat pump employment. Europe has maintained strong manufacturing capacity in wind, although it is facing intensifying global competition. Meanwhile, manufacturing employment in solar PV has been recovering after a temporary decline between 2010 and 2015. The R&D segment remains strategically important — notably for batteries — but on a smaller scale.

Labour demand is expanding but shortages represent a structural barrier

The expectation is that employment in the clean-tech sector will continue to grow. Despite a high level of uncertainty in the industry, projections suggest that by 2030 each of the four technologies featured in this report (wind, solar PV, batteries and heat pumps) could employ hundreds of thousands of workers. Such an extensive increase in labour demand risks exacerbating already acute labour and skills shortages. In turn, this could slow deployment and undermine the targets for manufacturing.

The analysis presented in this report reveals that the shortages of building and related technicians represent the most widespread gap, followed by plumbers and pipe fitters, electrical professionals and building construction labourers. These roles were identified as key occupations in terms of employment numbers in the value chains of the featured technologies.

These shortages are a structural barrier to achieving the EU's decarbonisation ambitions. They reinforce the need for a coordinated and long-term strategy to expand skills provision and strengthen Europe's technical workforce. At the same time, while the occupational analysis shows that technical and vocational roles are central to the net-zero workforce, there are many different types of labour required across the value chain. Alongside specialised roles, there are also many generalist positions across the featured technologies and notably in the operations segment.

Persistent inequalities threaten the fairness and inclusiveness of the transition

The clean-tech transition continues to reproduce significant demographic imbalances. Women are substantially under-represented across all four featured technologies and across all value chain segments. This is notably the case in the heat pump sector, largely due to low female participation in construction.

The highest female participation is observed in the R&D segment, but activities in this segment only represent a small share of the workforce. Gender imbalances persist not only in overall employment, but also in positions of leadership. Women continue to have limited access to decision-making and managerial pathways.

Moreover, despite the growth potential of the clean-tech industry and the opportunities it offers for new entrants, young workers also remain under-represented across the wind, solar PV and heat pump value chains. This is particularly challenging in the context of an ageing European workforce, at a time when digitalisation and AI are becoming critical enablers of the clean energy transition.

It is essential to better integrate women and young people in order to build a resilient and inclusive economy. It is also necessary to achieve this in order to address occupational shortages.

Territorial concentration of clean-tech employment and implications for cohesion

Employment growth is currently geographically concentrated. Of all the EU Member States, Germany has the highest absolute numbers employed in wind energy, solar PV and batteries. However, it does not have the highest share of workers in these sectors relative to total employment.

For heat pumps, Portugal, Spain and Italy lead in terms of direct absolute job numbers. Meanwhile, Hungary and Poland are becoming strong battery manufacturing hubs, exhibiting high employment growth rates.

The concentration of jobs across Member States often reflects pre-existing industrial strengths, skill bases and innovation ecosystems. However, the uneven territorial distribution may raise issues for territorial cohesion if it contributes to persistent regional disparities. Policies should ensure broader regional participation and contribute to diffusing the benefits. Measures could include targeted support for regions facing industrial decline or demographic pressures, which may otherwise miss out on new employment opportunities.

Job quality remains uneven and risks undermining the just transition

Although the clean-tech sector is generating many new jobs, job quality varies markedly across the four technologies featured in this report and their value chain segments. Wages in the heat pump industry are around 40% lower than in the wind sector, which is the highest paid. Operations and maintenance roles — more prevalent in wind energy — offer relatively stable employment and higher participation in training.

In contrast, contruction and installation roles — which are more common in the solar PV and heat pump sectors — are inherently project-based and offer more limited training opportunities. Construction is also the clean-tech value chain segment most exposed to physical risks — notably in terms of extreme temperatures. Meanwhile, the manufacturing segment involves significant concerns about chemical exposure. Workers in construction and manufacturing also report being less well informed about occupational risks.

From a technology perspective, the impact of battery manufacturing on workers' health and safety, as well as local communities and the environment, is an ongoing source of concern and controversy.

These disparities in job quality shape the overall attractiveness of clean tech. They also directly affect recruitment and retention in occupations that are already experiencing acute shortages. This undermines both climate and competitiveness goals.

Towards a just and competitive clean-tech transition

To ensure that the clean-tech transition delivers on its promise of being just and inclusive, social and employment considerations need to remain firmly embedded within the broader industrial policy framework. The Clean Industrial Deal (CID) signals this direction by highlighting the importance of high-quality jobs, skills and social fairness, as well as the intention to align industrial transformation with social objectives.

There is, however, room to further strengthen this dimension through future implementation measures. This includes exploring how EU funding instruments might more systematically encourage high-quality employment outcomes, such as decent wages and secure, good-quality jobs, in line with the EU's cohesion and social objectives.

It is essential to ensure that all investments supporting the CID — including those foreseen under the post-2027 Multiannual Financial Framework (MFF) — contribute meaningfully to the EU's broader social goals. This is necessary to achieve a fair, sustainable and climate-resilient industrial transformation.

The territorial dimension of the transition to a climate-neutral economy is highly significant for delivering benefits across all regions. Areas with a strong reliance on fossil fuel industries face specific adjustment challenges. This is especially the case where capacities for economic diversification and skills development differ. Strengthening place-based and inclusion-oriented strategies can help to ensure that all territories are well positioned to seize the opportunities of the clean-tech transition and that existing regional and social disparities are not reinforced inadvertently.

It is necessary to place job quality, social dialogue and worker protection at the heart of industrial strategy in order to ensure that the transition delivers not only more jobs, but better ones. At the same time, it is important to scale up and modernise education and training programmes to address structural shortages.

The EU has strengthened its skills framework through important initiatives such as the net-zero industry academies, the Union of Skills, the skills guarantee pilot and numerous Erasmus+ projects. The recently launched Quality Jobs Roadmap is expected to ensure that skills expansion goes hand in hand with fair wages, secure contracts, collective bargaining rights and strong health and safety standards.

Although skills provision across the EU is evolving, current training and education capacities in technical fields are facing increasing pressure as labour market needs expand and evolve rapidly. Workers also need stronger digital, artificial intelligence (AI)-related, system integration and cross-technology competencies. This is in a context where AI will increasingly be embedded across clean-tech design, manufacturing, deployment and operations. Training remains a crucial component of lifelong learning and is essential for keeping pace with technological developments.

In this context, targeted support for workers transitioning from declining fossil fuel sectors will remain important. Ensuring that workers can continuously update and expand their skillsets will be key to maintaining a resilient workforce. This will support the uptake of emerging technologies and secure the timely deployment of net-zero solutions across the EU.

In summary, delivering a just and competitive clean-tech transition will require sustained attention to the social, territorial and skills dimensions of Europe's industrial transformation. It will be essential to strengthen the quality of jobs, promote equal opportunities and support regions and workers undergoing more profound restructuring. This will ensure that the benefits of the transition are broadly shared.

By reinforcing these elements in forthcoming implementation measures, the EU can help secure a clean-tech transition that is not only economically and technologically ambitious, but also socially inclusive, regionally balanced and — ultimately — sustainable.

List of abbreviations

Abbreviation	Name
AI	artificial intelligence
BEPA	Batteries European Partnership Association
BESS	battery energy storage systems
CAGR	compound annual growth rate
CCS	carbon capture and storage
CETO	Clean Energy Technology Observatory
CF	Cohesion Fund
CID	Clean Industrial Deal
CINEA	Climate, Infrastructure and Environment Agency
CISAF	Clean Industrial Deal State Aid Framework
CO_2	carbon dioxide
CRM	critical raw material
CRMA	Critical Raw Materials Act
CSP	concentrated solar power
DG EMPL	Directorate-General for Employment, Social Affairs and Inclusion
DG REGIO	Directorate-General for Regional and Urban Policy
EAfA	European Alliance for Apprenticeships
EBA	European Battery Alliance
EC	European Commission
ECCP	European Cluster Collaboration Platform
EED	Energy Efficiency Directive
EGD	European Green Deal
EHPA	European Heat Pump Association
EIB	European Investment Bank
EIF	European Investment Fund
EIT	European Institute of Innovation and Technology
ELA	European Labour Authority
ERDF	European Regional Development Fund
ESIA	European Solar PV Industry Alliance
ESCO	European Skills, Competences, Qualifications and Occupations
ESF	European Social Fund
ETS	Emissions Trading System
EU	European Union
EU-27	the 27 EU Member States
EUPI-PV	European Partnership for Innovation in Solar PV
EURES	European Employment Services
EUWES	Empowering Underrepresented Women in the Energy Sector
EWCS	European Working Conditions Survey
FDI	foreign direct investment
GDIP	Green Deal industrial plan
GVA	gross value added
GHG	greenhouse gas

GW	gigawatt
GWh	gigawatt hours
HVAC	heating, ventilation and air conditioning
IAA	Industrial Accelerator Act
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
ISCO	International Standard Classification of Occupations
JTF	Just Transition Fund
JTM	Just Transition Mechanism
JTP	Just Transition Platform
LFS	Labour Force Survey
Li-ion	lithium-ion
MFF	Multiannual Financial Framework
MW	megawatts
NACE	nomenclature of economic activities
Na-ion	sodium-ion
NCO	national coordination office
NEET	not in education, employment or training
NECP	national energy and climate plan
NRRP	national recovery and resilience plan
NZEP	Net-Zero Europe Platform
NZIA	Net-Zero Industry Act
O&M	operations and maintenance
OECD	Organisation for Economic Co-operation and Development
PDA	project development assistance
PV	photovoltaics
RED	Renewable Energy Directive
RES	renewable energy source
RRF	Recovery and Resilience Facility
R&D	research and development
SCF	Social Climate Fund
SME	small and medium-sized enterprise
STEM	science, technology, engineering and mathematics
STEP	Strategic Technologies for Europe Platform
TCTF	Temporary Crisis and Transition Framework
TRL	technology readiness level
TWh	terawatt hour
VET	vocational education and training

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Annex 1 Methodological annex

A.1.1 Approach for analysing employment in clean energy technologies

The figures on employment in the net-zero industry presented in this report are derived from the Prognos envigos model for environmental goods and services. This model encompasses economic goods and services associated with net-zero technologies and aligns with established international classification systems such as the nomenclature of economic activities (NACE) and Prodcom. This alignment facilitates a clear delineation of relevant goods and services, which allows information to be allocated accurately to specific net-zero technologies and value chain segments. The clean energy technologies in focus in this report are: wind energy, solar photovoltaics (PV), heat pumps and batteries.

The analysis measures the direct effects of the economic activities that are analysed, along the defined value chain for each technology. Next to technology manufacturing, this also includes downstream activities (e.g. construction and operations) and upstream activities (e.g. research). Additional indirect and induced effects beyond the identified activities are not considered.

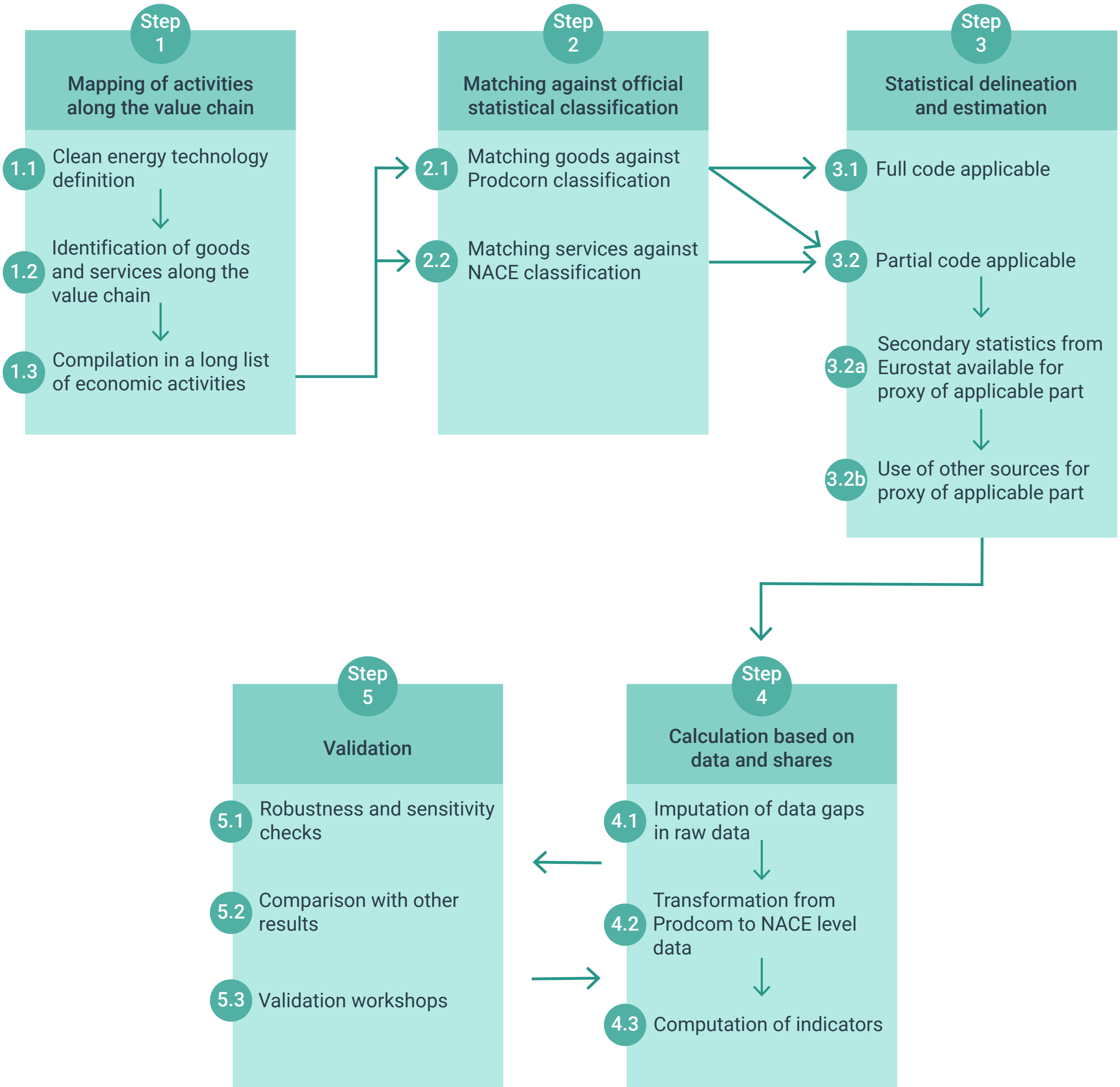
The geographical coverage includes all 27 EU Member States (EU-27), with the exception of Cyprus, Luxembourg and Malta due to limited data availability.

The input data primarily originate from Eurostat structural business statistics; this source provides economic metrics across various indicators, including employment figures and gross value added (GVA), at the most detailed four-digit NACE level.

Additional secondary data — from sources such as Eurostat, the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA) — are used to estimate year- and location-specific shares for the considered NACE codes. For a detailed overview of the goods and services included in the statistical analysis, see Appendix 2 of the recently published *Assessment of the competitiveness of clean energy technologies* by the European Climate, Infrastructure and Environment Executive Agency (CINEA).

The principal methodological steps for the statistical model are visualised in Figure A1.1.

Figure A1.1 **Principal methodological steps for the statistical model**



Source: Prognos, 2025.

Compared to other estimation methods, the envigos model offers relatively in-depth data. The results are recorded according to detailed value chain segment levels and offer broad geographical and temporal coverage. This enables a comprehensive analysis of trends in net-zero technologies. However, this modelling approach also has limitations, as it relies on detailed primary data — such as the structural business statistics — as well as adequate secondary data sources. Furthermore, certain technologies — including carbon capture and storage (CCS) and hydrogen technologies — cannot be incorporated into this framework at present due to the fact that they are currently of minimal economic significance.

A.1.2 Approach for modelling employment projections

To estimate future employment in wind energy, solar PV, batteries and heat pumps, employment projections were developed by linking expected developments in installed or production capacity with employment intensities derived from recent historical data. This approach allows for consistent, data-driven projections while reflecting the uncertainties of rapidly evolving clean energy markets.

For wind and solar PV, projections were based on the POTEnCIA 2024 scenario (Neuwahl et al., 2024). This provides long-term estimates of installed generation capacity in megawatts (MW) through to 2050. Employment intensity was first calculated by dividing employment figures from the envigos model by the corresponding installed capacity, using a five-year average from 2019 to 2023 to smooth the annual fluctuations. This intensity — expressed as jobs per MW — was then applied to the projections of future capacity to estimate employment for the 2025-2030 period. For example, an average employment intensity of 1.18 jobs-per-MW for wind energy, applied to a projected capacity of 426,218 MW in 2030, results in an estimated 500,000 jobs.

In the case of batteries, installed capacity alone was insufficient for a calculation due to high volatility in the market. Employment projections were therefore based on the Fraunhofer Institute's 2025 assessment of European battery cell production. This sets out multiple pathways for future production capacity measured in gigawatt hours (GWh) (Wicke et al., 2025).

Using production output as a basis better reflects actual industrial activity and avoids distortions caused by external factors such as permitting delays. Employment was estimated by applying the jobs-per-unit method to production rather than installed capacity. The most ambitious scenario projects that production will grow from 250GWh in 2024 to 2,250GWh in 2030. To account for uncertainty, a range of employment scenarios was created using optimistic and conservative pathways, supplemented by additional studies.

For heat pumps, no projections were available in the POTEnCIA scenario, so European Heat Pump Association (EHPA) data were used (EHPA, 2025c). Employment intensity was calculated by dividing employment figures from the envigos model by the current and projected stock of installed heat pumps. Three scenarios were developed to reflect different potential growth pathways:

- one aligned with the EU 2030 targets;
- a moderate pathway based on average sales between 2022 and 2024;
- a conservative pathway reflecting 2024 sales.

A.1.3 Approach for analysing the gender composition of the workforce

The workforce composition analysis for the featured net-zero technologies is based on employment figures from the envigos model, combined with detailed demographic data extracted by the Labour Force Survey (LFS) and made available by Eurostat in July 2025.

The LFS dataset includes data for all EU Member States and the EU-27 aggregate for the years 2010-2024 at the NACE three-digit level, differentiated according to gender (male and female). Total employment values were derived by summing both categories. The dataset was then filtered to include only NACE codes relevant to the net-zero technologies examined in this study. In cases where excessive data gaps occurred for one gender in a Member State, that Member State was excluded from further analysis. Notably, for the EU-27 aggregate, data gaps did not exist for the relevant NACE codes and years.

The envigos model produces results at the NACE four-digit level. To align with the LFS data, these results were aggregated by year, Member State, technology and value chain segment to match the three-digit NACE classification. Subsequently, the gender shares derived from the LFS dataset were applied to the corresponding employment figures from the model. For example, in 2023, approximately 3,000 persons were employed in NACE 26.11 (solar PV manufacturing) across the EU-27. Based on LFS data, the share of female persons employed in NACE 26.1 for the EU-27 is 39%. Multiplying this share by the total employment yields an estimated 1,200 women employed in this segment.

By applying this approach consistently at the most detailed level available (NACE three- and four-digit), the results can be aggregated across multiple perspectives, including the EU-27, individual Member States, technology and value chain segments. This methodology provides a robust database for assessing demographic representation, such as the share of women in specific segments or countries.

A.1.4 Approach to identifying key occupations

The quantitative analysis of key occupations in the four featured net-zero technologies builds on the results of the envigos model, which provides detailed employment data according to NACE sectors at the four-digit level. To translate this sectoral employment data into an occupational perspective, relevant occupations as defined by the International Standard Classification of Occupations (ISCO) at the four-digit level were identified using a correspondence table that links NACE sectors to ISCO codes. This table is based on a highly detailed dataset provided by the German Federal Employment Agency.

The dataset covers approximately 1,300 distinct occupations, classified according to the German classification of occupations 2010 (KldB 2010); it links each occupation to its corresponding sectoral focus. This dataset serves as an input to the Prognos skilled-worker model, which identifies the most common occupations within sectors relevant to the green technology industry. This results in mapping that gives the shares of all occupations per relevant sector.

For example, the NACE sector C26.11 (manufacture of electronic components) is important in the manufacturing of solar PV. In the part of the NACE sector related to producing solar cells and solar modules, the three most prevalent ISCO occupations are 7223 (metal-working machine-tool setters and operators) with 14.5 % of employment, 7412 (electrical mechanics and fitters) with 5.2 % of employment and 8212 (electrical and electronic equipment assemblers) with 4.2 % of employment.

The resulting ISCO shares for each economic activity within each net-zero technology sector are subsequently applied to the sector-specific results for the analysis of employment for each EU Member State (see Chapter 3). This approach is based on the assumption that the occupational structure within each sector is comparable across Member States, using Germany as the reference case.

In this way specific results can be obtained for all Member States — with the exception of Cyprus, Luxembourg and Malta due to limited data availability. Accordingly, the aggregated results presented in this chapter reflect employment figures at the EU level, covering employed people according to occupation across all four featured technologies for the year 2023. In every value chain segment as well as in the aggregate, the 15 occupations with the greatest number of jobs make up at least 50% of total employment. Those occupations are described as the key occupations in each of the respective value chain segments for the four featured net-zero technology sectors.

A.1.5 Approach to assessing relevant skills

To assess the skills requirements for the key occupations identified in this study, the relevant ISCO four-digit occupational codes were linked to more detailed occupational profiles available in the European Skills, Competences, Qualifications and Occupations (ESCO). ESCO is developed by DG Employment, Social Affairs and Inclusion of the European Commission in collaboration with stakeholders. It provides detailed mapping of occupations to skills, competences and knowledge areas across Europe and offers greater granularity than the ISCO classification, which differentiates only up to the four-digit level.

For each featured net-zero technology, a subset of ESCO occupations was chosen based on the key ISCO four-digit occupations identified in the analysis. The selection of representative ESCO occupations was conducted through text research of the ESCO database. Specifically, occupations were selected when their title and description explicitly referenced one of the net-zero technologies or clearly described activities relevant to it. This qualitative selection ensured that the chosen profiles accurately reflect the technological focus and value chain segments.

In most cases, two ESCO occupations were identified per technology, with at least one for each of the four value chain segments. For heat pumps, only one specific ESCO occupation explicitly referring to heat pumps is currently included in the classification. While additional, more general occupations exist that relate to geothermal energy or broader heating and cooling technologies, these were not included as they fall outside the scope of this study.

For each ESCO occupation, the framework provides an overview of essential as well as optional skills, competences and knowledge areas. The lists vary in length and detail, reflecting the diversity of tasks and requirements within each occupation — from general foundational skills to highly specialised technical knowledge.

As the ESCO classification does not indicate the relative importance of individual skills or their frequency of use, the resulting compilation should be interpreted as indicative mapping of the skills landscape. It highlights the types of skills relevant to each occupation, but does not imply a ranking in terms of priority or prevalence. These results are intended to provide a representative but non-exhaustive overview of the skills and competencies associated with net-zero occupations.

A.1.6 Approach to assessing occupational shortages

To identify current labour shortages for the key occupations relevant to the four featured net-zero technologies, data were taken from the European Labour Authority (ELA) based on information collected from the national coordination offices (NCOs) of the EU Member States. The dataset was compiled as part of the European Employment Services (EURES) report *Labour shortages and surpluses 2024*, published by the ELA in June 2025.

The ELA dataset covers the EU-27, as well as Norway and Switzerland; it includes information for approximately 440 occupations, classified at the ISCO four-digit level. For each country and occupation, the dataset assigns one of four possible statuses:

- labour shortage;
- balance;
- labour surplus;
- shortage and surplus, indicating mixed situations within a Member State (e.g. regional differences).

For the purposes of this study, the dataset was processed in three steps:

- Geographical filtering: Only data for the EU-27 were retained to align with the project's scope.
- Status filtering: Only entries classified as labour shortages were included. Observations marked as balance, surplus or shortage and surplus were excluded.
- Relevance filtering: The dataset was further narrowed down to the key occupations identified in the preceding analysis of workforce composition and occupational mapping.

This process enabled the number of EU Member States where a shortage has been reported to be identified for each relevant occupation. For instance, 21 EU Member States reported shortages of building and related electricians (ISCO 7411), according to the respective NCOs.

The dataset provides only a categorical indication of the labour market situation — shortage, balance or surplus — without any information on the severity or magnitude of shortages. Therefore, the results should be interpreted as an overview of the geographical spread of occupational shortages rather than as a direct measure of their intensity.

A.1.7 Approach to assessing wages and salaries

Data on wages and salaries for the net-zero technologies were derived from the Eurostat structural business statistics; this source provides information on both employment and compensation at the NACE four-digit level for all EU Member States along with the EU-27 aggregate. The dataset was extracted in July 2025, with the most recent wage and salary data for 2022 used as the base year for this analysis.

The first step involved calculating the average wage per employee for each NACE code by dividing total wages and salaries by the number of people employed. These averages were then combined with the employment figures obtained from the envigos model to estimate total wages and salaries attributable to net-zero technologies. Specifically, the average wage per NACE code was multiplied by the corresponding number of people employed in the model; this gives total wages that can subsequently be aggregated by value chain segment or technology.

For example, in 2022, NACE 28.25 (part of the heat pumps value chain) reported total wages and salaries of EUR 9.4 billion for the 240,000 employed people in the structural business statistics dataset. This corresponds to an average of roughly EUR 39,000 per employee. Applying this average to the approximately 19,000 employed persons in this NACE code according to the envigos model yields total wages of approximately EUR 740 million attributable to the heat pump manufacturing segment. Summing across all relevant NACE codes for heat pumps allows total wages for the full value chain to be calculated. Dividing this aggregate by the total number of people employed in the segment then provides the average wage per employee for the value chain.

The granularity of the data allows analysis at multiple levels, including for the EU-27, individual Member States, specific technologies and value chain segments, providing detailed insights into the distribution of wages and salaries across the EU net-zero industry.

A.1.8 Approach to analysing data from the European Working Conditions Survey 2024

Publicly available data on working conditions in the EU, particularly for net-zero technologies, is scarce. To address this gap, the European Working Conditions Survey (EWCS) was used as the primary source of information. It provides a highly detailed and well-established database built on many years of survey experience. In February 2026, Eurofound supplied a custom extract of the most recent survey, EWCS 2024, which contains responses to a wide range of questions on working conditions, job quality, workforce composition and skills. The dataset provided includes 28,621 individual observations covering the EU economy as a whole.

To ensure consistency with the scope of this study, the dataset was filtered according to two dimensions:

- key occupational groups, identified by ISCO codes at the four-digit level, which reflect the occupations most relevant for the selected net-zero technologies;
- relevant economic activities, based on the NACE codes at the three-digit level, as used in the envigos model for modelling employment across the four value chain segments.

These filters were applied systematically for all four value chain segments, resulting in a focused subset of survey responses for each segment. The unfiltered dataset was retained in order to calculate comparative figures for the economy as a whole, ensuring a benchmark for interpretation.

The analysis proceeded by categorising survey variables according to their type, with the following methods applied:

- continuous variables were analysed using weighted averages to ensure representativeness;
- categorical variables were expressed as relative shares within each segment;
- binary variables were assessed through estimated probabilities, again applying weights.

Post-stratification weights assigned by Eurofound were applied to each observation throughout the analysis to correct for sampling biases and to ensure representativeness across EU Member States and sectors. The methodology and results were discussed with Eurofound to ensure that survey variables, the application of weights and the filtering approach had been correctly interpreted.

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