Strategic Energy Technology Plan

Implementation Working Group on Wind

Thematic Vision on WIND ENERGY

Adopted by the SET Plan Steering Group on 8 July 2026

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Executive Summary

Wind energy occupies a key role in achieving the European Union's energy and climate objectives. Its importance lies in its ability to simultaneously address several key priorities:

- Affordability: Wind energy is a major driver of **competitiveness, economic growth, and jobs**. The sector generates **€86.8 billion in annual turnover** [1]and contributes around **€54.5 billion to Europe's GDP**, supporting **over 360,000 jobs**[2] across the value chain. Each additional gigawatt of wind energy installed creates up to **€3.5–4.4 billion in economic value**[3], illustrating its strong industrial multiplier effect.

- Security : Its value is first and foremost strategic for **energy security**: in 2024, wind energy already provided 19% of the EU's electricity demand, avoiding the equivalent of **97 bcm**[4] **of fossil fuel imports annually**[5]**.** In a context of geopolitical uncertainty and volatile energy prices, wind is a key domestic resource that directly reduces Europe's dependence on imported energy.

- Sustainability: Finally, wind energy remains a cornerstone of Europe's **climate ambitions**. It already avoids **142 million tonnes of CO_2 emissions annually**, corresponding to around **€8 billion in carbon cost savings**, and it is indispensable to achieve the EU's energy and climate targets, which require at least **55% greenhouse gas emissions reduction**i and **42.5% renewable energy by 2030**[6] . Delivering on these objectives implies a massive scale-up of wind capacity, with EU expectations exceeding **500 GW by 2030** and reaching up to **1,300 GW by 2050**, where wind could provide up to half of Europe's electricity.[7]

Achieving this trajectory requires targeted research and innovation efforts structured around five key domains. Each connected to a long-term outcome.

- **Industrialisation and competitiveness:** ensuring that the European wind industry remains globally competitive, capable of scaling manufacturing sustainably while supporting affordable and secure energy supply for European consumers and industry. This includes strengthening European manufacturing capacities, increasing supply chain resilience, accelerating industrial deployment and reducing strategic dependencies on critical technologies and materials.

- **Operations, digitalisation and cybersecurity:** accelerating the deployment of digital technologies, automation and artificial intelligence across the wind value chain to improve performance, reliability and operational efficiency. At the same time, high standards of cybersecurity and physical resilience must be embedded by design to protect critical energy infrastructure in an increasingly interconnected energy system.

[1] European Wind Energy Competitiveness Report, ETIPWind, June 2025

[2] European Wind Energy Competitiveness Report, ETIPWind, June 2025

[3] European Wind Energy Competitiveness Report, ETIPWind, June 2025

[4] bcm = billion cubic metres of gas.

[5] European Wind Energy Competitiveness Report, ETIPWind, June 2025

[6]Renewable Energy Directive (2023/2413)

[7] SWD/2020/176 final, European Commission, September 2020

- **Wind energy system integration:** positioning wind energy as the backbone of a climate-neutral, resilient and flexible European energy system. This requires seamless integration with electricity grids, storage, hydrogen production, demand-side flexibility and sector coupling, enabling wind to provide not only renewable electricity but also essential system services and security of supply.

- **Sustainability and circularity:** ensuring that wind energy delivers positive environmental outcomes throughout its entire lifecycle. Research and innovation should support circular design, recycling of critical materials and components, reduced environmental footprints, biodiversity protection and more sustainable use of natural resources while strengthening Europe's strategic autonomy.

- **Skills, societal engagement and coexistence:** fostering public support for wind energy, promoting coexistence with other users of shared spaces, such as fisheries, shipping and local communities, and developing a highly skilled workforce capable of supporting Europe's rapidly expanding wind sector. Social acceptance, education and stakeholder engagement will remain essential enablers of large-scale deployment.

This Thematic Vision does not start from scratch. It builds on the 2nd SET Plan Implementation Plan for offshore wind , the 2023-2027 Strategic Research and Innovation Agenda (SRIA), the NeWindEERA Report (long-term needs) and the Roadmap "From Innovation to industrial competitiveness" already developed within the SET Plan Wind community, providing continuity while refining new priorities in light of evolving challenges.

1. Introduction

The European Union has established a comprehensive policy framework in which wind energy plays a central role in delivering industrial competitiveness, energy security and climate neutrality. Several key legislative and strategic documents explicitly set targets and expectations that position wind as a cornerstone technology:

- **The European Green Deal** and its legislative implementation through the Fit-for-55 package, the EU has committed to reducing greenhouse gas emissions by at least **55% by 2030** and increasing the share of renewable energy to at least **42.5%** (with an ambition towards 45%). In this context, the Commission estimates that the EU will need between **425 GW and 501 GW**[8] **of installed wind capacity by 2030**, implying a significant acceleration from current deployment levels.

- **The EU Offshore Renewable Energy Strategy** sets specific targets for offshore wind, aiming for at least **60 GW by 2030** and **300 GW by 2050**. These targets are further reinforced through regional cooperation initiatives, notably the North Sea Summit, where Member States agreed to jointly develop large-scale offshore capacity, including cross-border projects.

- **The European Wind Power Action Plan** (2023) provides a dedicated framework to accelerate wind deployment across Europe. It addresses key barriers such as permitting, auction design, access to finance, and supply chain resilience, and calls for stronger coordination between Member States. This political commitment is reinforced by the Wind Energy Charter[9], signed by 26 Member States, which confirms a shared objective to scale up wind energy rapidly and strengthen the European industrial base. In addition, key EEA countries are also committed to deploying wind energy and integrating it into European electricity grids, where relevant.

- **The Net-Zero Industry Act** (NZIA) identifies wind energy as a **strategic net-zero technology** and supports the scaling up of European manufacturing capacities, in line with the EU objective of producing **at least 40%** of its annual deployment needs for strategic net-zero technologies by 2030, including an indicative target of around **36 GW of annual manufacturing capacity for wind**. This reflects the EU's ambition not only to deploy wind at scale but also to maintain industrial leadership and reduce strategic dependencies.

In 2025, wind energy generated 475 TWh of electrical energy, which corresponds to 19% of the EU's electricity consumption. The EU installed wind power capacity is 241.7 GW, of which 221 GW onshore, and 20.7 GW offshore.[10]

Achieving these policy objectives will require addressing a range of research and innovation challenges that remain critical for the large-scale deployment of wind energy in Europe, including technology performance, industrial competitiveness, sustainability, grid integration, digitalisation, and the development of offshore and floating wind solutions.

The Implementation Working Group (IWG) on Wind Energy, established in 2016 under the Strategic Energy Technology (SET) Plan, brings together European countries to coordinate research and innovation (R&I) priorities in wind energy. It currently includes Belgium, Denmark, France, Germany, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Malta, Netherlands, Norway, Poland, Portugal, Slovakia,

[8] The Commission scenario expects 501 GW and WindEurope expects 425 GW

[9] European Wind Charter, 2023

[10] Wind energy in Europe: 2025 Statistics and the outlook for 2026-2030, WindEurope, 2026

Slovenia, Spain and Sweden[11]. The IWG has developed successive strategic frameworks to guide this cooperation, including a first Implementation Plan for offshore wind in 2018 and a revised version in 2022, reflecting evolving priorities and technological developments

The objective of this Thematic Vision is to provide a clear and consolidated overview of the European Union's expectations and ambitions for the wind energy sector towards 2030, 2040, and 2050. It sets out aspirational benchmarks and strategic orientations to guide the collective R&I efforts of governments, industry, and academia. By establishing a shared reference framework, the Thematic Vision aims to support alignment, strengthen collaboration, and help ensure that coordinated actions across Europe effectively deliver on these common ambitions. In parallel, maintaining a clear trajectory for wind energy cost reduction will remain essential to support large-scale deployment, investment certainty and industrial competitiveness. Future developments in Levelised Cost of Energy (LCOE), including under Contracts for Difference (CfD) schemes, will depend not only on technological innovation but also on market design, grid integration and coordinated R&I efforts across Europe

The IWG Wind Energy with support from the wind industry has identified five megatrends or key developments in the European wind energy sector.[12]

1. **Scaling up manufacturing**. Wind turbine components have grown in size and need to focus on how automation efficiently can enable production at higher volumes. This requires innovation in manufacturing, logistics and installations. In the last ten years (2016-2025), the average power rating of onshore wind turbines ordered has more than doubled, increasing from 2.9 MW to 6.1 MW for onshore wind, and from 7.1 MW to 15 MW for offshore wind. Likewise, rotor diameters increased by 41% for onshore wind and 51% for offshore wind[13]. Floating offshore wind will play a critical role in achieving Europe's long-term offshore wind ambitions, requiring coordinated R&I efforts to mature and demonstrate innovative technologies across the entire system value chain.

2. **Optimising wind farm performance**. New wind energy component designs will help optimise electricity generation, reducing need for fossil fuel imports. Whilst electricity production is dependent on the available wind resources, new onshore wind farms typically achieve capacity factors of 25-40%, and around 50% for offshore wind.

3. **More efficient and interconnected systems**. Managing large shares of wind energy in the electricity systems will require both investment in infrastructure and new technologies across grid hardware, software and control systems. In addition, storage and power-to-x will help balance the system

4. **Digitalisation and security**. The rapid development of digital technologies induces an urgent need to push the industry to keep innovating, including optimizing performance as well as safeguarding the cybersecurity of its assets and the grid. In particular, an efficient use of the massive amount of (sensor) data and AI capabilities will be key to effectively scale up wind energy digitalization. Moreover, physical installations and each component must be designed to be efficiently protected from extreme hazards and intentional attacks, in order to achieve a higher operational resilience.

[11] Active members are Denmark, Germany, Ireland, Italy, Netherlands, Norway, Portugal, Spain and Sweden.
Temporary Observers are Belgium, France, Latvia, Liechtenstein, Lithuania, Malta, Poland, Slovakia and Slovenia

[12] Five megatrends in wind energy technology, ETIPWind, 2024

[13] Wind Turbine Orders Monitoring 2025 Statistics, WindEurope, 2026

5. **Sustainability**. Wind energy systems already have one of the lowest carbon footprints among energy technologies. Research in blade and permanent magnet recycling advanced significantly to help deliver 100% circular wind energy systems.

The need for such a vision is underscored by a growing gap between ambition and implementation. Deployment rates remain below what is required to meet 2030 targets, reflecting persistent barriers in deployment, most notably long permitting processes, but also financing and infrastructure limitations. In addition, implementation can only accelerate if supported by sufficient electricity demand, which requires stronger electrification of Europe's main industrial sectors, supported by appropriate incentives and policy frameworks, as well as the further development and interconnectivity of European electricity grids.

At the same time, the European wind supply chain also faces increasing pressure from global competition, rising costs, raising concerns about long-term resilience. Despite Europe's technological leadership, grid and system integration challenges in Europe are also intensifying. Europe is not expanding its electricity networks at pace and volume required to meet its energy supply, security and competitiveness targets. This limits the much-needed switch to electrification of EU industry, transport and heating sectors, slows down deployment of new wind energy capacity, and leads to increased curtailment of existing wind farms. In parallel, fragmented R&I efforts and funding landscapes across Europe can reduce overall efficiency, limit synergies and slow down the large-scale deployment and uptake of innovation. At the same time, the successful market adoption of innovative wind technologies also depends on favourable regulatory frameworks, market conditions and industrial demand. Strengthening coordination between European and national programmes, while reinforcing existing R&I instruments, will therefore be essential to maintain Europe's industrial leadership and energy sovereignty. Considering the challenges in the wind sector, R&I is needed with the focus on developing and scaling up innovative wind energy technologies and concepts with the focus on large scale market entry towards 2040-2050.

In 2024, the European wind industry invested more than €1.4bn in R&I, corresponding to 4.1% of the industry's direct contribution to EU GDP. This remains significantly higher than public support levels reported in Europe. As of October 2025, EU Member States had reported only €142.6m in public wind energy R&D funding for 2024, compared to €258.4m in 2023, representing a 44% decrease. Similarly, EU-level funding reported for wind energy fell from €286.7m in 2023 to just €40m in 2024. While these figures may increase due to late reporting submissions, current estimates suggest that 2024 could become one of the weakest years for public wind energy R&I funding in Europe, with an overall decrease potentially reaching 45%-50%.

In this context, members of the Implementation Working Group (IWG) on Wind Energy commit to addressing these challenges, notably by improving the visibility of national wind R&I budgets, strengthening coordination, and, to the extent possible, increasing and better aligning public funding to support the sector's long-term development.

In summary, wind energy continues to present major opportunities for technology enabled gains and represents both an opportunity and a strategic necessity for Europe. Its success depends on aligning policy, industry, and research around a shared vision, supported by coordinated action and sustained investment. This Thematic Vision provides the guideline for European collaboration on wind energy research and innovation.

2. Vision and targets

The Implementation Working Group (IWG) on Wind Energy develops this Thematic Vision in line with the SET Plan framework, which requires the definition of clear **targets**, associated **milestones**, and, where relevant, measurable **indicators** to track progress. Targets define the objectives to be achieved, while milestones represent the intermediate steps towards their delivery.

These are the aspiration goals for the European wind energy sector by 2050:

1. The European wind industry must be healthy and competitive at the global scale, while delivering value and affordable electricity prices to the European consumer.

2. The European industry will have harnessed the potential of digitalisation, automation with high cybersecurity standards.

3. Wind energy should be at the backbone of a climate-neutral energy system centred around electrification and open new markets with eventually new wind energy concepts.

4. Wind farms are fully circular, less exposed to supply chain risks for key materials and components and have a positive environmental impact.

5. Society should actively support and recognise wind energy as indispensable to European prosperity and climate-neutrality

This Thematic Vision complements previous targets with a more comprehensive and forward-looking set of milestones and priorities, aligned with current EU ambitions and the long-term R&I strategy of the SET Plan community on wind energy.

In doing so, the IWG also aims to address fragmentation and strengthen synergies between national R&I programmes, while considering the SET Plan Guiding Principles and relevant Task Force recommendations to ensure coherence between strategy and implementation.

2.1. Short-term (2030)

- **Industrialisation and standardization**

To meet 2030 energy targets, Europe needs to double its annual wind energy installations. This could mean prioritizing wind energy in national and EU industrial policies, also with a view on avoiding fragmentation. R&I will be at the core of doubling manufacturing output, shortened testing times, accelerating supply chain expansion, and deploying more standardised and modular turbine designs to enable (semi-) automated production.

R&I funding priorities (non-exhaustive list): automation in component manufacturing, mass production of jackets and sub-structures, testing facilities, logistics, transportation, assembly of components, modular blade and turbine concepts including floaters

Policy target: 425GW to 501 GW of installed wind capacity in the EU.

- **Digitalisation, automation and cybersecurity**

Digitalisation becomes a key lever for cost reduction and optimisation operation and maintenance. By 2030, predictive maintenance, advanced sensors, robotisation, and AI-driven monitoring tools should be widely deployed across wind farms.

R&I funding priorities (non-exhaustive list): cybersecurity protocols, digital twins, new power and metocean forecasting tools, data-driven maintenance optimization.

- **System integration**

The progress on the electrification of the energy system relies on policy changes, grids expansion, and the deployment of new technological solutions. The objective is to ensure that wind energy can reliably deliver around one-third of Europe's electricity while minimising curtailment and maintaining system stability. System optimisation should increasingly rely on integrated planning of generation, storage and demand-side flexibility across sectors.

Future wind energy systems will increasingly depend on interoperable digital ecosystems enabling predictive optimisation, autonomous operations, advanced forecasting and secure data exchange across assets and infrastructures. Strengthening cybersecurity and resilient Operation Technology/Information Technology (OT/IT) integration must become a strategic priority to ensure reliable and secure large-scale system operation.

R&I funding solutions (non-exhaustive list): grid-forming capabilities, hybrid wind plants, multi-terminal HVDC and integration towards data centres, co-location with storage, power secure access to X, grid balancing supply raw materials and demand, components

Policy target: 34% of EU annual energy demand to be met with electricity

- **Circularity & sustainability**

The wind energy sector is committed to achieve full circularity and uphold high and competitive sustainability standards, only possible with policy changes, market incentives, and continuous R&I. Harmonised methodologies to assess environmental and social impacts should be in place, alongside initial deployment of nature-positive solutions. Scaling up industrial recycling capacities, particularly for blades and critical materials, will be essential to achieve economically viable circularity at sector level.

R&I funding priorities (non-exhaustive): scaling up recycling technologies particularly for blades and critical components (such as permanent magnets), piloting recyclable-by-design turbine concepts

- **Skills & coexistence**

Meeting Europe's wind energy deployment targets will require a significant expansion of the sector's workforce, potentially reaching up to 600,000 people by 2030. Addressing existing and future skills shortages will therefore be essential, supported by harmonised European training frameworks, large-scale reskilling programmes, and improved public communication and stakeholder engagement to strengthen societal awareness and acceptance of wind energy deployment.

R&I funding priorities (non-exhaustive): European-wide training centres, industry-education-academia partnerships, stronger stakeholder engagement and communication strategies, and initiatives supporting public acceptance and citizen involvement.

Policy target: 600,000 workers in the European wind industry

2.2. Medium-term (2040)

- **Industrialisation and standardization**

The European wind industry continues to progress in new installations and capacity towards the long-term targets and continues to scale up its supply chain. Turbine design evolution stabilises, enabling optimisation of reliability, lifetime, and cost efficiency. Europe maintains strong global competitiveness through continuous innovation and industrial leadership. Innovative wind energy systems (e.g. airborne wind energy systems and floating offshore wind) are fully mature and ready to be scaled up.

R&I funding priorities (non-exhaustive list): improve reliability and optimised lifetime of wind energy systems, quality requirements and standards

- **Digitalisation, automation and cybersecurity**

AI driven and automation solutions are widely available for wind farms operations & maintenance and logistics. Cybersecurity and operational efficiency is enabled by quantum computers and is fully integrated by design across wind farms and energy systems, ensuring resilience against evolving threats in a highly interconnected infrastructure.

R&I funding priorities (non-exhaustive list): AI-driven operations, quantum computing, LT extension, predictive maintenance and RUL estimation, autonomous inspection and maintenance solutions, including robotics, are widely deployed, significantly reducing operational costs and improving safety, data-driven asset management.

- **System integration**

Electrification of the energy system and the integration of onshore and (floating) offshore wind energy progresses, on track to achieve 2050 targets.

R&I funding priorities (non-exhaustive list): interconnected HVDC networks and advanced grid management systems, interactions with storage, hydrogen production and power-to-x hubs, sector coupling applications.

- **Circularity & sustainability**

Circularity is fully integrated into industrial processes by 2040 and continues to promote nature positive solutions.

R&I funding priorities (non-exhaustive list): components designed for recyclability, reuse, or refurbishment, supported by mature recycling industries and efficient secondary material markets, lifecycle assessment …

- **Skills & coexistence**

By 2040, the wind sector benefits from a highly skilled and mobile European workforce supported by harmonised qualifications and lifelong learning systems.

R&I funding priorities (non-exhaustive list): Training programmes, public acceptance, transparent governance, participatory planning processes, widespread recognition of wind energy's socio-economic benefits,

2.3. Long-term (2050)

- **Industrialisation**

By 2050, Europe has established a fully sovereign and globally competitive wind industry, sustaining large-scale deployment with net-zero industrial processes. Manufacturing is highly automated, resource-efficient, and climate-neutral, supported by a resilient and strategically autonomous supply chain.

R&I funding priorities (non-exhaustive list): net-zero manufacturing processes, advanced materials reducing dependency on critical raw materials, AI-driven factories, additive manufacturing, next-generation turbine designs, supply chain resilience technologies.

Policy target: Wind energy is 50% of the EU electricity mix

- **Digitalisation, automation and cybersecurity**

Wind energy systems are highly autonomous and cybersecure. Advanced AI enables self-optimising operations, reducing costs and risks in a fully digital and interconnected energy system.

R&I funding priorities (non-exhaustive list): autonomous wind farm management, real-time optimisation, system-level digital twins, quantum-resistant cybersecurity, human-machine interaction.

- **System integration**

Wind energy forms the backbone of a fully decarbonised and electrified energy system, providing around half of electricity demand. The system is flexible, interconnected, and integrates renewables, storage, hydrogen, and sector coupling. Wind energy will not only act as a generation source but as a system backbone, providing stability, flexibility and ancillary services to the energy system.

R&I funding priorities (non-exhaustive list): European super grid architectures, interoperable HVDC systems, integration of storage and hydrogen, AI-driven system balancing, cross-sector optimisation tools, HVDC substations

- **Circularity & sustainability**

Wind energy achieves full circularity and delivers net-zero or nature-positive impacts. Turbines are designed as zero-waste systems with minimal reliance on primary raw materials, contributing to biodiversity and ecosystem restoration.

R&I funding priorities (non-exhaustive list): fully recyclable and bio-based materials, closed-loop recycling, zero-waste design, lifecycle assessment tools, nature-positive solutions.

Policy target: Corporate targets on 100% circular wind turbine

- **Skills & coexistence**

Wind energy is fully embedded in society, supported by a highly skilled workforce and strong public acceptance. It coexists seamlessly with other sectors through optimised spatial planning and multi-use approaches.

R&I funding priorities (non-exhaustive list): advanced training ecosystems, continuous reskilling, human-centric automation, public engagement tools, participatory planning frameworks.

3. Conclusions and next steps

Wind energy is indispensable to achieving Europe's climate neutrality, energy security, and industrial competitiveness objectives, and its role will only grow in importance as the energy transition accelerates. As outlined throughout this Vision, wind energy has the potential to become the backbone of a fully decarbonised and electrified European energy system. However, realising this potential depends on Europe's ability to act decisively across several critical dimensions**.**

Achieving large-scale deployment targets will require stronger focus on practical implementation barriers, including permitting, port infrastructure, transport logistics, testing capabilities and manufacturing scale-up. Research and innovation efforts should therefore be closely aligned with deployment readiness and industrial execution capacity as well as with continuous R&I efforts in less-mature technologies, such as floating offshore wind, until they reach their full deployment by 2040 and beyond.

Coordinated and well-targeted research and innovation investments are crucial to drive technological progress, reduce costs, and enable the large-scale deployment of next-generation solutions. Accelerated deployment is essential to close the gap between current installation rates and 2030 targets, requiring urgent improvements in permitting procedures, infrastructure development, and investment conditions.

At the same time, a strong and resilient industrial base must be maintained and expanded to ensure that Europe retains its technological leadership and captures the economic value of the transition. This must be supported by the development of fully integrated energy systems capable of managing high shares of variable renewable energy through enhanced flexibility, digitalisation, and sector coupling.

Research and innovation funding at both private, EU and national levels must be increased and better streamlined to avoid fragmentation and maximise impact. while ensuring transparency, clear rules, as well as a level playing field for all R&I stakeholders. This includes improving coordination between programmes and ensuring that funding instruments are aligned with long-term strategic priorities. At the same time, the challenge of effective implementation must be clearly acknowledged, and the SET Plan Steering Group is invited to take a proactive role in addressing it, ensuring that Member States and stakeholders work towards shared objectives and fully benefit from synergies.

Looking ahead, several next steps are needed to translate this Vision into action. The SET Plan Wind Energy community has already published a Strategic Research and Innovation Agenda (SRIA), which provides a solid foundation; the next step will be to review and update this document where necessary, to ensure continued alignment with evolving priorities. At the same time, clear guidance is needed on how the implementation of the Wind Energy's Thematic Vision, SRIA and Implementation and Investment Commitments (IIC) will be enforced under the SET Plan governance.

Particular attention will be given to the SET Plan Task Forces on societal needs, circularity and material substitution, as well as to key enablers such as digitalisation, including cybersecurity, and skills development. Improving market conditions—especially through more efficient permitting and access to financing—will also be essential to accelerate deployment.

Finally, stronger synergies with other SET Plan Implementation Working Groups, notably on grids, hydrogen, and energy storage, will be key to addressing cross-cutting challenges and ensuring a fully integrated energy system. In addition, exploring synergies with the defence sector could support the development of resilient infrastructure, cybersecurity capabilities, advanced materials, and offshore technologies with dual-use potential

Together, these steps will help ensure that wind energy can fulfil its central role in delivering a climate-neutral, secure, and competitive European energy system.

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