Charging Ahead

A Roadmap for an Electrified, Competitive and Resilient European Energy System

Copenhagen Infrastructure Partners

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1.1 Foreword
by Michael Liebreich

Europe's future competitiveness, security and prosperity will be shaped by the choices we make about energy today.

At a time of geopolitical fragmentation, conflict and intensified global competition, it has once again become clear that energy is much more than just a commodity. It is a condition for industrial strength, economic growth and most crucially, strategic autonomy.

European industries and households continue to face energy costs significantly above those of global competitors. At the same time, Europe continues to remain reliant on imported fossil fuels. This structural exposure to external energy shocks has only been exacerbated by the geopolitical turmoil in Ukraine and the Middle East. In a world defined by volatility, dependency is a vulnerability – and the transformation of Europe's energy system is therefore as much a strategic and economic necessity as it is a climate imperative.

Increased electrification and accelerated deployment of homegrown clean energy offer Europe a pathway to regain control over its cost base, reduce exposure to global commodity markets, and strengthen domestic industries.

Scale, speed and the energy system of the future

But power generation alone will not suffice. Energy grids, storage and energy system flexibility must also be developed at scale and at speed.

This requires long-term clarity, predictability and more fit-for-purpose regulatory frameworks, mobilisation of private capital, and unwavering political and public ambition. As the energy system becomes more infrastructure-based and capital-intensive, reducing risk and lowering the cost of capital becomes central to delivering affordable energy for citizens and competitive conditions for the industry.

Europe has the technologies, the innovation, the capital and the industrial capabilities. The defining question is whether it can align policy and markets quickly enough to turn its potential into a structural advantage.

The stakes are high

Copenhagen Infrastructure Partners' (CIP) report provides a structured, fact-based and positive contribution into the ongoing debate on energy transition in Europe. It very clearly highlights that affordability, resilience and decarbonisation are not mutually exclusive objectives in the long run, but instead are interdependent conditions for long-term prosperity for Europe in response to geopolitical and macroeconomic changes.

Europe's energy transition is not about politics or ideology. It is about creating a future Europe that is competitive, resilient and prosperous. The decisions taken in this decade will determine whether Europe leads or follows in the global economy of the future. The stakes are high. But the opportunities are endless if we dare to be Charging Ahead.

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1.2 Executive Summary

In times of increased geopolitical uncertainty, the case for an integrated European energy system, deeper cross-border coordination, and faster delivery of shared infrastructure has never been stronger. Europe's energy system is being reshaped at a time when it has once again become clear that generation our own energy is a key condition for long-term competitiveness and security.

Europe is structurally exposed to imported fossil fuels and, thus, geopolitical volatility. Today imported fossil fuels account for around 40% of European energy demand[1], costing an estimated **EUR 250 billion** per year. In the EU, fossil fuel imports amount to EUR 400 billion per year. This presents Europe with the opportunity of a lifetime. The political and investment choices on energy made this decade will determine whether Europe creates a new path or locks in its long-term vulnerabilities.

At the core of this choice lies solving the triple challenge: deliver affordable energy for households and industry, strengthen resilience of the energy system by reducing external dependency; and achieve clean energy deployment at scale. Solving this requires system-wide solutions that address all three dimensions in parallel.

This report is written for policymakers and investors who will shape that trajectory. Policymakers set the frameworks that determine pace and risk as well as provide public funding for project execution and crowding in private capital. Investors help provide the capital that turns plans into actual build-outs. The common requirement is clarity on what the system needs, where the bottlenecks sit, and which choices that matter the most.

Energy security and electrification

Replacing imported fossil fuels with homegrown clean energy has a three-fold system benefit:

- It lowers structural costs by reducing the number of hours where gas determines the power price, which today is roughly 60% of the time in the EU. This imposes a significant cost challenge for the region as gas prices are 2-3 times higher than for instance in the U.S.
- It strengthens resilience by cutting import exposure.
- It reduces emissions as a direct consequence of the shift.

The energy transition is already happening, but unevenly. Onshore wind and solar PV are scaling, and battery storage is accelerating, while offshore wind and new hydrogen/PtX value chains require stronger policy support to reach the volumes implied by Europe's long-term targets and system needs. Achieving electrification remains a bottleneck relative to the levels required to reach Europe's **32% electrification goal by 2030**, and the electrification levels implied by the model towards **2050**.

Three scenarios towards 2050

Copenhagen Infrastructure Partners (CIP) has – together with Ea Energianalyse – built an integrated energy system model and based on that, conducted an analysis of how Europe's energy system could evolve towards 2050 under different strategic choices. This report presents the results and analyses of that model, showing how affordability, resilience and clean energy at scale can be pursued in parallel, and what it will take to deliver the system in practice.

The report explores Europe's energy transition through three scenarios. These scenarios are not forecasts, but rather strategic directions that illustrate how different choices on policy ambition, investment commitment, and infrastructure build-out shape outcomes against the triple challenge mentioned.

Scenario: Competitive & Resilient illustrates a balanced direction where Europe prioritises affordability and security while delivering substantial emissions reductions through pragmatic sequencing and targeted investment.

Scenario: Slow Transition illustrates a system where constraints persist, investment momentum weakens, and infrastructure delivery lags, delaying electrification and keeping Europe more reliant on domestic production and imports of fossil fuels and thereby exposed to long term higher costs.

Scenario: Net Zero illustrates a more climate-ambitious direction where aggressive decarbonisation targets drive faster electrification and more rapid deployment of clean energy and infrastructure.

Notes: 1) In this report, the model area referred to as 'Europe' accounts the UK, Norway and the EU with a few country exceptions.

The European energy system in 2050 as described in this report is therefore conditional. It depends on whether Europe makes consistent policy choices, mobilises investment at scale, and delivers enabling infrastructure on time. The Competitive & Resilient scenario is assessed as the most strategically relevant reference because it reflects a transition that is realistic under constraints while still supporting Europe's competitiveness and security of supply. At the same time, it highlights that a balanced approach involves trade-offs and does not assume full decarbonisation in every segment by 2050.

What the modelled 2050 energy system implies for the triple challenge

The analysis in this report is based on a bottom-up energy system model that optimises Europe's electricity, hydrogen, and heating systems towards 2050. This provides a system-level view of how Europe, in the three scenarios, could produce, transport and consume energy in 2050, and the repercussions for affordability, resilience and the deployment of clean energy at scale.

Affordability

Affordability increasingly comes from a structural shift in the energy cost base. Europe moves away from exposure and volatile global fuel markets and towards domestically produced clean electricity and long-lived infrastructure. In the Competitive & Resilient scenario power prices are forecasted to decrease by **around 40%**. Europe moves away from exposure to volatile global fuel markets and moves towards domestically produced clean electricity and long-lived infrastructure. Over time, this can lower and stabilise energy costs because the system relies less on imported fuels and more on assets with predictable operating costs. Affordability is therefore not only a question of short-term price peaks but of long-term system design and the cost of capital.

Resilience

Resilience is shaped by reduced dependency on imported fossil fuels but also by operational robustness. Europe's fossil fuels import can be reduced by **~80% by 2050**. As electrification increases, electricity becomes more system-defining, and resilience depends increasingly on system stability, redundancy, and flexibility. A resilient system must be able to absorb shocks, manage variability and intermittency, and maintain reliability under stress. This makes grids, interconnectors, storage and other flexibility solutions critical infrastructure for European security of supply.

Clean energy at scale

Clean energy in 2050 is delivered primarily through a clean power system and large-scale electrification. In 2050, Europe can achieve **~2,800 GW** of clean energy capacity, supplying **close to 95%** of all electricity demanded. Direct electrification becomes the main route to decarbonisation where feasible, because it replaces inefficient fossil combustion with highly efficient end-use technologies. Where electrification is limited or uneconomic, green hydrogen, clean fuels and carbon management solutions play targeted roles. Clean energy at scale therefore requires both large, clean energy generation deployment and the enabling system to integrate it.

Affordability
40% reduction in power prices

Resilience
80% reduction in import of fossil fuels

Clean energy
95% of electricity supplied by clean energy

Investments required
EUR 5.2 trillion or EUR 210 billion annually in generation and infrastructure

Electrification as the driver, infrastructure and system flexibility as enablers

A defining feature of the energy transition is electrification, and the distinction between primary and final energy consumption. Fossil energy systems are inherently inefficient because large shares of primary energy are lost in combustion and conversion. Electrification is more efficient, allowing the same useful energy to be delivered with less energy input. As electrification accelerates and as electricity becomes the backbone of the energy system, total energy demand declines even as economic activity continues to grow, and electricity demand rises. This makes enabling infrastructure the critical condition for success. Without accelerated build-out of grids and interconnectors, new electricity generation, and power storage to maintain system flexibility, Europe cannot solve the triple challenge of delivering an affordable, resilient and clean energy system of the future.

The role of key technologies and what holds them back

Onshore technologies such as onshore wind and solar PV remain core pillars of the transition, and the model assumes a substantial and stable build-out towards **2050 (~570 GW** of onshore wind and **~1,680 GW** of solar PV). Europe must mobilise investments in power generation at a scale of **EUR~ 2.1 trillion** towards **2050**, corresponding to annual investment needs of **EUR~ 85 billion**. As the current market expansion of these technologies is on track towards 2050, this report treats them as foundational market-driven volume technologies, while focusing on the system enablers and constraints that determine whether the wider transition can be delivered at scale.

Grids and interconnectors are the backbone of the system, enabling electrification, integrating clean energy, and strengthening resilience through stronger connectivity and redundancy.

However, they are also becoming the binding constraint in the energy transition: rising demand, aging assets, lead times for key components, and regulatory models that often do not sufficiently reward anticipatory investment are converging at the same time. Europe needs to accelerate investment in power infrastructure at a scale of **EUR~ 2.9 trillion** towards **2050**, corresponding to annual investment needs of **EUR~ 120 billion**, to ensure that electrification, generation, and system integration can proceed in parallel.
Battery storage and other flexibility solutions are increasingly becoming defining for a resilient and stable energy system. They provide balancing, fast response, and reduce the cost of integrating high shares of variable energy sources. In the report's Competitive & Resilient scenario, utility scale battery capacity grows from **~10 GW** today to **~350 GW** by **2050.** The key challenge is market design: flexibility and system services are often under-remunerated, which can delay deployment even when the overall system need is so evident.

Offshore wind is a cornerstone of the energy supply stack of the future, offering high capacity factors and more stable output than many other **generation technologies**. In the Competitive & Resilient scenario, the model points to a build-out of **~220 GW by 2050**, compared to a current installed capacity of **~37 GW**. Its main challenge is projected to be investability and delivery risk where especially auction design, supply chain constraints, and cost inflation can undermine project economics and delay build-out if risk is not shared in a bankable way across public and private players. If the 2026 Hamburg Declaration's ambitions on offshore wind LCOE cost-outs and stable build-out pipelines become a reality, significant offshore wind capacity additions may also become more viable in the European energy system.

Clean hydrogen is necessary for energy intensive sectors where direct electrification is limited, such as heavy road transportation, steel, chemicals, and segments of shipping and aviation. In the Competitive & Resilient scenario, clean hydrogen demand grows materially towards 2050 to **~35 mtpa** amounting to an investment need of **EUR~ 230 billion** or **EUR 9 billion** annually towards **2050**. The main barrier for scaling clean hydrogen production is coordination where supply, demand and infrastructure timelines are currently out of sync, and the cost gap ("green premium") inhibits bankable offtake.

Implications for Europe: competitiveness, stability, and investability

If Europe succeeds in solving the triple challenge, the implications are tangible. They show up in the affordability of energy for households and industries, in reduced exposure to external shocks, and in the reliability and stability of the power system. They also show up in European industries' ability to compete globally.

As highlighted in the Draghi report, the success of European industry is increasingly defined by Europe's ability to provide affordable energy. Long-term competitiveness therefore lies in building a structural cost advantage: a system anchored in homegrown clean energy, enabled by energy grids and system flexibility, and financed at the lowest possible cost of capital.

This will require unprecedented investment levels and new ways of mobilising private capital. Across power generation, system flexibility and grid infrastructure, Europe needs to invest **EUR ~5.2 trillion** over the next 25 years - equivalent to **EUR ~210 billion** annually - to realise a competitive and resilient European energy system.

This is why remuneration frameworks and market design matter. Financing is not a result of the model, but it is a condition for action. As the system shifts from dependency on fossil fuels to a capital-intensive new energy infrastructure, Europe needs market frameworks, that reward not only energy volumes, but also adequacy, flexibility and system services
– so the assets that keep the system reliable can be financed and delivered at scale.

1.3 Policy Recommendations Summary

The 16 policy recommendations throughout this report are designed to guide legislators and decision makers in solving the triple challenge by making the energy transition deliverable. Faster build-out, lower system cost through reduced financing risk, stronger security of supply, and accelerated deployment at scale will help support that goal.

Market design certainty and accelerated electrifcation

1. **Preserve robust electricity market design**
Prioritise full and consistent implementation of the 2023 electricity market reform and avoid distortive interventions that weaken price formation, undermine cross-border integration, or reduce investment incentives for renewables, grids and flexibility.
2. **Increase the competitiveness of electricity relative against fossil consumption**
Use targeted tax and tariff reforms to make electrification the economically attractive choice, including higher fossil taxation or lower electricity taxes and more supportive grid tariff structures.
3. **Incentivise household electrification**
Reduce upfront costs and remove practical barriers by combining targeted support for Electric Vehicles (EVs) and heat pumps with enabling infrastructure, such as smart-charging requirements and rollout of charging capacity.

Unlock grid build-out at scale

4. **Leverage private capital and knowhow to meet investment requirements**
Mobilise significantly more private capital and capabilities by enabling access to private markets, updating regulated returns to reflect today's cost of capital, and involving private investors early to ensure optimisation and bankability.
5. **Public capital can enable innovative and catalytic capital instruments**
Use guarantees and subordinated or patient equity to reduce risk and crowd in private investment, while bridging affordability impacts as regulated returns adjust over time.
6. **Anticipatory investments to proactively address congestion costs**
Incentivise grid operators to invest ahead of demand through aligned planning cycles, greater transparency in grid connection queues, and prioritisation of projects that are ready to connect.

Unlock faster deployment and higher system value

7. **Allow behind-the-meter storage to scale**
Allow generation projects to install behind-the-meter storage without additional approvals from TSOs or planning authorities, to increase local flexibility, improve renewables economics, and reduce congestion costs.
8. **Fast-track grid import connections where storage delivers balancing value**
Introduce fast-tracked applications for separate grid import connections for storage assets where needed, and ensure battery connections do not impose operational limits on charging or discharging.
9. **Remove grid fees and charging costs that penalise battery storage**
Remove grid fees, double charging and other network-related charges that distort market signals and undermine the flexibility value batteries provide to congestion management and security of supply.

Unlock offshore wind scaling and lowering costs

10. **Provide clear visibility on volumes and auction timelines**
Ensure a stable and transparent offshore wind tender pipeline so developers and supply chains can invest ahead of demand, expand capacity, and reduce delivery and financing risk.
11. **Develop national implementation plans to deliver on the Hamburg Declaration**
Translate the 15 GW/year (2031–2040) commitment into executable national plans, including 10 GW/year backed by two-sided CfDs. Support this with cross-border coordination to make frameworks fit together and enable cost reductions at scale.
12. **Strengthen investability through targeted flexibility and simplicity**
Improve auction bankability through price indexation and realistic ceilings and keep non-price criteria (incl. NZIA implementation) simple and consistent, while enabling targeted instruments (e.g. CfDs with counter-guarantees for corporate PPAs) where they strengthen investability.

Unlock scalable supply, bankable demand, and timely infrastructure build-out for hydrogen

13. **Create demand incentives that work for products made with Renewable Fuels of Non-Biological Origin (RFNBO) hydrogen**
Create bankable demand by implementing RED III and establishing binding lead-market quotas (e.g. public procurement), supported by clear product differentiation (e.g. labelling and targeted taxation).
14. **Build infrastructure to help the industry deliver renewable hydrogen volumes**
Treat electricity and hydrogen networks as overriding public interest and align integrated planning, fast-track permitting and EU de-risking tools, so infrastructure build-out keeps pace with production and demand.
15. **A funding framework fit for scaling**
Strengthen the European Hydrogen Bank with sufficient scale and flexibility to close the cost gap and avoid penalising projects for delays outside their control, while enabling temporary complementarity of EU and national support where needed.
16. **Enable early market formation through clean hydrogen book-and-claim systems**
Introduce a credible clean hydrogen book-and-claim framework to support early offtake and demand aggregation before full physical infrastructure, with clear rules to preserve integrity and transparency.

1.4 Solving the Triple Challenge

Energy systems are the backbone of today's societies and are fundamental for economic and societal purposes. Access to reliable and affordable energy has always been a prerequisite for industrialisation, productivity gains, and rising living standards.

Throughout history, major economic transformations have been underpinned by advances in energy technologies and the way energy is produced, transported, and consumed. Today, Europe stands at another inflection point, where the design of the future energy system will play a decisive role in industrial competitiveness, geopolitical resilience, and prosperity.

A structural transformation

Designing and building an energy system that is deeply embedded in industrial value chains and everyday life is capital-intensive, and a long-term undertaking. Decisions taken today shape outcomes for decades, and misalignment between policy, markets, and infrastructure can lead to high costs and systemic vulnerabilities. As a result, the energy transition cannot rely on incremental innovation alone. It requires an understanding of the structural trade-offs inherent in the system and their potential consequences for our future societies.

At the core of transitioning this system lies a triple challenge: ensuring resilience of the energy system, delivering affordable energy, and achieving clean energy at scale.

Energy resilience extends beyond physical supply to include resilience to geopolitical shocks and vulnerabilities in global supply chains. It also depends on the operational robustness of the power system, including system flexibility, redundancy in critical nodes and corridors, and the ability to prevent, contain, and recover from disruptions. Recent grid disturbances and outages in Europe (cf. Iberia in April 2025 and Berlin in January 2026) underline how failures can cascade when systems lack sufficient flexibility, and how consequences can quickly have societal and economic impact.

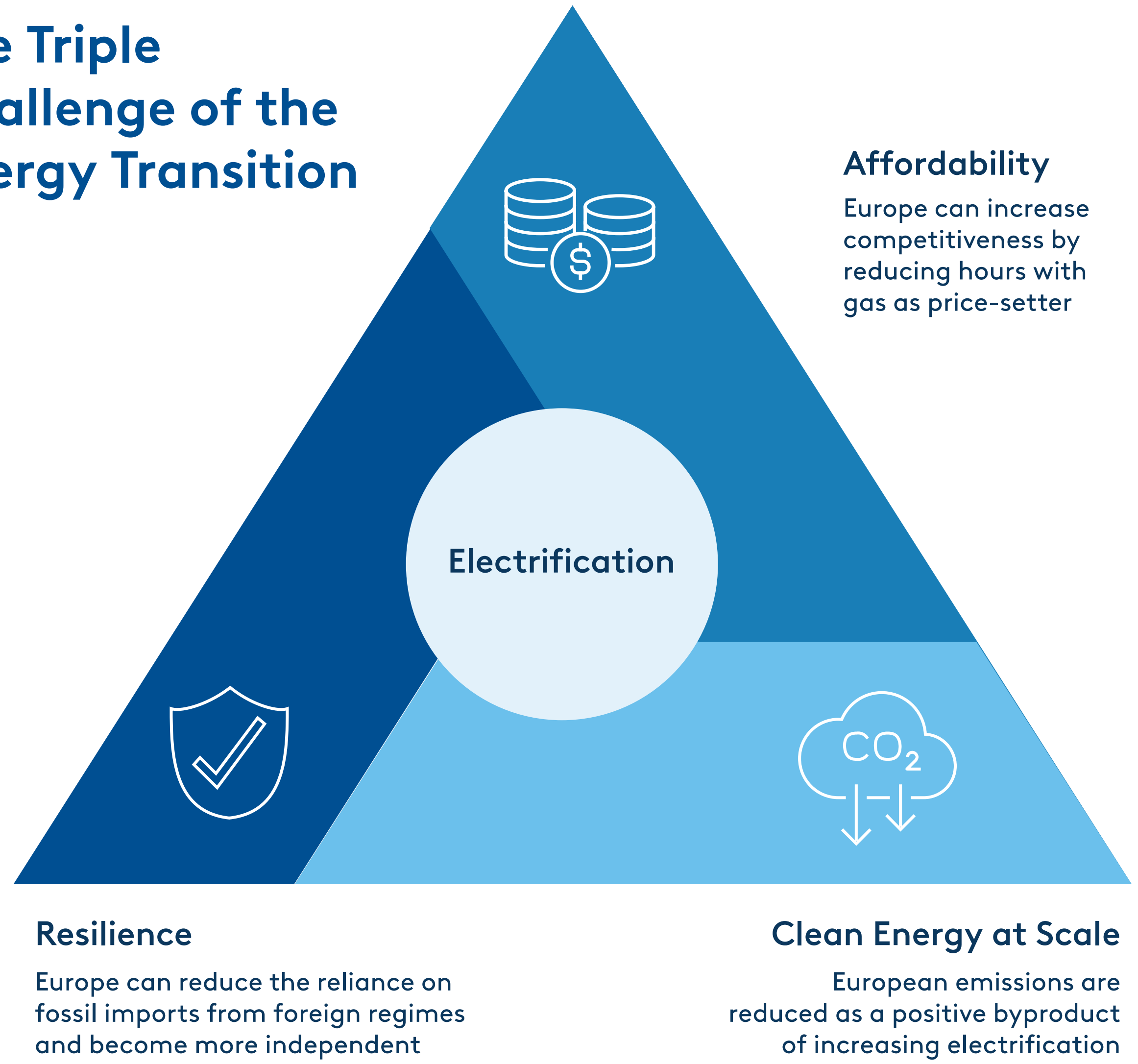
Affordable energy requires universal and fair access to energy at prices that households and industries can afford to deliver prosperity and ensure sustainable growth. As pointed out by Mario Draghi, affordable energy prices are a prerequisite for productivity and European competitiveness. Clean energy reflects the imperative to reduce emissions and mitigate climate change.

An energy system that is clean but unaffordable risks eroding public and political support. One that is affordable but dependent on concentrated external fossil energy sources exposes Europe to geopolitical volatility and supply chain risks. And a system that is resilient but fails to address decarbonisation risks increasing Europe's exposure to future climate related hazards. Solving the energy transition therefore requires integrated solutions that address all three dimensions in parallel.

Policy direction and system outcomes

The trajectory of Europe's energy system is not predetermined. It will ultimately depend on future policy choices, regulatory clarity, and the credibility of long-term investment commitments. Insufficient coordination between governments, industry, and system operators, uncertainty around electricity market design, or delayed infrastructure investments can increase overall system costs and undermine resilience and competitiveness. Conversely, decisive and consistent action can unlock significant economic and strategic benefits while reducing climate change.

The Triple Challenge of the Energy Transition



A central feature of the transition is electrification and the distinction between primary, final and useful energy demand (See definitions on next page). Fossil-based energy systems are inherently inefficient, as large shares of primary energy are lost in combustion and conversion processes. Electrification, by contrast, is significantly more efficient – often by a factor of three – allowing the same level of useful energy services to be delivered with substantially less primary energy input. As electrification of transport, heating/cooling, and industrial processes accelerates, the amount of energy lost between primary and useful energy is reduced. This structural shift reduces energy demand, lowers system costs over time, and fundamentally reshapes the macroeconomic relationship between energy consumption, growth, and emissions.

Once the initial capital investment has been made, clean energy sources have a lower operating expenditure (OPEX) due to low marginal cost of production. In contrast to fossil fuels where costs are significant over the lifetime of the project, clean energy sources have the opportunity to be significantly cheaper because the means of marginal production are essentially free. At the same time, marginal cost of fossil fuels is highly volatile in line with global markets, which is a cause for political concern, especially considering Europe's strong fossil energy import dependency.

Against this backdrop, solving the triple challenge is also an economic opportunity. A well-designed energy system can deliver affordable energy to support competitive industries and reduce exposure to external shocks, while enabling Europe to meet its climate objectives.

1.5

Why we adopt a model-based approach

The energy system is inherently complex: it is a multi-metric, multi-stage and deeply interconnected system that can only be understood through a holistic model approach.

Europe's future energy system can be analyzed through many different energy models, but they often reach different conclusions, because they assume different political trajectories and, in some cases, use different modelling approaches.

Today, electricity, hydrogen and heat are deeply interconnected in a sector coupled energy system, and analysing Europe's future energy system by modelling the electricity system or individual assets in isolation risks producing a misleading picture of what the future energy system must ultimately deliver.

Also, energy is referenced in many different units depending on its form and geographical location; m³ or MMBTU for gas; litres or gallons for gasoline; kWh or GJ for electricity; while tons oil equivalent is also frequently used to represent energy.

Similar confusing measures are used to describe energy consumption, depending on when and how the energy is used. Primary energy, final energy, and useful energy are all used in various contexts to describe consumption. Useful energy being the most relevant to consumers, as it explains the actual energy required for delivering a service. That said, often this is not the used measure especially by fossil friendly groups, whereas primary energy reflects energy content at extraction and is less meaningful for end users.

For these reasons, this report applies a bottom up, holistic modelling approach that captures the European energy system across the three interconnected sectors: electricity, hydrogen, and heat.

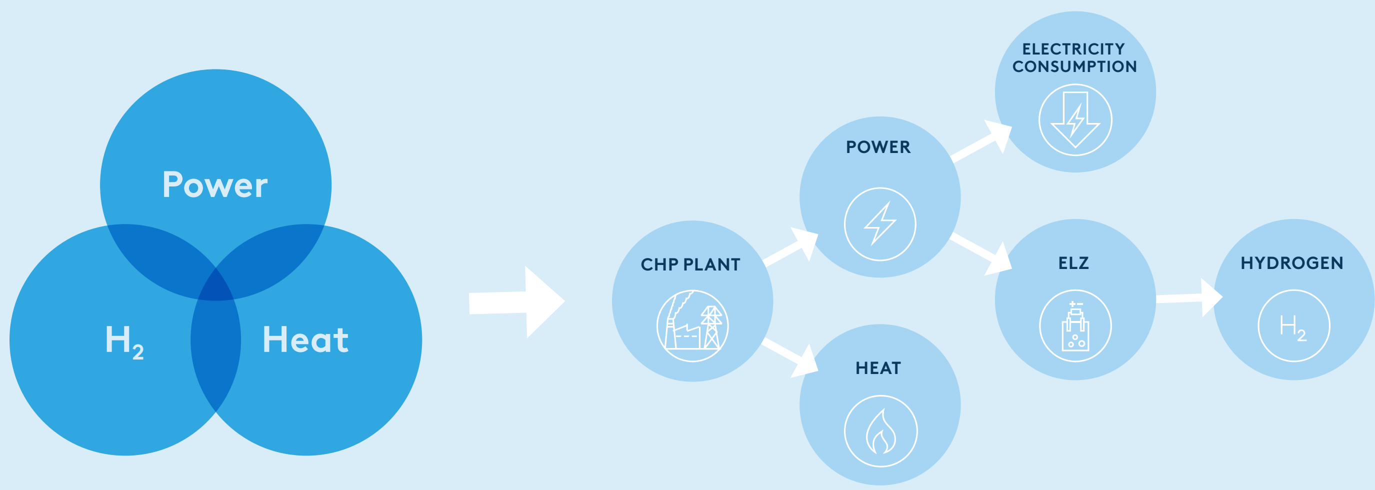
FACTS

Primary energy demand: Energy extracted directly from natural sources before any conversion or processing (e.g., crude oil, natural gas, coal, wind, solar, nuclear heat).

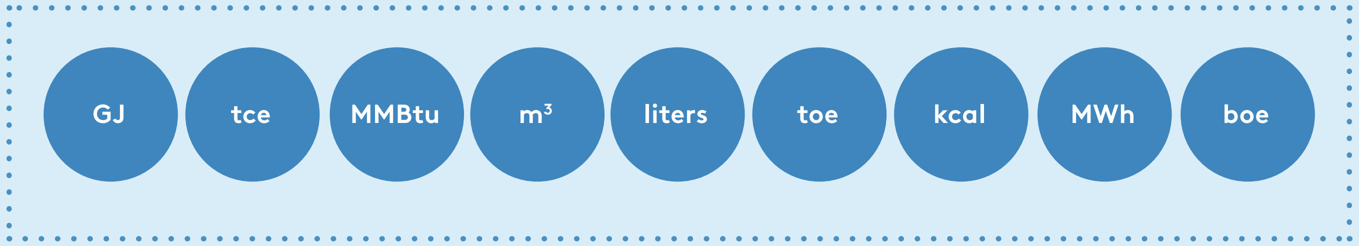
Final energy demand: Energy transformed into fuels, heat, or electricity and delivered to homes, transport, and industry. The energy required in the end-use sectors that provide energy services, measured at the point where energy is consumed.

Useful energy demand: The actual outcome energy delivers for the end user (heat, mobility, or lighting) rather than the fuel itself, reflecting what remains after all conversion, distribution, and device losses.

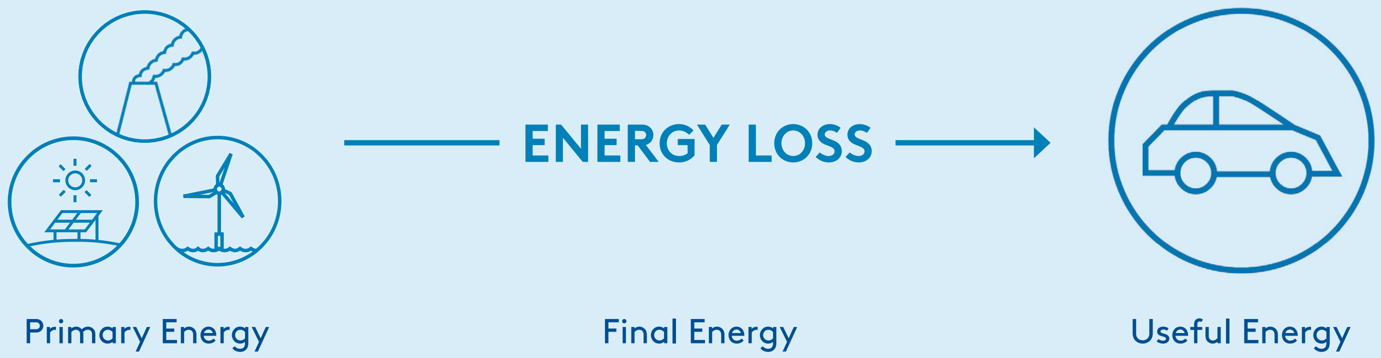
1. Interconnected energy sectors forming a sector coupled system



2. Diverse energy definitions along the transformation chain



3. Multiple ways of communicating and measuring energy consumption



1.6

Reading Guide: Model-based Approach

This chapter outlines the challenges ahead and presents a data-driven roadmap to address the triple energy challenge. To support this analysis, Copenhagen Infrastructure Partners (CIP) has developed a proprietary energy model that integrates Europe's electricity, gas, hydrogen, and heating systems.

This report builds on CIP's 2025 analysis of Europe's energy system, which explored a set of alternative scenarios reflecting earlier policy assumptions and market conditions. This report updates and expands that work by incorporating new data, revised assumptions (explained in detail in Appendix I), and a refreshed political context shaped by recent geopolitical developments and energy market shifts.

Most notable adaptations to model assumptions are:

- Increased focus on energy security, ensuring that all countries can supply their own need in all hours of the year
- Increased cost of power transmission (to follow recent years trend)
- Reduced deployment of offshore wind towards 2030 (to align with current market development)
- Implementation of a Geographic Information System (GIS) analysis to map where solar and wind can feasibly be deployed, factoring in terrain conditions and proximity to urban areas
- Reduced capacity for onshore technologies (in line with increase in local political opposition)
- Increased deployment of nuclear energy (in line with national ambition across Europe)

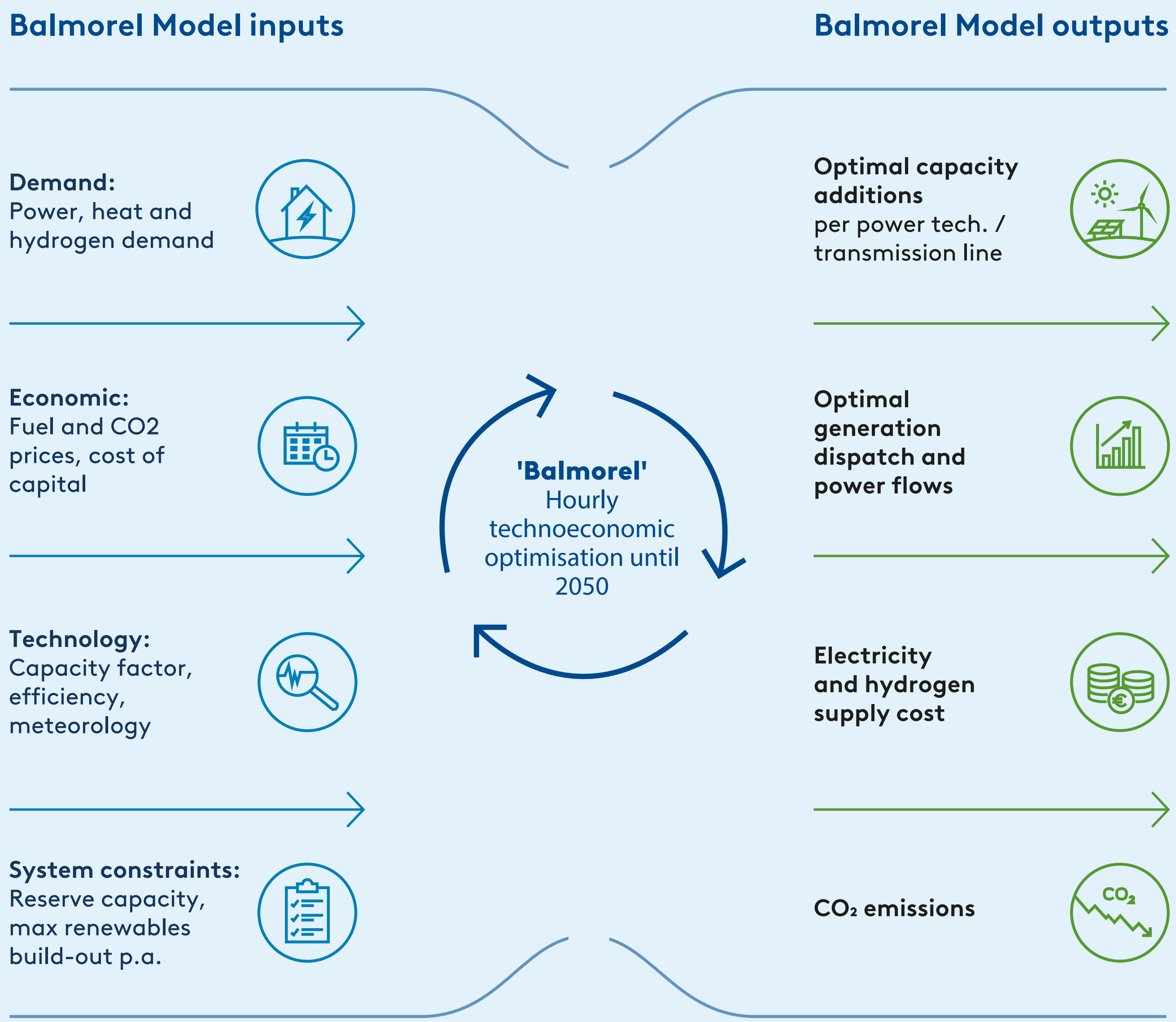
The analysis uses a bottom-up energy system model that optimises Europe's electricity, hydrogen, and heating systems on an hourly basis towards 2050. The model identifies cost-optimal capacity additions, generation dispatch, power flows, energy system costs, and CO emissions, subject to technical and system constraints.

The model area referred to as 'Europe' accounts the UK, Norway and the EU with a few country exceptions.

CIP developed the model in collaboration with Ea Energianalyse, a Danish specialist consultancy.

Based on the model, this report presents a fact-based, technical bottom-up analysis of how Europe's energy system could be shaped towards 2050. The purpose is – independent of political ambitions – to show how an affordable, resilient, and clean integrated European energy system could look by 2050. Using a scenario-based approach, the report illustrates different strategic directions rather than focusing solely on long-term political goals and ambitions.

Energy Model



2. A View to 2050: Three Scenarios

Looking ahead to 2050, the analysis provides a roadmap of where, how, and when to invest to achieve an optimal build-out that can deliver affordable, resilient, and clean energy. This work provides structured input to the debate on the future development of Europe's energy system, which is being shaped by a new political landscape, severely challenged by geopolitical circumstances.

This is reflected in initiatives such as the EU Clean Industrial Deal, the European Grids Package, and the RePowerEU Roadmap - initiatives in which European industrial competitiveness, affordable energy, and resilience are front and centre. The energy model used in this report is designed to provide a structured, data-driven basis for the investment choices required to get there, highlighting how a renewables-led system, enabled by infrastructure and flexibility, can strengthen both affordability and resilience over time.

This report seeks to shape the debate and help set the political direction for Europe's energy future.

CIP remains firmly committed to playing a leading role in building the energy system of tomorrow. We will continue to connect the world of capital with the world of energy infrastructure at scale, mobilising investment to strengthen Europe's competitiveness and energy sovereignty, while providing affordable, resilient, and clean energy. By delivering attractive risk-adjusted returns for our investors and accelerating the build-out of critical infrastructure, we aim to drive sustainable growth, local value creation, and long-term prosperity across Europe.

How to read the results: three scenarios to 2050

The analysis is structured around three scenarios, each defined by a specific set of assumptions regarding policy ambition, investment momentum, and structural constraints. These assumptions are embedded in the model, which then generates differentiated outcomes.

Three scenarios for Europe's future energy system

A model-based approach using three scenarios for Europe's energy system

01

Competitive & Resilient

In the Competitive & Resilient scenario, Europe follows a balanced transition path with direct electrification of household heating/cooling and road transport, while relevant energy-intensive industries are decarbonised by bio- or e-fuel alternatives, which are prioritised where economically viable. Dependence on fossil energy imports is significantly reduced, while a clean transition is delivered across most of the energy system, except in sectors with the highest CO2 abatement costs.

02

Slow Transition

In the Slow Transition scenario, structural change is limited, transition progress is constrained, and investment slows, reflecting that the status quo is largely maintained. Reduced direct electrification of both households and industries results in a European energy system that remains dependent on fossil fuels and energy imports, leading to higher energy prices for European consumers and industry.

03

Net Zero

In the Net Zero scenario, rapid, comprehensive, and centrally driven decarbonisation of the energy system is prioritised over shorter-term political and societal challenges. This includes addressing the difficulty of socialising this pace of transition with society, and prioritising energy spending over other government priorities. Ambitious political clean energy targets drive a fully decarbonised energy sector, including energy-intensive industrial sectors. Europe becomes fully energy independent and reaches net zero emissions by 2050 through rapid deployment of clean energy and infrastructure.

The three scenarios, along with their underlying assumptions and implications, are explored in detail in later chapters of this report.

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2.1

What Could the Future Look Like?

To understand the strategic choices facing the design of Europe's energy system, this report explores three distinct energy scenarios based on different assumptions about policy ambition, and market development.

These scenarios are not forecasts. Rather, they are potential directions that illustrate how Europe's energy system could evolve under alternative strategic priorities, including what requirements it places on technology deployment, and what this implies for affordability, resilience, and clean energy outcomes.

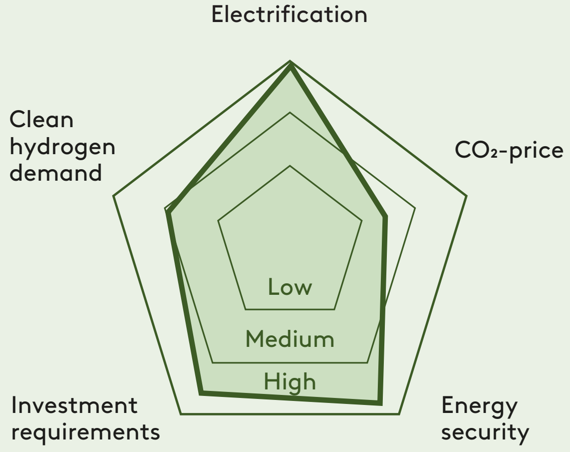
Together, the scenarios span a range of possible strategic directions. From a transition focused on competitiveness and resilience to a slower transition characterised by continued constraints and delayed investment, and finally to an ambitious net-zero scenario driven by high decarbonisation targets and rapid infrastructure deployment. In the slow-transition case, permitting timelines remain long, grid and connection capacity lag demand, supply chains stay tight, and financing uncertainty limits delivery. Across all scenarios, investment in new renewable energy generation and energy grids must increase to historic levels, though the scale and speed vary between scenarios. Across all scenarios, investment in new renewable energy generation and energy grids must increase to historic levels, though the scale and speed vary between scenarios.

By comparing these scenarios, the analysis highlights the trade-offs inherent in different approaches to the energy transition, and provides a structured basis for assessing their economic and system-wide implications.

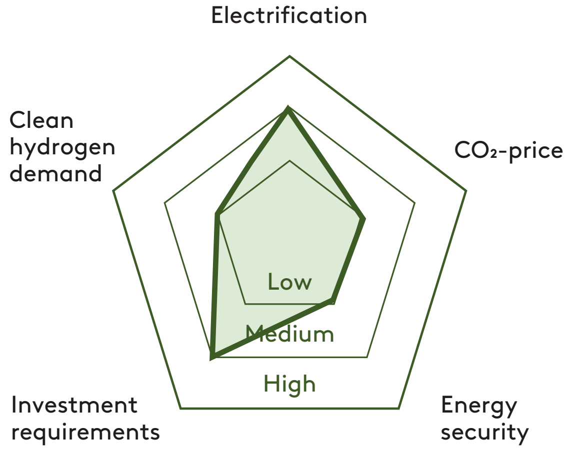
See the appendices in Section 7 for. detailed overview of the different characteristics between the three scenarios on final energy demand, electrification rate, CO2-price and clean hydrogen demand.

The focus of this report

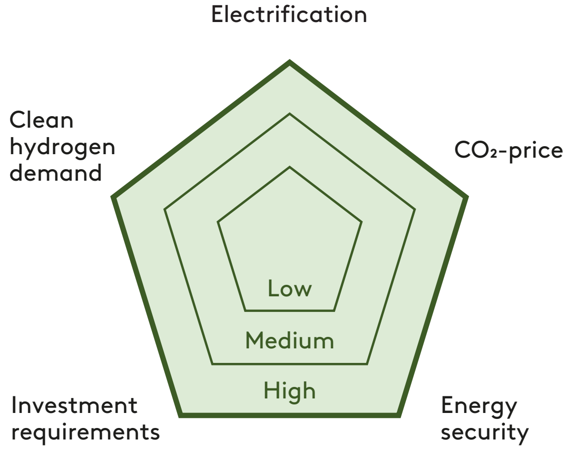
Competitive & Resilient



Slow Transition



Net Zero



2.1.1 Competitive & Resilient

The Competitive & Resilient scenario represents a more balanced approach to the energy transition. In this scenario, Europe delivers on affordability, resilience, and clean energy through targeted investment and enabling policy frameworks. It builds on pragmatic assumptions about technologies at scale, cost developments, and industrial competitiveness.

Electrification advances quickly and across most sectors including road transport and household heating/cooling. Decarbonisation focuses on sectors, and applications with the lowest CO_2 abatement costs such as energy efficiency and electrification. Meanwhile sectors facing very high CO2 abatement costs – such as parts of aviation, peak-load generation and some energy-intensive industrial processes – remain reliant on fossil fuels also in the medium term.

At the system level, investments are directed towards expanding new, homegrown energy generation, strengthening electricity grids and interconnectors, and developing system flexibility solutions that support robustness and stability. Dependence on fossil energy imports is reduced, which improves energy security and resilience, and avoids excessive short-term cost increases for European households and industries. Even though this is a balanced approach, the trade-offs are distributed more evenly between cost to consumers and ambition on pace of deployment of clean energy. This scenario requires significant political support as the pace of systemic evolution in the energy transition can only be achieved with centralisation of decisions.

This scenario illustrates how a well-coordinated energy transition can support European industrial competitiveness and energy resilience. There are different ways to achieve such coordination. It could require detailed planning (e.g. specific incentives) as often suggested by governments and transmission system operators, or be an outcome of a market-based solution (e.g. uniform and strict CO2 taxation).

By aligning energy infrastructure deployment with demand growth and technology maturity, the Competitive & Resilient scenario delivers emissions reductions while maintaining the cornerstones of energy affordability and system reliability. While it delivers large scale decarbonisation, it does not assume full net zero across all segments by 2050, reflecting a pragmatic approach to energy-intensive industry. Delivering this scenario nevertheless requires sustained, large-scale investment in clean generation and enabling infrastructure – in particular grids and flexibility – over multiple decades. It highlights the importance of sequencing, political prioritisation, and stable regulatory frameworks to increase investor confidence, to achieve a cost-competitive and resilient energy transition.

2.1.2 Slow Transition

The Slow Transition scenario reflects a future where progress in the energy transition is constrained by limited political ambition or ability, low investment levels, and persistent structural bottlenecks in new homegrown energy generation deployment.

In this scenario, EU emissions targets are not adequately addressed, postponed or cancelled. Similarly, CO_2 pricing remains broadly in line with historical averages. In essence, this scenario maintains the status quo. Electrification advances slowly, thereby failing to electrify cost-competitive solutions and many energy-intensive sectors, which continue to rely on fossil-based solutions.

As a result, the build-out of new homegrown energy solutions proceeds at a reduced speed which delays the energy transition and continues the reliance on fossil fuel imports.

Infrastructure development, including interconnections, distribution and transmission grids and system flexibility solutions, lag behind overall system needs, limiting the integration of intermittent new energy generation.

From a system perspective, this scenario results in lower near-term investment requirements but higher long-term, structural system costs due to a less optimised and less electrified energy system. Continued exposure to volatile global fossil fuel prices and dependence on external supply risks undermining resilience, while slower decarbonisation increases the likelihood of not attaining European climate objectives. The Slow Transition scenario illustrates the risks associated with delayed policy action and insufficient coordination across policy, markets, and infrastructure.

2.1.3 Net Zero

The Net Zero scenario reflects a direction where accelerated clean energy deployment and supporting regulatory frameworks drive rapid electrification and large-scale deployment of energy infrastructure across Europe. This scenario assumes strong and sustained policy commitment and high CO_2 pricing.

In the Net Zero scenario, the EU reaches net zero emissions by 2050 as a result of mandated fossil fuel restriction and significantly higher carbon prices.

Electrification advances rapidly and in line with the Competitive & Resilient scenario. However, decarbonisation is pursued across all sectors, leading to a substantial increase in the use of clean fuels such as biofuels, hydrogen, and hydrogen derivatives across energy-intensive industries, including shipping and aviation. Clean hydrogen also plays a key role in balancing the power system and supplying peak-load electricity generation.

All of this leads to a rapid expansion of homegrown renewable energy generation capacity, electricity networks, and supporting infrastructure. The energy system becomes fully energy independent, with fossil fuels largely phased out.

While this scenario delivers the fastest emissions reductions and the highest level of energy independence, it also requires very high upfront investments. It requires the highest degree of central control of the energy system build-out among the three scenarios and places significant demands on supply chains, permitting processes, and system integration. The Net Zero scenario illustrates both the potential and the challenges associated with pursuing maximum ambition at maximum speed.

FACTS

Energy system flexibility is the ability to efficiently integrate variable wind and solar production. The need for flexibility will increase in both the short-term (seconds) and the long-term (hours and days). Flexibility can be delivered from supply, storage, and demand resources. On the supply side, different types of gas turbines, including CCGTs, provide important back-up resource during prolonged periods of low renewable output. Different types of demand side flexibility are important in both short-term and long-term circumstances. For example:

- Electric heating/cooling in combination with thermal storage can increase electricity consumption when power prices are low
- Smart EV charging and Green Hydrogen production facilities have the same function and have the potential to be the main suppliers of flexibility as we look towards 2050. Green Hydrogen thus acts as a flexible agent for indirect electrification of energy intensive industries.
- Batteries (BESS) can store electricity for hours to smooth peaks and relieve grid congestion thereby potentially save grid investments and act as "grid boosters".

Together, these solutions reduce system costs, limit clean energy curtailment, and reduce the need for new grid build-out.

2.2 A Likely Pathway for Europe: Competitive & Resilient

While the three scenarios illustrate distinct strategic directions for Europe's energy transition, current policy signals, investment patterns, and technology readiness suggest that Europe is most likely to evolve along a scenario broadly aligned with the Competitive & Resilient scenario. This reflects a continued emphasis on balancing affordability, resilience, and decarbonisation, rather than prioritising a single objective in isolation. It is closely aligned with the European Competitiveness Compass (2025), the European Clean Industrial Deal (2025), and the European Grids Package (2025), all building on Mario Draghi's report on European Competitiveness (2024).

This likely trajectory is characterised by targeted electrification, phased infrastructure deployment, and a pragmatic approach to decarbonisation. Investments are directed towards technologies and sectors that are rapidly deployable, cost-competitive, and scalable. At the same time, structural constraints such as ageing grids, permitting timelines, and supply chain considerations are at risk of limiting the pace of transformation in certain parts of the energy system.

Importantly, this does not rule out periods of faster or slower progress, or higher ambition in specific sectors or countries. Rather, it describes an energy transition shaped by the policy and regulatory changes needed to remove barriers, scale deployment, strengthen investment, and preserve industrial competitiveness and system stability.

As such, the Competitive & Resilient scenario provides a relevant and reliable reference for assessing near- and medium-term decisions, and what Europe's energy system could look like if current policy direction and investment momentum are sustained or slightly increased. Meanwhile the Slow Transition and Net Zero scenarios serve as important reference cases in highlighting the risks of delayed action and the challenges associated with pursuing maximum ambition at maximum speed.

The next chapter will translate the Competitive & Resilient scenario into concrete system outcomes. It will describe how energy demand, supply, infrastructure, costs and price levels, resilience and CO_2 emissions will evolve towards 2050. Before focusing on individual technologies in isolation, this section presents an integrated picture of the future European energy system and the structural shifts that underpin it.

3.

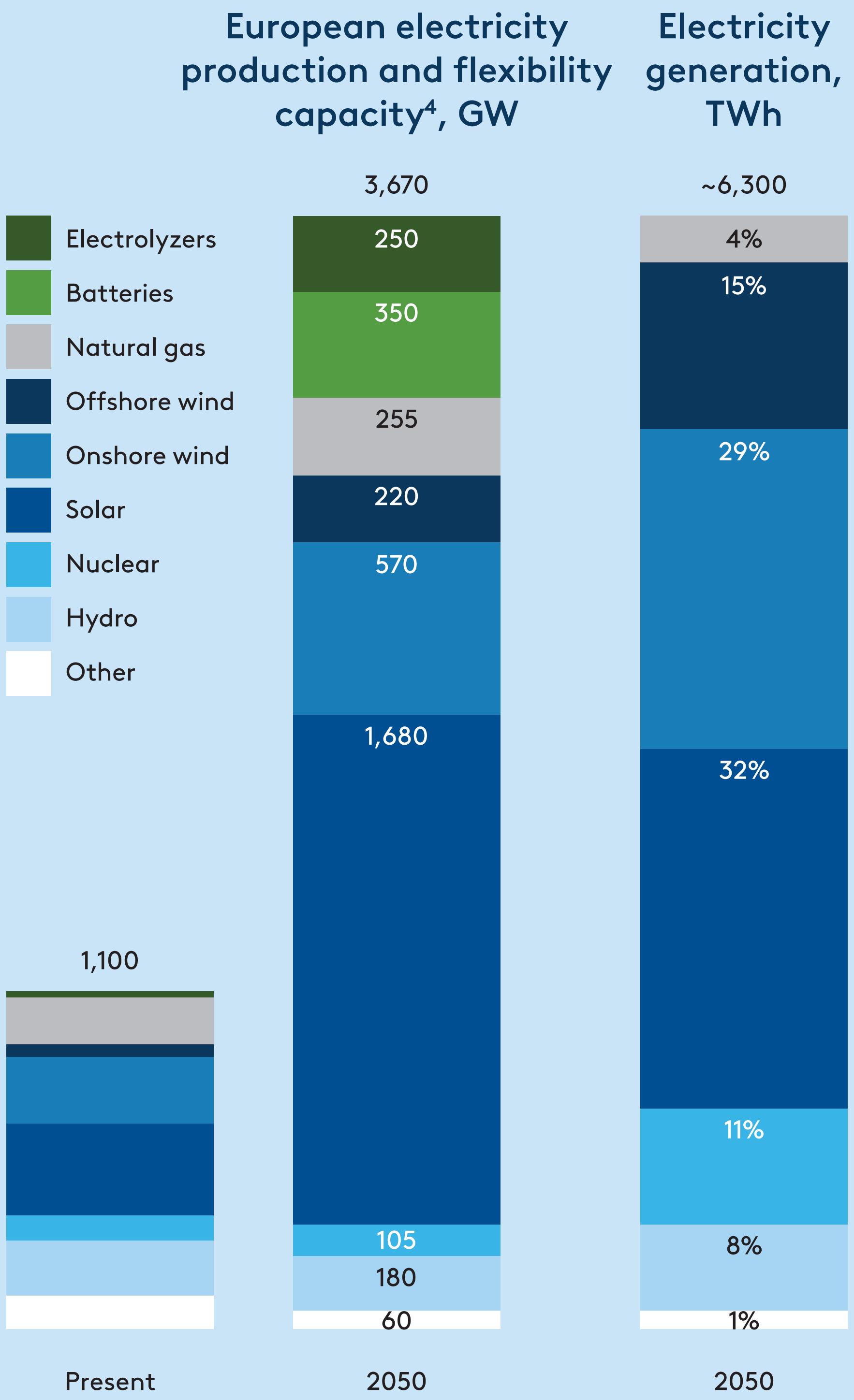
A Competitive and Resilient Energy System

Economically optimised electricity build-out from our energy model

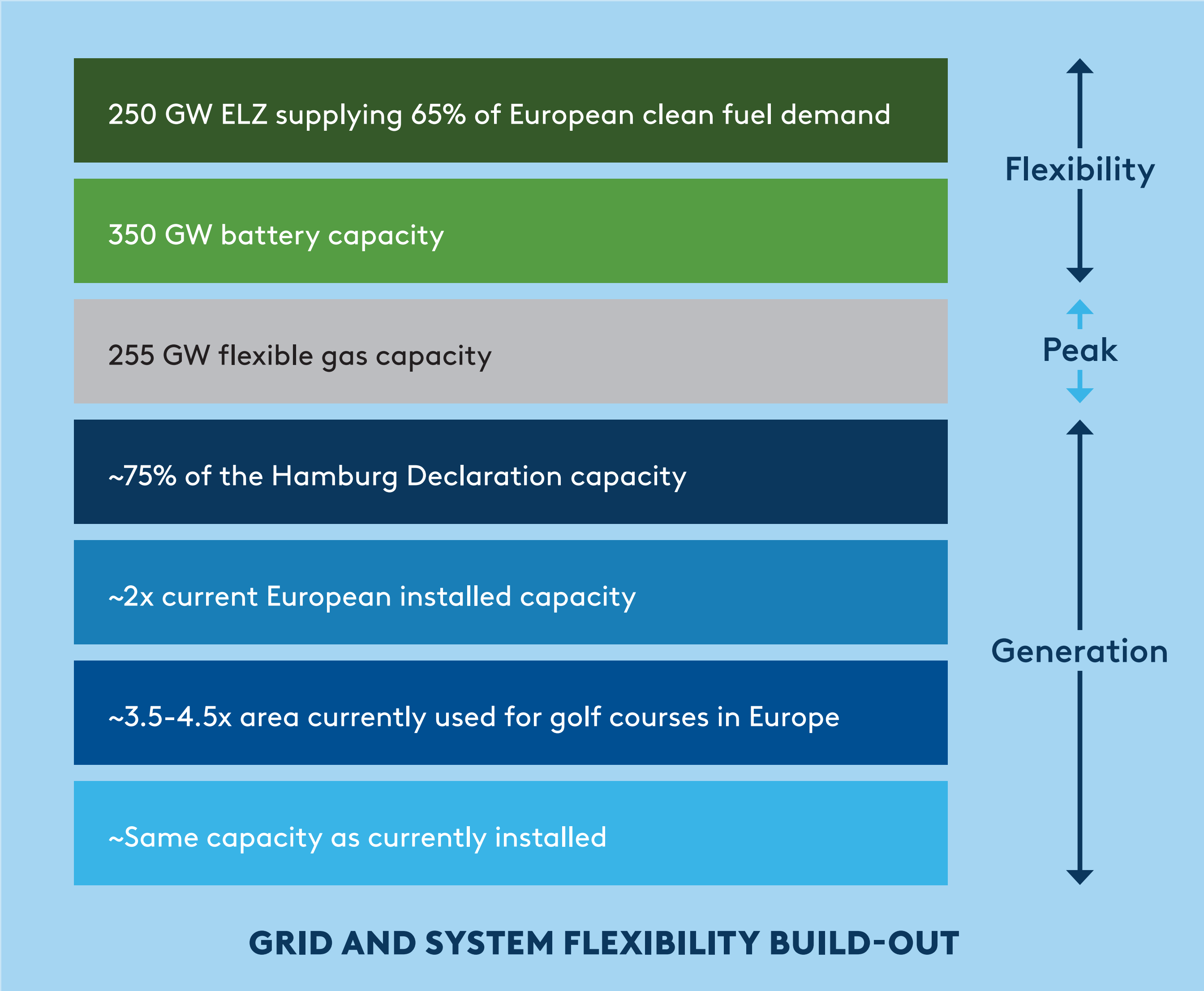
A renewables-led system can deliver affordability, security and resilience simultaneously.

Europe can by 2050 build a competitive and resilient electricity system through an economically optimised mix of generation and flexibility. The electricity system becomes renewables-led, with wind and solar accounting for more than 90% of installed capacity and nearly 80% of power generation, while fossil generation constituting less than 5% of total generation - and shifts from baseload to backup, ensuring system reliability at low cost.

Wind and solar dominate power production, supplying the majority of electricity. Offshore wind reaches ~220 GW, onshore wind roughly doubles from today's levels, and solar expands to around 1,700 GW but within realistic land-use and capacity constraints. Batteries and gas peakers provide system stability, while nuclear and hydro provide stable baseload.



A renewable-led energy system



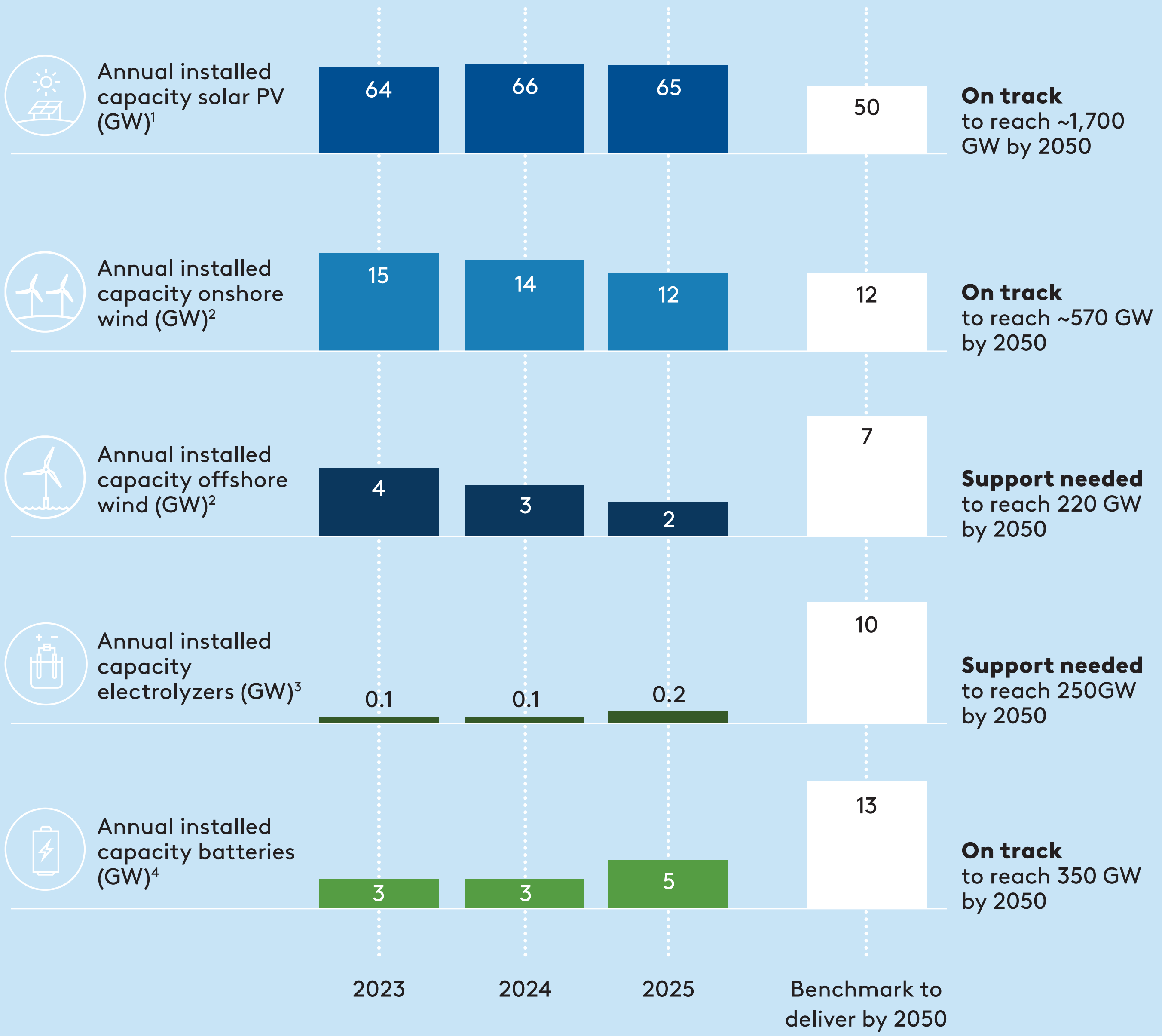
Important Information: The model-based insights presented are based on historical data and current market trends and are intended for informational purposes only. They should not be construed as financial advice or a guarantee of future market performance.

Notes: 1) 2022-real prices, 2) Eurostat 2019, May 2025, 3) Increased forestation, DACC, biochar etc. 4) Values rounded to the nearest multiple of 5; 5) FLH = Full load hours

Sources: EA Energianalyse, IEA World Energy Outlook 2024

3.1 What is Happening in the Real World

Status of the build-out of new energy sources and flexibility



Notes: 1) Solar PV capacity is from SolarPowerEurope 2025 report; 2) Onshore wind and offshore wind is from WindEurope H1 2025 report, with H2 installations expected to be like H1; 3) Electrolyzer capacity is based on Clean Hydrogen Monitor, Hydrogen Europe; 4) Battery capacity is based on Wood Mackenzie Energy Storage Forecast; 5) EU generation data is from European Electricity Review 2026 by Ember.

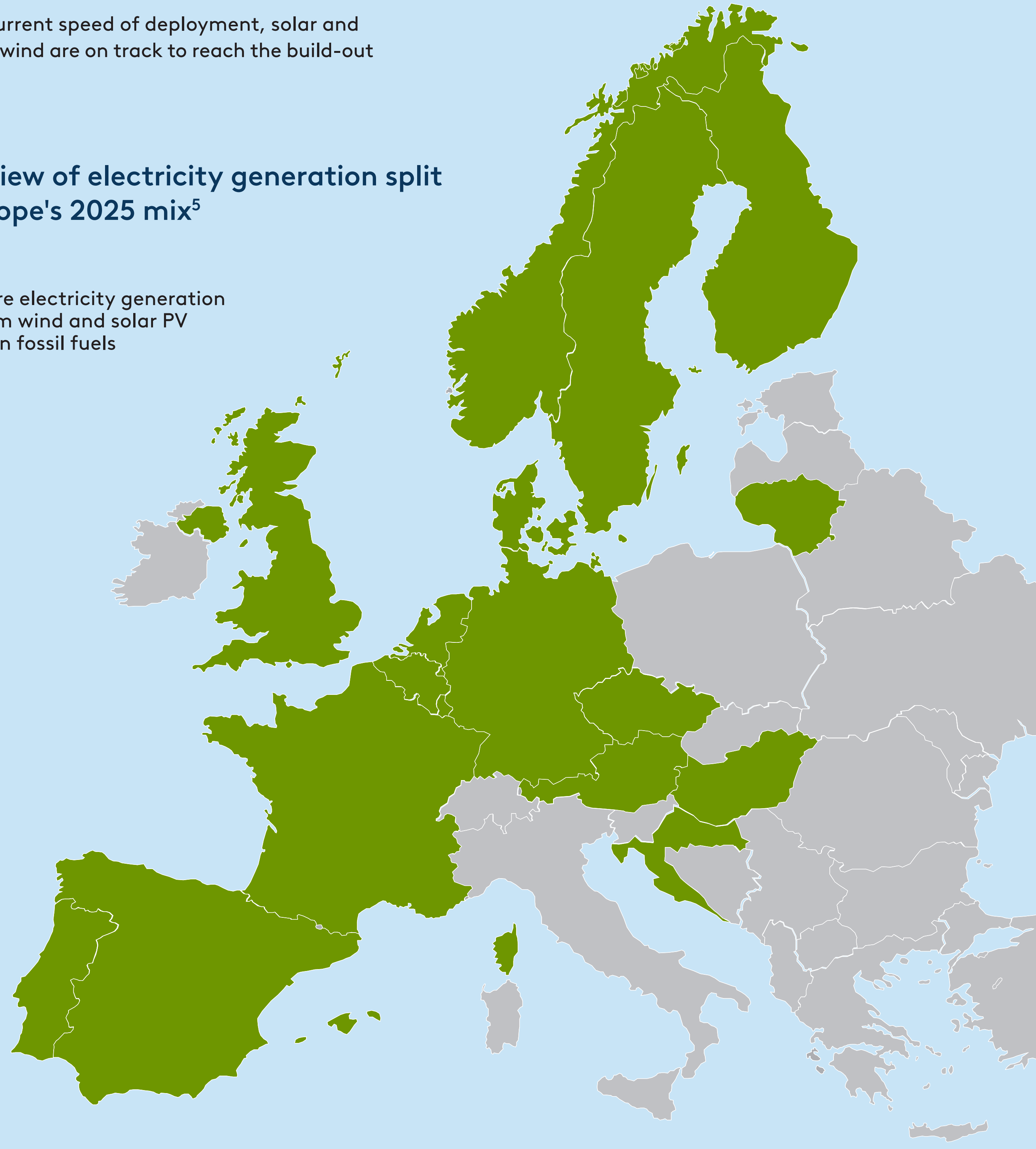
Wind and solar has surpassed fossil fuels in Europe's 2025 electricity mix for the first time

The energy transition is already reshaping Europe's power system. Over the past three years, Europe has deployed renewables, particularly onshore wind and solar, at an unprecedented scale. As a result, wind and solar surpassed fossil fuels for electricity generation in Europe for the first time in 2025.

At the current speed of deployment, solar and onshore wind are on track to reach the build-out required by 2050 for a competitive, resilient and clean power system. Battery capacity is also scaling rapidly, driven by steep cost reductions. Offshore wind and electrolysers are expanding but require additional support to reach long-term ambitions.

Overview of electricity generation split in Europe's 2025 mix[5]

More electricity generation from wind and solar PV than fossil fuels



3.2

Two Important Model Drivers

Europe's energy transition is shaped by a triple challenge: delivering affordable energy, strengthening resilience and independence of the energy system, and achieving clean energy at scale.

The model results presented in this chapter describe what Europe's energy system could look like in 2050, including the benefits to affordability, resilience and clean energy that could be unlocked if the Competitive & Resilient scenario is followed.

In this system, electrification is the primary driver of change. It reshapes demand, reduces conversion losses, and makes electricity the dominant energy carrier across sectors. This generational shift in energy sources can only be enabled by sustained investment in energy infrastructure and renewables. Without faster expansion of grids, flexibility, and clean generation, the system cannot achieve the affordability, resilience, and emissions outcomes shown in the model. The shift in the energy system ultimately causes a shift in the cost structure of Europe's energy supply: from a fuel-driven cost base (with high and volatile import costs) towards an infrastructure-driven cost base (with higher capex but lower and more stable operating costs over time).

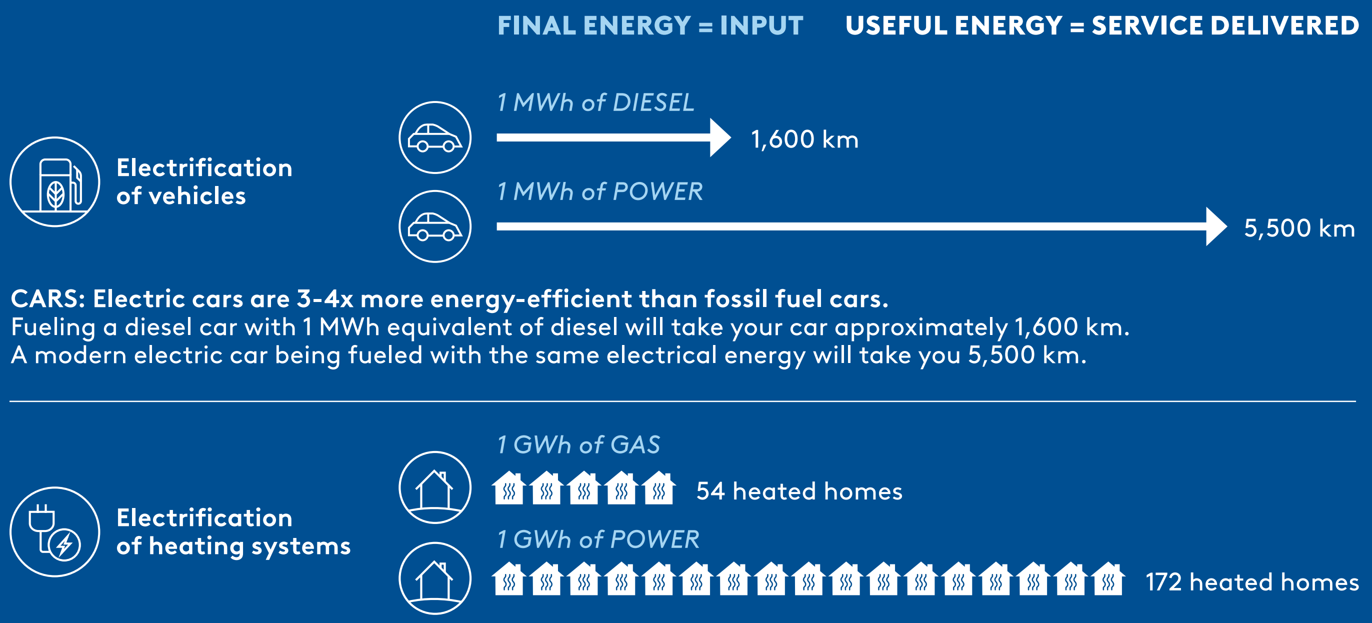
The following sections therefore presents the system-level outcomes for the European energy system in 2050 structured around the triple challenge, while keeping electrification and infrastructure investment as the core drivers and enablers that underpin the transition.

1 Cost Competitive Energy from Renewables

	Cost of Energy European LCOE benchmarks, EUR/MWh[1]	Time to Market Lead time of selected technologies[2], years
Solar	40 – 75	2-4 years
Onshore wind	45 – 110	2-4 years
Offshore wind[4]	70 – 110	4-7 years
Coal	190 – 210	8-10 years
Gas	165 – 325	8-11 years
Nuclear	100 – 400 (SMR[3])	9-12 years

1) LCOE = levelised cost of electricity. Source Balmorel energy model based on DEA Energikatalog. Difference in upper and lower range is based on change in FLH compared to model area geography e.g. ONW capacity factor of 30%-40%.
2) CIP analysis based on Power Engineering 2025, IEA Energy Technology Perspectives 2023, S&P Global 2025, Carbon Brief 2024.
3) SMR numbers are for 2035 based on Danish Energy Agency 2026 analysis. Nuclear 100 EUR/MWh based on Swedish public estimates – higher LCOE estimates of up to 400 EUR/MWh presented by Fraunhofer
4) 10-year anticipated reduction of OFW LCOE by 30% according to the Hamburg Declaration, January 2026.

2 Electrification as a Driver for Reduced Energy Demand



CARS: Electric cars are 3-4x more energy-efficient than fossil fuel cars.
Fueling a diesel car with 1 MWh equivalent of diesel will take your car approximately 1,600 km.
A modern electric car being fueled with the same electrical energy will take you 5,500 km.

HOMES: Heat pumps deliver 3-5x more useful heat than gas boilers.
Heating an average European home requires 18,500 kWh of natural gas per year.
Heating the same house with a modern heat pump requires just 5,800 kWh of power per year.

Electrification as a Driver for Reduced Energy Demand

A defining outcome of the Competitive & Resilient scenario is that European industries and households consume less energy by 2050. Not because activity declines, but because the energy system becomes more efficient as electrification replaces fossil fuel combustion in end-use sectors. Where fossil systems lose large shares of **primary energy** in conversion and combustion, electrified end-use technologies deliver the same useful energy with **far lower primary energy input**.

The model results show that the increased efficiency materially reduces final energy consumption across the system by **38% towards 2050**. At the same time, the composition of final energy demand changes fundamentally, driven primarily by increased electrification across transport, buildings, and parts of industry which leads electricity demand to increase from **21% to 55% of final energy demand by 2050**.

The model, however, does not assume full elimination of fossil energy in all sectors in the modelled 2050 system, as some applications remain difficult or costly to abate under the Competitive & Resilient assumptions.

As a result, fossil fuel consumption will decrease by 80% towards 2050 but will still constitute **20% of the final energy demand in 2050**. This development is reflected in the continued use of fossil fuel in selected energy-intensive applications. At the same time, the model results show that Europe's reliance on imported energy declines materially towards 2050, with fossil imports accounting only for around **~10%** of primary energy demand in 2050.

The shift from fossil fuel combustion to electrification is therefore central to why the Competitive & Resilient scenario can deliver affordability, resilience and decarbonisation simultaneously. Electrification reduces conversion losses, which means that fewer units of primary energy are needed to deliver the same energy services. This lowers overall fuel demand and reduces the need for imported energy, and limits Europe's exposure to volatile global commodity markets and geopolitical supply risks. Meanwhile, a higher share of electricity makes it possible to integrate renewables at scale and substitute fuel costs with upfront infrastructure investment – supporting a more stable and lower-cost energy system – also under the merit order market.

The merit order confirms that the marginal cost of electricity sets the price for all supply. In this design, natural gas still acts as a price-setting technology in which renewables benefit from a higher power price.

At the same time, electrification shifts demand towards electricity, increasing power consumption even as total final energy demand declines. As electric vehicles replace internal combustion engines, heat pumps replace fossil heating, and electrification expands in industry where it is economically viable, electricity becomes the central carrier in the energy system. The model results project that electricity demand grows substantially: Europe will require **~6,300 TWh of power in 2050** in this scenario compared to today's demand of ~2,900TWh This level of electricity consumption is consistent with the broader structural shift in final energy composition described above, where electricity becomes the dominant end-use energy carrier.

A key implication is that Europe's future energy system becomes, in practice, an electricity-led system. This makes electricity generation, transmission capacity, and system flexibility not just important, but system-defining.

Resilience as the outcome of reduced fossil dependency and stronger security of supply

This scenario also strengthens resilience by reducing Europe's dependency on imported fossil fuels. Today's system is structurally exposed: Europe currently imports fossil fuels amounting to **approx. 40% of primary energy demand**, at an estimated cost of **EUR ~250 billion per year**.

Under this scenario, the model results indicate a significant decline in fossil import dependency. By 2050, fossil import dependency declines to **~10%,** reflecting the combined effects of electrification, renewables build-out, and reduced fossil demand. In addition, fossil fuel imports are reduced by **~80% by 2050** compared to the present. The model results also recognise that some energy carriers may still be imported, particularly clean fuels for certain energy-intensive applications where Europe is not necessarily the lowest-cost production region. This is an economic rather than structural dependency: the same fuels could in principle be produced in Europe using clean technologies but at likely higher cost. The resilience improvement therefore comes primarily from reducing exposure to fossil fuel markets and geopolitical supply risk.

Affordability as an outcome of system design and a renewables-led supply

Because the scenario is optimised for competitiveness and system affordability, the model results indicate material reductions in power price levels by 2050. Notably, **the model results show that European households and industries could benefit from power prices that are around 40% lower than today's cost levels**, even taking into account the costs associated with building the underlying grid infrastructure. This decline is driven primarily by a reduction in the share of hours where natural gas is setting the price, from today's levels of 60% of the time.

This result is central to the "Competitive" element of the scenario: the energy system shifts from fossil fuel exposure towards domestically produced renewable electricity supported by infrastructure investment and system optimisations. As a result, Europe's industrial competitiveness is strengthened by lowering and stabilising power prices relative to other major economies such as the US and China, while not being able to close the gap completely.

FACTS

Industrial electrification:
Most energy demand can and should be directly electrified where feasible: buildings, light industry, digital infrastructure, low to mid-temperature heat, and much of transport offer mature, cost effective electrification scenarios.

By contrast, energy-intensive industries such as steel, chemicals, refining, cement, aviation and shipping face far more complex choices. Here, electrification often implies very high upfront capital expenditures (CAPEX), process redesign and reliance on still scaling technologies, with clean hydrogen remaining technically attractive despite higher system costs. For these sectors, the transition becomes a trade off between investing early in new electrified- or hydrogen-based processes or remaining molecule dependent and absorbing rising carbon costs.

Substantial emissions reductions towards 2050 as the outcome of clean energy

Finally, the Competitive & Resilient scenario delivers major emissions reductions through large-scale electrification and a predominantly renewables-based power system. **The model results show that gross emissions decline materially towards 2050 across scenarios**. In the Competitive & Resilient scenario specifically, the system stops short of full net zero by design, reflecting its balanced treatment of high-abatement-cost sectors and a pragmatic transition profile.

This is important framing: the scenario delivers a large structural emissions decline while maintaining affordability and system stability, but it does not assume the full, economy-wide decarbonisation measures required for net zero in every segment by 2050.

Renewables build-out as the enabler of an electricity-led system

On the supply side, the model outcome is a system dominated by clean energy sources and structured around large-scale renewable generation. The results show a system where renewable energy is the norm rather than the marginal contributor: in the optimal electricity mix in 2050 **new clean energy** accounts, for more than **90% of installed capacity,** with **nearly 80% of final electricity generation coming from solar and wind.** Delivering this scale requires a massive expansion of new power generation capacity. In the model results, Europe's system in 2050 relies on a total production capacity of **~3,100 GW** to supply the **~6,250 TWh** of electricity demand referenced above.

The results also point to the broad distribution of generation technologies underpinning the system. In the model's economically optimal capacity distribution, the scenario includes **~220 GW offshore wind**, **~570 GW onshore wind**, and **~1,680 GW solar PV** by 2050.

In relative terms, this corresponds to a steep expansion compared to today: offshore wind capacity increases sixfold, onshore wind doubles and solar quadruples. This deployment profile reinforces that the scenario's system design depends on sustained build-out over multiple decades, not a short-term surge alone.

Investments in energy infrastructure as the enabler of system integration and resilience

Generation capacity:
A renewables-based, electrified system requires more than generation capacity. As renewables become the dominant source of power, it requires the infrastructure to transport and integrate that energy reliably. Large-scale flexible solutions are required to manage variability and maintain energy system stability across Europe. For example, battery storage systems and modernised and expanded grids and transmission will be crucial.

The scenario implies that the generation build-out alone will result in sustained investment levels, amounting to year-on-year investment levels of around **EUR 85 billion on average towards 2050, totalling around EUR 2.1 trillion towards 2050.**

Grid infrastructure:
Additionally, Europe will need to accelerate investment in grid infrastructure at a scale of around **EUR 2.9 trillion** towards **2050**, corresponding to roughly **EUR 120 billion** per year, and hydrogen transmission of around **EUR 40 billion**, corresponding to approximately **EUR 1.6 billion** per year. These figures underscore that a Competitive & Resilient system is not achieved through marginal adjustments, but requires significant capital formation across decades. The figures also illustrate the magnitude of the importance in reducing system costs, integrating intermittent generation, and taking full advantage of times of peak load for system integration opportunities.

In aggregated terms, this competitive and resilient energy system will require unprecedented investment levels and new ways of mobilising private capital. Across power generation, system flexibility and grid infrastructure, Europe needs to invest EUR ~5.2 trillion over the next 25 years - equivalent to EUR ~210 million annually - to realise a competitive and resilient European energy system.

Policy Recommendations (1-3): Market design certainty and accelerated electrification

An essential priority for facilitating the transition to a competitive and resilient European energy system is to provide regulatory clarity on market design while at the same time creating incentives and eliminate regulatory barriers for electrification in all sectors. In some areas, new political actions are needed while in others, inspiration can be found in national legislation and decisions across Europe:

1. **Preserve robust electricity market design**
   Avoid reopening or weakening the fundamental principles of the European electricity market design. The existing marginal pricing model has proven effective in delivering efficient dispatch, strong cross-border integration and large-scale deployment of renewable energy. Recent price volatility reflects external fossil fuel shocks rather than structural market failures and should not justify distortive interventions. Measures that suppress price formation, subsidise fossil-based generation, or fragment the internal market risk undermining investment incentives precisely when unprecedented capital is needed for renewables, grids and flexibility. The priority should instead be the full and consistent implementation of the agreed 2023 electricity market reform, including strengthened frameworks for long-term contracts, which can enhance investment certainty while preserving efficient market-based price signals.
2. **Increased competitiveness of electricity against fossil consumption**
   Increased fossil fuel taxation, as demonstrated by Sweden, or reduced electricity taxes, as adopted by Denmark, highlight the appeal of electricity as an energy source. Additionally, adjusting electricity and gas grid tariffs and incentivising flexibility for industrial consumers could further encourage the transition to cleaner energy sources. Denmark is also funding heavy-duty electrification by offering dedicated grants for electric trucks, encouraging a shift in commercial transport towards electricity.
3. **Incentivising household electrification**
   Targeted support and infrastructure development are key to expanding electric mobility and household heating/cooling. Norway, Denmark and Germany have lowered the upfront cost of electric vehicles (EVs) via tax incentives or VAT exemptions, making EVs more accessible. In addition to this, the Netherlands requires smart-charging capability in all new charging points, integrating EV charging into buildings and urban planning.

   Similarly, Denmark and Germany provide financial subsidies for installation of new electric heat pumps with high efficiency to replace household heating systems such as gas boilers and other fossil-based heating systems.

4.0 Technologies That Will Get Us There

The model results above describe how Europe's energy system could be structured in 2050. The chapters that follow explain how this system can be built in practice, by showing how key technologies and supporting system infrastructure, when deployed at scale and integrated effectively, contribute to affordable energy, a resilient energy system, and lower emissions.

In the Competitive & Resilient scenario, technologies create value in three distinct ways. First, in the production or transportation of large volumes of affordable energy, forming the backbone of supply and reducing exposure to volatile fossil fuel markets. Second, in lowering power costs and increasing transmission flexibility, allowing end-use sectors to electrify in a cost effective way and unlock efficiency gains that reduce final energy demand while maintaining competitiveness and welfare. Third, in providing system services and flexibility, ensuring that a renewables-led system remains reliable, resilient, and stable at all times.

The chapters that follow are structured to reflect this system logic. They focus on the core building blocks required to deliver a Competitive & Resilient European energy system: grids, offshore wind, batteries, hydrogen, CCS, and biomass. Each plays a distinct role in the system, either as a source of clean energy, as an enabler of direct and indirect electrification,as a system balancer or as a provider of flexibility. Crucially, their value is maximised only when they are deployed in a coordinated manner, aligned with infrastructure development, permitting and supply chain realities, as well as a market framework that rewards system contribution rather than individual technologies in isolation.

Onshore renewables, both onshore wind and solar PV, indisputably also play a distinct role in Europe's future energy system. In the model, these technologies are assumed to scale materially towards 2050 and form a core part of the modelled 2050 power system. In the Competitive & Resilient scenario, the energy system requires **~570 GW** of onshore wind and **~1,680 GW** of solar PV by 2050. Importantly, a large share of this expansion is assumed to be driven by continued cost competitiveness and market-based deployment, rather than by new, technology-specific subsidy schemes or policy frameworks. For this reason, the report will not explore these technologies in depth.

For each of the technology areas, the analysis will consistently address three questions:

- What is its role in the overall system, and why does it matter in this scenario?
- What do the model results imply in terms of scale, timing, and system contribution?
- What is needed to unlock full system value, including infrastructure requirements, regulatory enablers, and market design considerations?

This approach ensures that the technology discussion remains anchored in system needs and model outcomes, rather than technology preferences. It also makes explicit the conditions required for Europe to translate the Competitive & Resilient scenario into a functioning energy system by 2050, one that delivers affordable energy, strengthens resilience, and reduces emissions at scale.

4.1 Grids

Grid infrastructure enables the transmission and distribution of electricity, and forms the backbone of a resilient, affordable, and clean European energy system.

As Europe accelerates the build-out of intermittent electricity generation, the ability to move electricity within countries, across regions and borders, and to end-use sectors and consumers efficiently and reliably becomes a defining condition for unlocking the benefits of the energy system.

Europe is successfully expanding wind and solar capacity, driving a rapid surge in new electricity generation on the continent. However, new electricity generation cannot deliver affordability or resilience without timely grid connections for new generation and end users, an efficient and resilient grid, and cross-border connection opportunities that optimise power flows.
In an intermittent energy system – based primarily on clean energy sources – grids are not simply a transport layer, but play a key role in system resilience and stability. As emphasised in the European Commission's Grids Package from December 2025, grids are an active system enabler that determines whether low-cost power can be utilised efficiently, electrification can scale, and the system remains stable under generation or consumption variability driven by weather changes, among other factors.

European grids are under pressure

Grid infrastructure is increasingly the binding constraint in the transition, and in many parts of Europe it already constitutes one of the most significant bottlenecks for renewables integration and electrification. The parallel growth of electrification and intermittent generation is placing unprecedented demands on aging European grids, with around 40% of distribution grids over 40 years old. This increases system vulnerability, reduces resilience, and reflects grid designs built for inflexible generation and demand patterns. Significant new grid build-out across Europe is required on top of modernising the existing networks. This is exacerbated by unprecedented supply chain constraints for all elements of the electrical system infrastructure. The EU estimates that 45% of cross-border electricity capacity needs will remain unaddressed by 2030. At best, this increases curtailment and power prices. At worst, it delays generation build-out and puts the societal benefits of an interconnected Europe at risk.

These dynamics imply a strategic conclusion: Europe's energy grids have been historically underfunded, responding to demand signals with short-term "lowest cost" solutions rather than future-proof anticipatory investments. They must now be expanded, upgraded and modernised at an unprecedented pace.

Such investment carries risk. It requires assumptions about future generation, demand patterns, and location, and some assets may end up underused. The scale of that risk is uncertain, but it can be reduced through integrated European energy system planning, particularly for new power generation. By contrast, continued underinvestment has clear and immediate financial and social costs. It slows electrification and decarbonisation, raises long-term system costs, weakens affordability and competitiveness, and leaves Europe more exposed to price volatility and external supply risks.

The costs of underinvesting in grids today are likely to be higher than the investment required to expand and strengthen the transmission and distribution system over the next decade. As an example, the costs from managing grid congestion across the EU in 2022, reached more than EUR 5 billion. The European Commission expects this cost to exceed EUR 26 billion by 2030. Investments in grid infrastructure can have an immediate and positive socioeconomic benefit by reducing grid charges linked to congestion, and spreading grid tariffs over a larger electrified consumption base, leading to a decrease in power prices for both consumers and businesses. Investments in energy infrastructure are estimated to generate cumulative savings of around twice the investment value through reduced congestion, re-dispatching and other system costs (2025-2040), and at EU level they are also estimated to generate between 1.0 and 2.9 times their value in Gross Value Added.

Transmission build-out as a system enabler and build-out of cross border interconnectors

The model results reinforce that an interconnected European power system is central to a cost-competitive and resilient energy transition. Cross-border transmission enables surplus renewable generation to be utilised across regions, reduces curtailment, smooths variability across weather systems, and lowers total system costs by reducing the need for redundant national back-up capacity.

Towards 2050, the model indicates a significant expansion of cross-bidding zone interconnector capacity. Total capacity increases from **~155 GW** to **~375 GW**, a rise of **~140%**. This build-out reflects where system integration delivers the greatest benefits and where large renewable volumes must be transported efficiently to centres of demand.

At a country level, the modelled interconnector build-out implies an increase in Germany from **65 GW** to **165 GW**, in the United Kingdom from **15 GW** to **60 GW**, in the Netherlands from **10 GW** to **60 GW**, and in France from **25 GW** to **40 GW**. For the rest of Europe, interconnector capacity increases from **40 GW** to **50 GW**. The associated cumulative CAPEX for new cross-bidding zone interconnectors is expected to reach approximately **EUR 105 billion** over **2025–2050**.

Massive investment gap need in energy grids

The interconnector expansion captured in the model is only one component of the broader grid challenge. The system-level requirement is first and foremost structural: Europe needs to accelerate investment in power infrastructure at a scale of around **EUR 2.9 trillion** towards **2050**, corresponding to roughly **EUR 120 billion** per year, to ensure that electrification, renewables deployment, and system integration can proceed in parallel. Cross-border links are part of the solution, but they do not substitute for the reinforcement of national transmission backbones and distribution grids that ultimately determine how much renewable electricity can be connected and delivered to consumers.

At the same time, Europe's transmission system operators (TSO) and distribution system operators (DSO) are expected to deliver unprecedented investment pipelines, increasing pressure on National Regulatory Agencies (NRA) to incentivise efficient CAPEX deployment while maintaining affordability and regulatory stability.

This also highlights a central cost implication. When transmission build-out lags behind generation and the increased demand from electrification, the system becomes more constrained and ultimately more expensive to operate. For example, renewables are curtailed, congestion increases, which results in higher-cost generation, meaning in many instances, natural gas sets prices more often.

Results further indicate that delays in grid expansion drive higher consumer electricity costs and increase in emissions subject to demand sector agility. Thus if grid delays cause a delay in clean energy build-out by two years, thereby slowing down the energy transition, would result in an additional consumer cost of **EUR 32-60 billion per year** (or **~8-10** EUR/MWh) and up to ~40% higher CO2-emissions. This reinforces the case for treating grid investment as a system enabler and not as a "nice-to-have" addition, and for prioritising timely delivery to avoid avoidable costs for European households and industry.

Hydrogen transmission as complementary infrastructure

In parallel with power grids, hydrogen infrastructure plays an increasingly important role, particularly for connecting production regions with demand centres such as energy-intensive countries like Germany. While electricity becomes the dominant energy carrier, hydrogen provides an additional route for sectors where direct electrification is difficult. At the same time, it can improve system flexibility and resilience if electrolysis capacity is localised strategically in areas with abundant electricity generation. This can reduce curtailment, lower system infrastructure costs, and improve energy affordability. Over long distances, hydrogen pipelines generally offer around 8-10 times lower transmission costs compared to High-Voltage-Direct-Current (HVDC).[5]

The model results indicate a substantial build-out of hydrogen transmission across Europe. Total pipeline capacity reaches approximately **~65 million tonnes per annum** (mtpa) by 2050, supported by cumulative investments of around **EUR 40 billion** from **2025–2050**, corresponding to approximately **EUR 1.6 billion annually**. The modelled network connects supply and demand through a set of corridors that support an integrated European hydrogen market, in line with the *Energy Highways* presented by the European Commission as part of its Grids Package from December 2025.

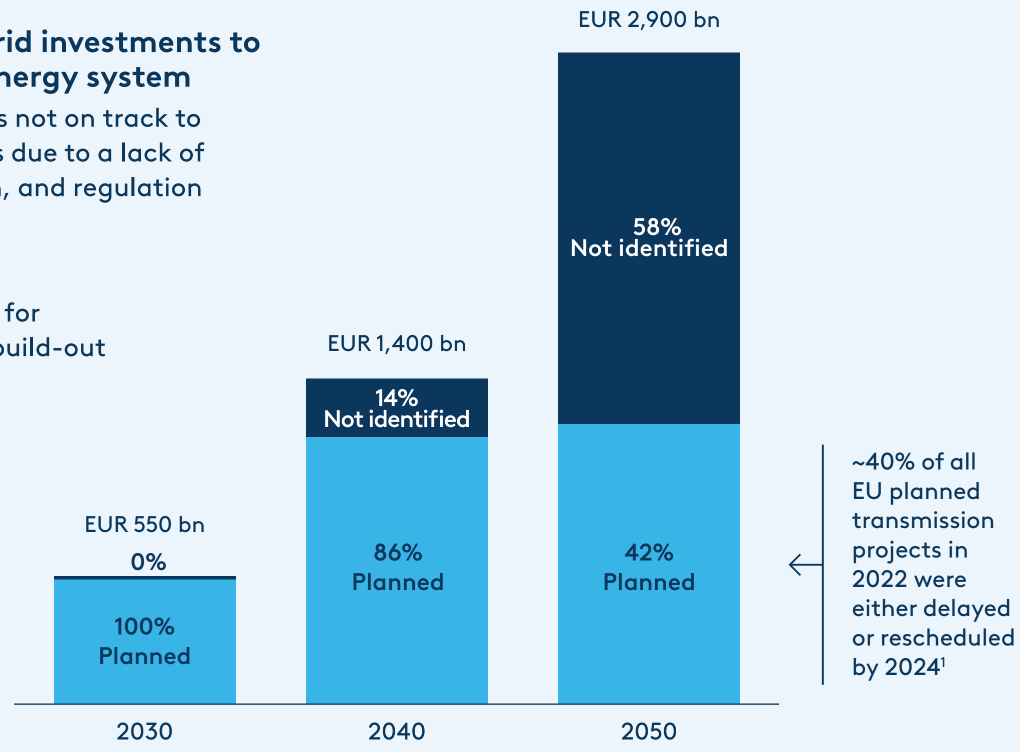
Notably, the model points to a particularly large build-out of hydrogen infrastructure in Germany. This is by far the largest across Europe, reflecting Germany's role as the main demand hub for hard-to-electrify industry and a central transit corridor that connects multiple cross-border pipelines into an integrated European hydrogen backbone. Selected pipeline capacities include Spain to France at **~7 mtpa**, France to Germany through Luxembourg and Belgium at **~4 mtpa**, France to the UK at **~6 mtpa**, the UK to the Netherlands at **~3 mtpa**, and Denmark to Germany at **~4 mtpa, meaning 2-3x the capacity already planned**. Additional corridors account for **~41 mtpa**, with internal build-out in Germany constituting **~21 mtpa** alone. As with electricity transmission, the value of hydrogen infrastructure is not limited to security of supply. A connected network can

5) Fraunhofer IEG, Techno economic comparison of HVDC lines and hydrogen pipelines, 2024.

Status of electricity grid investments to reach an integrated energy system

Electricity infrastructure is not on track to reach European ambitions due to a lack of funding, public opposition, and regulation

Overview of requirements for electricity infrastructure build-out towards 2050



Insufficient funding and ineffective financing models deemed key barriers to development[2]

Increased fiscal spending on other strategic priorities, such as defense, limits available budget for energy infrastructure

Private capital is required to address the missing funding for highly regulated infrastructure assets

1) ENTSO-E have made status showing 40% of projects from TYNDP2022 were either delayed or rescheduled;
2) 59% of stakeholders have listed this as a key barrier in public consultation for 'Grids Package'

also reduce system costs. It does so by enabling regional specialisation and avoiding the need for each country to build the full hydrogen value chain domestically at a scale that meets its demand. Without such integration, system costs would increase.

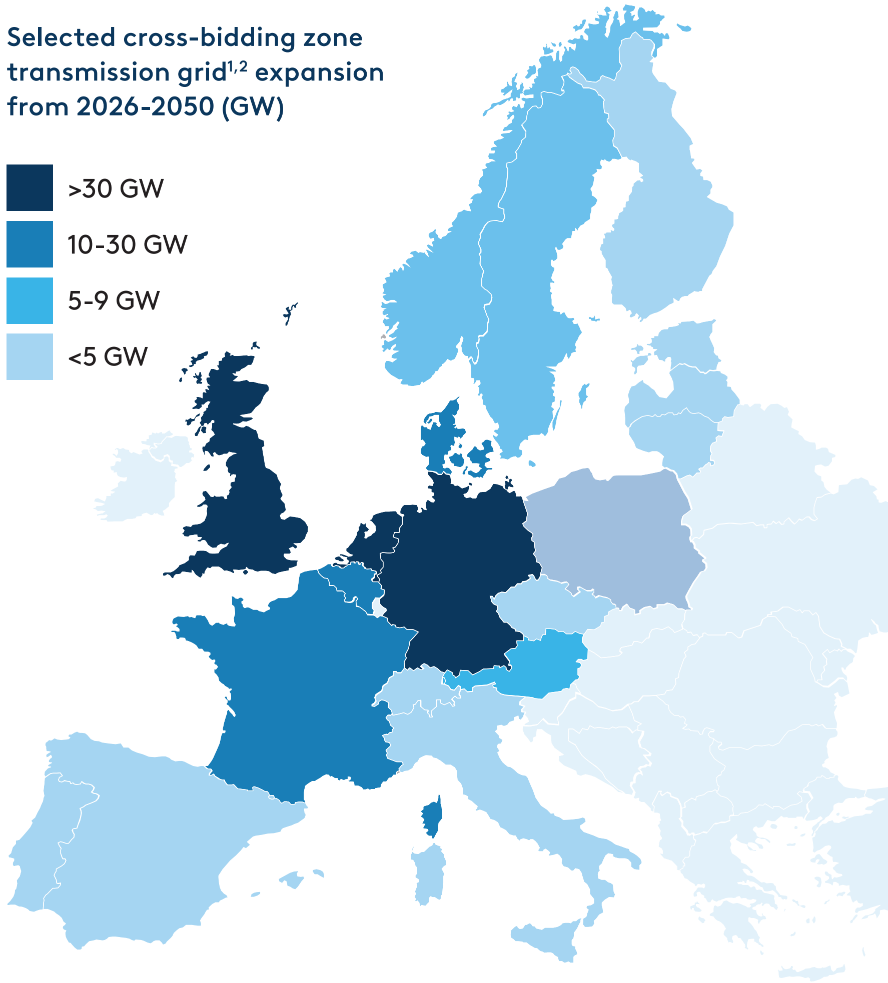
Capital structures and the emerging equity gap

While Europe's transmission system operators (TSOs) and distribution system operators (DSOs) differ widely in size, ownership models, and regulatory frameworks, several common features stand out in their capital structures. Historically, most have been highly successful in raising debt, benefitting from stable regulated revenues, strong credit profiles, and access to low-cost financing. This debt-heavy financing model has helped keep grid tariffs low and supported steady network expansion. However, as investment requirements accelerate, many TSOs and DSOs are now approaching structural leverage constraints. Balance sheets are becoming stretched, increasing the risk of credit rating pressure and, in turn, higher borrowing costs. This dynamic points to a growing need for new equity solutions rather than additional debt alone.

The challenge is compounded by ownership structures: many grid operators are wholly or partly owned by states or local municipalities that face competing demands on public capital – from defence and security to social spending – limiting their ability to inject fresh equity at the scale required. To date, the European Investment Bank (EIB) has played a critical role by providing roughly 40% of grid infrastructure financing through debt, reducing the cost of capital for the sector. Looking ahead, this share is unlikely to be sustainable given the magnitude of investment needed. Europe therefore faces a structural funding gap that cannot be closed by public balance sheets or public lenders alone.

Private capital has successfully financed Europe's infrastructure build-out for decades – across airports, roads, telecommunications, and power generation – when the right regulatory and risk-allocation frameworks have been in place. Mobilising similar pools of long-term private equity for grids will be essential to deliver the required expansion at pace, while preserving affordability and system resilience.

Selected cross-bidding zone transmission grid[1,2] expansion from 2026-2050 (GW)



	Interconnector build-out (2025-2050)			Interconnector CAPEX investments (2025-2050)
Germany	65 GW	+155%	165 GW	EUR ~40 bn
United Kingdom	15 GW	+300%	60 GW	EUR ~30 bn
Netherlands	10 GW	+500%	60 GW	EUR ~25 bn
France	25 GW	+60%	40 GW	EUR ~5 bn
Rest	40 GW	+25%	50 GW	EUR ~5 bn
Total	155 GW	+140%	375 GW	**EUR ~105 bn**

Not included;

1. Internal bidding zone transmission investments
2. Distribution system investments
3. Re-investment into existing grid
4. Digitalization of grid

Notes: 1) The total transmission is the sum of all links in and out of the country, the links transmission capacity is therefore included in both countries total; 2) Denmark, Sweden, Norway have multiple bidding zones. Germany currently has one bidding zone, however, it is considered to be split into more and split into four for the purpose of the model due to fundamental differences of the four zones.

Policy Recommendations (4-6): Unlock grid build-out at scale

Delivering the grid infrastructure required for a Competitive & Resilient European energy system will depend on policy and regulatory frameworks that enable faster build-out, as well as new financing models.

4. **Leverage private capital and knowhow to meet investment requirements:** The scale of investment required for grid infrastructure far exceeds what public budgets can provide and limitations on system operators can in many cases restrict their access to private markets. In addition, the implementation of new technologies and digitalisation have not historically been core to energy system developers and operators. Mobilising significantly more private capital and capabilities is therefore indispensable.

   However, private investment is structurally limited in many cases by state or municipal ownership of system operators. For others, regulated returns – which are set on a backwards-looking basis and do not take account of the current inflationary environment and true cost of capital – are insufficient to attract the necessary volumes of private capital on a long-term, risk-sharing basis. At the same time, private developers and investors must be involved at the planning and configuration stages in order to ensure techno-commercial optimisation and bankability.

5. **Public capital can enable innovative and catalytic capital instruments:** Catalytic capital instruments can provide a powerful solution to both the need for efficient public spending, and the imperative to attract private investment. By using public capital in forms such as guarantees or subordinated or patient equity – tools that also help reduce risk and enhance returns for private investors – governments can unlock significant volumes of private investment while achieving a financial return themselves. Such instruments can bridge energy cost affordability in the short- to mid-term, as they provide policy makers time to implement gradual increases to regulated returns. Among early adopters of these instruments is Germany, which launched the "Deutschlandfonds" in December 2025. This pioneering initiative targets, among others, the energy sector with financial instruments to crowd-in private capital. As such, it could serve as a blueprint – or at least an inspiration – for similar efforts across Europe.

6. **Anticipatory investments to proactively address congestion costs:** Investment in electricity grids must anticipate future demand rather than react to congestion. Operators should be incentivised to make anticipatory investments in areas where high-demand growth is expected to prevent future bottlenecks, speed up the build-out and optimise long-term network costs for end consumers. To increase visibility of such investments, it is crucial that European and national planning processes are aligned and updated in shorter cycles to cater for potential changes in expected demand and supply. Greater transparency of grid connection queues, replacing the "first-come-first-served" approach with prioritisation for projects ready to connect will also increase reliability of demand forecasts.

4.2 Batteries and System Flexibility

Europe's power system used to be based on large, centralised fossil generation. Power flows were mostly one-directional, and demand patterns were relatively predictable.

Europe is now moving towards a more integrated and decentralised system with higher shares of renewable generation, more variable output and more bidirectional flows. This shift can strengthen resilience over time, because it reduces exposure to imported fuels and spreads generation across more assets and locations. But it also raises the operational requirement for system stability.

Recent blackouts across Europe, including the Iberian blackout in April 2025, underline this point. These trends increase the need for solutions that can stabilise frequency, manage congestion, and provide back-up capacity that is well distributed across the region. Among these solutions, batteries stand out as a key flexibility resource. They absorb surplus renewable electricity when supply is high and release it when demand peaks or when transmission capacity becomes available, meaning when transmission congestion stops. This reduces curtailment, lowers system costs, and supports a faster and more reliable integration of renewables.

Flexibility scales to become system-defining by 2050

Model results indicate that by 2050, flexibility becomes a core system enabler alongside electricity grids and renewable generation. Batteries play a central role. In the Competitive & Resilient scenario, battery capacity increases from **~11 GW** today to **~60 GW** in **2030**, **~200 GW** in **2040**, and reaches **~350 GW** by **2050**.

Flexibility is provided by multiple technologies. In addition to batteries, the system includes **~260 GW** of natural gas CCGT capacity (including baseload, peaking plants, and gas-fired CHP), **~260 GW** of flexible industrial demand through electrolysers, and **~110-130 GW** of flexible demand from EV Charging. Batteries provide fast and scalable flexibility, while electrolysers, gas generation, and EV demand contribute to longer-duration balancing and system adequacy.

In addition, allowance of vehicle-to-grid (V2G) would add an additional ~870 GW of battery storage to the energy system by enabling electric vehicles to act as distributed energy storage, feeding electricity back to the grid during peak demand or high-load periods to improve stability and manage renewable energy fluctuations. This would further strengthen the resilience of the energy system and could also reduce requirements for transmission and distribution grid build out.

A small cost for a large resilience gain

Ensuring reliability and security of supply has a measurable but limited impact on system costs. The model shows that introducing reserve strategies to protect against infrastructure failure, sabotage, or extreme climate events increases average power prices by about **+0.8 EUR/MWh** in **2050**, roughly 1% of the projected European power price.

This resilience relies on two complementary reserve approaches. Geographically distributed capacity reserves provide back-up across countries, while dynamic reserves support balancing during periods of high renewable output. Together, they reduce the risk that local disruptions propagate across the system.

Batteries create the most value for fixing congestion and peak balancing

Batteries provide particularly high system value where renewable output is constrained by transmission capacity. In the United Kingdom, strong wind generation in the north can exceed the capacity of transmission lines to deliver electricity to demand centres in the south. Batteries can store electricity locally during periods of congestion and release it when transmission capacity becomes available, while also providing frequency response and peak balancing.

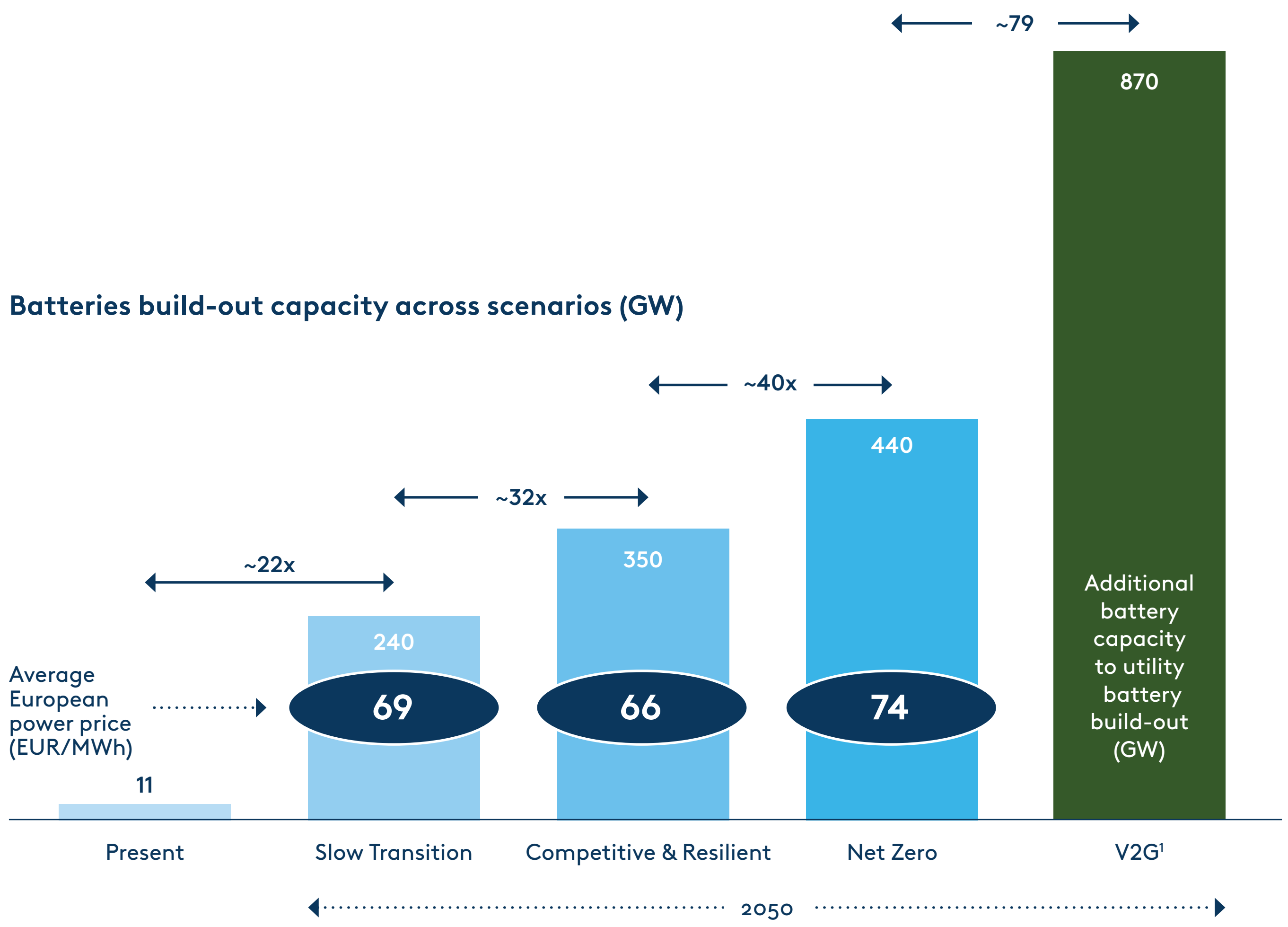
As renewable deployment increases, the system must also expand the assets that allow this generation to be used efficiently.

What holds deployment back: connection rules and market design

Despite strong growth in storage deployment, regulatory barriers remain. Grid connection rules and tariff structures in several markets require separate permits when storage is integrated into existing generation projects. This can delay projects and prevent the co-location of renewables and storage that would otherwise reduce congestion and improve system balancing.

Market design also affects investment. Batteries earn revenue from several services, including energy shifting, balancing and ancillary services, and in some markets capacity mechanisms. If these services are under-remunerated or uncertain, investment may fall short of system needs even when storage is cost-effective from a system perspective.

Batteries build-out capacity across scenarios (GW)



Notes: 1) V2G refers to EV batteries being used as distributed energy storage in the power system, charging and discharging similar to utility-scale battery storage systems.

Policy Recommendations (7-9):
Unlock faster battery deployment and higher system value

7. **Allow behind-the-meter storage to scale**
   Allow generation projects to install behind-the-meter storage without requiring additional approvals from TSOs or planning authorities. This increases local flexibility, improves the business case for renewables, and reduces congestion costs. A regulatory framework that recognises behind-the-meter storage as a flexibility lever can increase scalability of vehicle-to-grid (V2G) and ultimately increase overall system value.

8. **Fast-track grid import connections where storage delivers balancing value.**
   Introduce fast-tracked applications for separate grid import connections for storage assets where needed, and ensure that grid connections for batteries are unrestricted and do not impose operational limitations on charging or discharging. This strengthens system balancing, accelerates investment, and allows batteries to provide the full range of services the system requires as renewable penetration rises.

9. **Remove grid fees and charging costs that penalise battery storage.**
   Remove grid fees, double charging, and other network-related costs applied to batteries that distort market signals and undermine their flexibility value. Fair and consistent treatment of storage supports efficient dispatch, improves system utilisation, and enables batteries to contribute fully to congestion management and security of supply.

4.3 Offshore Wind

Offshore wind will continue to play a key role in supplying Europe with renewable electricity and in supporting the electrification of the European economy.

The model results suggest that even under stress from changes in technology costs, transmission build-out, or hydrogen assumptions, offshore wind remains both economically and systemically important, not least because of its favourable generation profile. Compared to onshore wind and solar, offshore wind combines a high-capacity factor with relatively stable output across seasons, making it a stabilising element in an electricity-based energy system.

In the Competitive & Resilient system this matters for two reasons. First, offshore wind provides large volumes of low marginal cost power that can support affordability. Second, it reduces exposure to weather volatility and strengthens system resilience when combined with grids, flexibility, and storage.

Robust build-out across model sensitivities

Despite recent steep increases in offshore wind costs – primarily due to global supply chain bottlenecks and geopolitical tensions – the model results indicate that offshore wind remains a core system component across a wide range of assumptions. Across the three scenarios, offshore wind capacity in 2050 spans a range of ~205-390 GW, illustrating that offshore wind build-out is robust compared to the capacity installed today. In the Competitive & Resilient scenario, the model points to an offshore wind build-out of ~220 GW by 2050, compared to a currently installed capacity of ~37 GW. While this is significantly lower than European political ambitions, it still represents a sixfold increase of today's capacity. However, under the tight economic assumptions of today's global offshore wind environment, such an expansion will be highly reliant on immediate action by policymakers to support a turnaround for the industry.

As renewable energy penetration grows, energy system planning needs to shift from focusing on the lowest unit cost, to recognising which technologies deliver the highest system value. Thus, as offshore wind may appear expensive on a unit basis (LCOE), it lowers system-wide costs by reducing storage and balancing needs, ultimately creating a more resilient energy system.

This should be read as a model-based allocation under the given assumptions, not as a political forecast. However, it provides useful political insights on where to prioritise cross-border collaboration and offshore wind build-out. Offshore wind build-out is strongly shaped by government targets, spatial planning, and cross-border initiatives that a dynamic optimisation model cannot fully anticipate. The Baltic Sea is a clear case in point. Today, the Baltic Sea has around **3 GW** of installed offshore wind capacity and additional 6 GW under construction. With announced projects such as the Danish–German Bornholm Energy Island – adding **3 GW** – the region could reach around **12 GW** by the mid-2030s, exceeding the model's base case output.

Moreover, political cooperation in the Baltic Sea region has accelerated in recent years (including the **2022 Marienborg Declaration** and **2023 Vilnius** commitments). If this momentum continues, the Baltic offshore build-out could exceed the model's baseline allocation towards 2050. In other words, the regional split is sensitive to political choices and coordinated infrastructure delivery, particularly for hybrid assets and cross-border grid integration. It could therefore shift under a more politically-driven "changing track" sensitivity.

This robustness reflects the systemic role offshore wind plays in a renewables-led power mix. When electricity demand expands materially towards 2050, the system requires scalable, high-yield renewable generation that can be deployed at a large scale and integrated efficiently. Offshore wind continues to fulfil that role. The model results show that even when key assumptions are subjected to stress – such as technology costs, the pace of transmission expansion, or hydrogen developments – offshore wind remains cost-effective and system-relevant, even if the modelled build-out falls short of political targets. The model also indicates that average European power prices are relatively stable across the three key scenarios, at **~66–75 EUR/MWh**, reinforcing that offshore wind build-out is linked to system cost efficiency rather than a single narrow set of assumptions.

Strong political momentum, with the North Sea as the anchor region

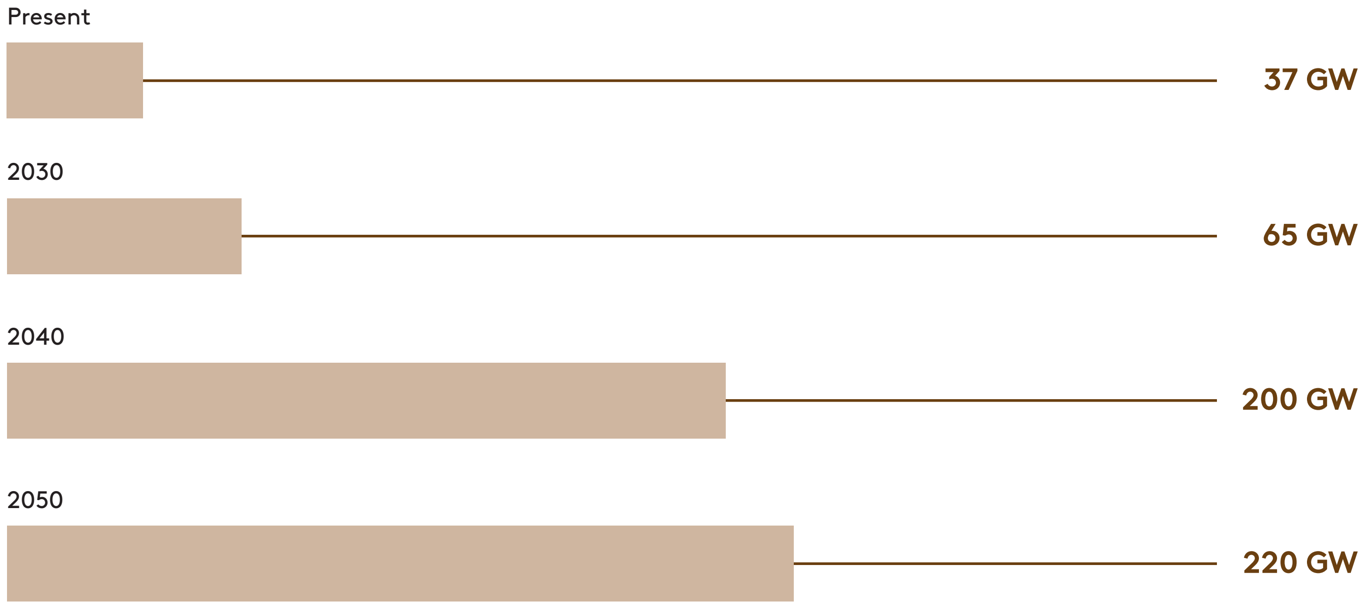
Political commitment to offshore wind remains strong. At the third North Sea Summit in January 2026, North Sea Heads of State and Government signed the Hamburg Declaration, reaffirming the collective ambition to reach at least 120 GW of offshore wind by 2030 and 300 GW by 2050. The declaration also places clear emphasis on leveraging 100 GW cooperation projects in the North Sea, such as energy hubs, hybrid interconnectors and cross-border infrastructure, with the first 20 GW cross-border cooperation projects to be implemented in the 2030s. These targets underscore a continued political commitment to advancing offshore wind as a foundation for European energy security, competitiveness, and decarbonisation.

FACTS

If the 2026 Hamburg Declaration's ambitions on offshore wind 30% LCOE decline combined with a stable build-out, pipelines becomes a reality, the model points to an increased offshore wind capacity towards 340 GW by 2050.

Offshore wind build-out capacity by 2050

Forecasted offshore wind power production capacity in GW



The North Sea offers a unique combination of strong wind resources, proximity to major demand centres, shallow-water development potential, and existing industrial and port infrastructure. It also provides ideal conditions to build a more integrated offshore electricity system that can support both large-scale generation and improved cross-border balancing of the energy system. In a future system, where renewable electricity becomes the dominant energy carrier, the ability to move offshore power efficiently into onshore grids and across borders becomes as important as the wind turbines themselves. Under these assumptions, the model points toward a significant build-out in the Danish part of the North Sea rather than further densifying the German zone, simply because this is the more system efficient outcome. Thus, cross-border cooperation and energy hubs are essential to achieving an affordable offshore wind build-out.

Offshore energy hubs as the next step in system integration

To achieve the significant level of offshore wind required over the coming decades necessary to strengthen Europe's energy resilience and industrial competitiveness, the current radial build-out approach will need to shift towards a meshed grid in the North Sea. In such a grid, energy can be transported to several countries at a time and sector coupling can take place.

Offshore energy hubs (OEHs) are essential to enable an interconnected offshore grid in the North Sea. This is also reflected by the model results where, 42% of offshore wind capacity in 2050 is hybrid projects amounting to ~93 GW of the installed offshore sites are connected to one or more foreign bidding zones, aligning closely with the Hamburg Declaration's 100 GW of so called "cooperation projects".

OEHs bring three key benefits to the energy system. First, they reduce offshore transmission build-out costs compared to radial connections through shared infrastructure and higher asset utilisation. Second, they increase flexibility of the energy system by enabling cost-efficient interconnection between countries. Third, they provide optionality to add electrolysers to combine power and hydrogen production from large-scale offshore wind and balance the energy system. OEHs are building blocks for cross-border offshore grids that connect national systems more efficiently than today and allow Europe to capture larger system benefits from offshore wind deployment.

Headwinds that require government action

Despite its central role and the continued political support, offshore wind currently faces significant headwinds. Cost inflation, higher financing costs, supply chain pressure, and auction design challenges have increased execution risk and weakened investability in many markets.

In several countries including the UK, Germany, the Netherlands, France, Lithuania and Denmark, failed auctions have revealed that volume targets alone are not sufficient if delivery frameworks do not provide credible risk allocation, predictable revenues, and timely permitting. If these constraints persist, they risk slowing build-out at a time when offshore wind needs to scale.

This is why government action is needed now as also highlighted in the Hamburg Declaration. Now is the time for action and implementation – not least at national level. The objective should be to restore bankability, create visibility on long-term volumes, and reduce delivery risk at the system level. Doing so can improve cost efficiency, strengthen supply chain investment incentives, and ensure the necessary scale is delivered within the required timeframe.

Policy Recommendations (10-12): Unlock offshore wind scaling and lowering costs

Delivering offshore wind at the scale required for a Competitive & Resilient energy system depends on stable frameworks that provide long-term visibility, reduce risk, and support industrialisation across the value chain.

10. **Provide clear visibility on volumes and auction timelines**
    Governments should ensure a stable and transparent tender pipeline for offshore wind. Clear visibility on future volumes and auction schedules allows developers, ports, and manufacturers to invest ahead of market demand, expand supply chain capacity, and reduce project and financing risks.

11. **Develop national implementation plans to deliver on the Hamburg Declaration**
    The joint government commitment to deploy 15 GW per year of new offshore wind from 2031 to 2040, as agreed in the Joint Offshore Wind Investment Pact from Hamburg, is a step in the right direction, but implementation at national level will require immediate political action. According to the pact, governments must deliver 10 GW supported by two-sided contracts-for-difference (CfDs) annually. In return, industry can deliver a 30% cost reduction through standardisation, industrialisation, and scaled supply chains, ultimately increasing system viability of offshore wind. Cross border coordination and "cooperation projects" are essential to ensure that these national frameworks actually fit together. This approach aligns public risk sharing with private delivery discipline and creates a bankable scenario for large-scale deployment.

12. **Strengthen investability through targeted flexibility and simplicity**
    Governments can further improve investment conditions by allowing contracts-for-difference (CfDs) to be combined with counter guarantees for corporate power-purchase agreement (PPAs), and by keeping the application of non-price criteria, resulting from implementation of the Net Zero Industry Act, simple, transparent, and consistent across countries, avoiding unnecessary complexity that could undermine auction outcomes. At the same time, governments must implement price indexation and realistic ceiling prices in auctions reflecting increases in input costs and changing market conditions impacted by macro changes.

4.4 Clean hydrogen

Without green (RFNBO) hydrogen, Europe cannot fully decarbonise energy-intensive industries, such as steel, chemicals, aviation, and shipping.

Direct electrification will remain the most efficient route wherever it is technically and economically viable. However, for parts of heavy industry and for several transport applications, clean molecules are required. Clean hydrogen therefore functions as a complementary decarbonisation lever in a future European energy system that is otherwise increasingly electrified.

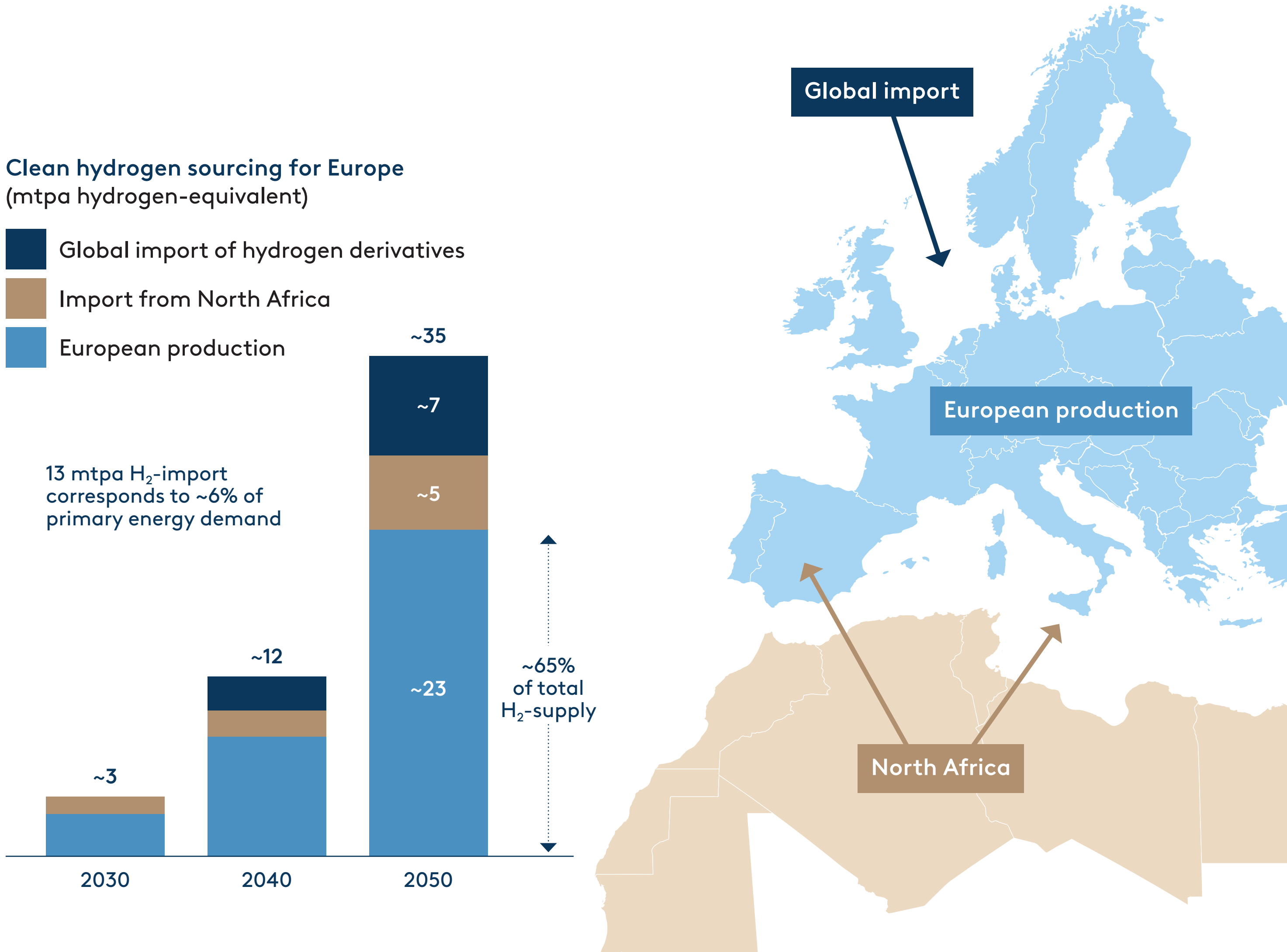
Green hydrogen can play a decisive system-balancing role in Europe's future energy system, by enabling a more integrated and cost-efficient interaction between electricity and hydrogen infrastructures. The system-friendly localisation and operation of large-scale electrolysers allow hydrogen production to respond to grid conditions, absorbing surplus renewable electricity during periods of high generation and thereby reducing curtailment and congestion in power networks. By acting as flexible demand, electrolysers support higher penetration of renewables while deferring or reducing the need for costly grid reinforcements, ultimately lowering overall system costs. At the same time, coordinated planning of electricity and hydrogen networks enables renewable energy to be converted into hydrogen where it is most efficient for the system, improving asset utilisation across sectors. These efficiencies are critical to reducing the cost of green hydrogen itself, making it increasingly affordable for energy-intensive industries and strengthening Europe's competitiveness, energy resilience and independence from fossil fuel imports.

In July 2020, the European Union launched its Hydrogen Strategy with a bold vision that catalysed the emergence of a new industrial value chain across Europe. Five years since the Strategy's launch, around 600 MW of electrolyser projects are operational and 3 GW are under construction across Europe. The Hydrogen Strategy aimed to install 6 GW by 2024.

Hydrogen demand is driven by heavy industry and energy-intensive applications

The model results assume that clean hydrogen demand grows materially towards 2050, reflecting its role in replacing fossil-based feedstocks and fuels in sectors where alternatives remain limited. By **2030**, demand reaches **~3 mtpa** (hydrogen-equivalent), rising to **~12 mtpa** by **2040**, and further to **~35 mtpa** by **2050**.

Demand in 2050 is primarily concentrated in energy-intensive and process-dependent sectors. The modelled sector split shows clean hydrogen consumption across major industrial uses, including steel, refining, chemicals, ammonia, with additional demand emerging in transport and other energy-intensive applications. This illustrates a key point for the overall system design. Green hydrogen is not a broad-based substitute for electricity. It is a targeted solution for specific use cases where clean molecules are needed to unlock significant emissions reductions.



A balanced sourcing approach with significant European production

The model results also indicate that Europe will rely on a balanced hydrogen sourcing mix. In 2050, total clean hydrogen supply reaches ~35 mtpa. Of this, ~65% – corresponding to approximately ~23 mtpa – comes from European-based clean hydrogen production, reflecting both strategic value and system feasibility. Hydrogen imports will make up the remaining share and will be split between clean hydrogen imports from North Africa and global imports in the form of clean hydrogen derivatives, implying that hydrogen trade becomes an integrated part of Europe's future energy system. At the same time, the model underlines that hydrogen imports remain a complement rather than a substitute for domestic capability. A significant European production base is required to meet industrial demand reliably and reduce exposure to external supply and geopolitical risks. This makes the rapid deployment of European hydrogen infrastructure essential.

The modelled import component is also material in energy terms. An import volume of **~12 mtpa** corresponds to **~6%** of final energy demand, illustrating that clean hydrogen and derivatives can contribute meaningfully at the margin without becoming the dominant energy carrier.

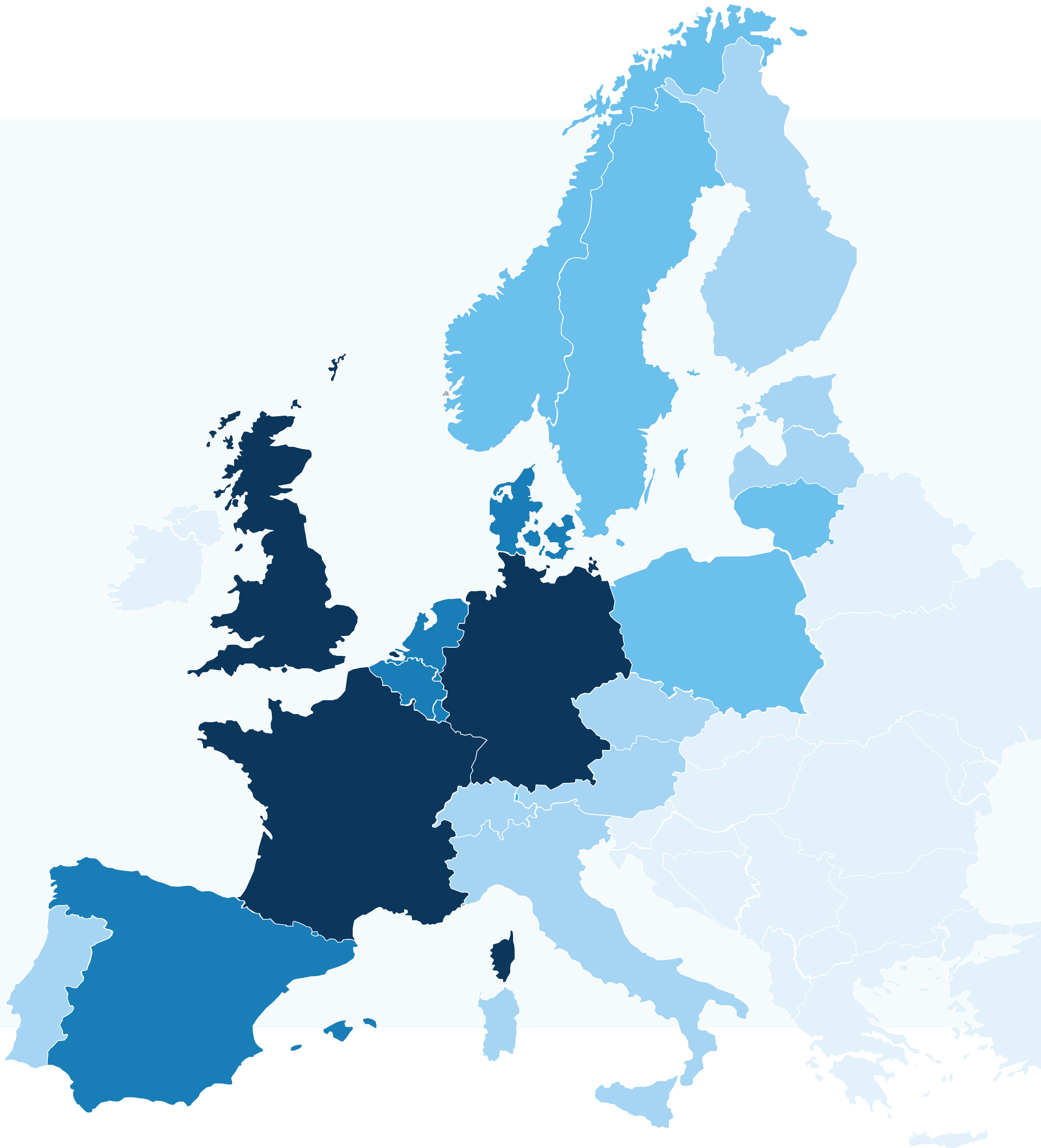
Infrastructure as the binding constraint

While demand and supply are central to the green hydrogen transition, one of the most immediate barriers to scale is infrastructure. Today, one of the biggest challenges accelerating hydrogen production is pipeline capacity. Across Europe, several projects are technically mature and ready to move. However, the timeline for hydrogen transportation infrastructure lags behind production schedules, including strategic cross-border sections like the Barcelona-Marseilles (BarMar) pipeline and the Delta Rhine Corridor connecting Germany and the Netherlands. This creates a chain reaction where producers, infrastructure developers, and off-takers become out-of-sync.

This misalignment has system-wide consequences. Without credible transport infrastructure, producers cannot reach demand centres, end-users cannot commit to long-term offtake – even if regulatory requirement forces them to – and investors face uncertainty. The result is delayed deployment, higher system cost, and a risk that the decarbonisation potential of green hydrogen does not materialise at scale and in time.

A coordinated build-out of hydrogen transmission is therefore a prerequisite for unlocking the full system value of green hydrogen. It is also a planning challenge, because hydrogen infrastructure is inherently network-based. Its value grows as it becomes interconnected across regions and borders, linking production locations with industrial clusters and import entry points. In the optimal energy system, electrolysis capacity is localised strategically in areas with abundant electricity generation. This helps reduce curtailment, lower system infrastructure costs and improve energy affordability.

Selected hydrogen transmission grid[1] expansion from 2025-2050 (mtpa)



1) Hydrogen transmission assuming only new build hydrogen pipelines cost in accordance with Hydrogen Backbone study;

Flow			Pipeline capacity	Cost of hydrogen network expansion
Spain	H_2 →	France	~7 mtpa[2]	EUR ~4 bn
France	H_2 →	Germany	~4 mtpa[3]	EUR ~3 bn
France	H_2 →	UK	~6 mtpa	EUR ~8 bn
UK	H_2 →	Netherlands	~3 mtpa	EUR ~1 bn
Denmark	H_2 →	Germany	~4 mtpa	EUR ~1 bn
Germany	H_2 →	Germany	~21 mtpa	EUR ~11 bn
Other			~20 mtpa	EUR ~12 bn
Total			**~65 mtpa**	**EUR ~40 bn**

Notes: 2) Investment figures are not provided as Morocco is not part of the model scope and the capacity is estimated based on pipeline data and used as a model constraint; 3) The capacity includes pipeline to Luxembourg and Belgium as they act as transit countries towards Germany

Policy Recommendations (13-16):
Unlock scalable supply, bankable demand, and timely infrastructure build-out

Existing policies have provided a strong starting point, but additional measures are needed to create viable business cases, reliable demand, and the scale required to scale hydrogen. With the right enabling policies in place, the industry could collectively bring online close to 18 GW of green hydrogen production projects between 2026 and 2032[1].

Scaling green hydrogen requires coordinated action across demand, supply, and infrastructure to ensure that projects can move from early development to large-scale deployment.

13. **Create demand incentives that work for products made with renewable hydrogen**
    The green hydrogen sector has a demand creation problem. To deliver the binding green hydrogen targets and ensure the cost-competitiveness of clean products and informed choices, policymakers must establish binding minimum quotas in public procurement in priority sectors. These include: vehicle manufacturing (e.g., cars made with green steel), defence (e.g., for EU-made e-fuels for military aviation and shipping), and construction (e.g., buildings or infrastructure made with green steel) as "lead markets". To this end, EU Member States must urgently ensure full implementation of **Renewable Energy Directive III**. Governments should also consider establishing preferential taxation and product labelling that clearly differentiates between fossil versus renewable energy-based products.

14. **Build infrastructure to help the industry deliver green hydrogen volumes**
    Electricity and hydrogen infrastructure should be treated as being in the overriding public interest, with delivery accelerated through binding timelines, fast-track permitting, and priority grid access for mature projects. Planning for power and hydrogen networks should be better integrated so that renewable supply hubs are connected efficiently to industrial demand centres. Cross-border hydrogen interconnectors, both onshore and offshore, will be critical to scaling the hydrogen market. Because these networks will often need to be built ahead of demand, EU instruments should be used to de-risk investment, and intertemporal cost-allocation mechanisms will be needed to support anticipatory infrastructure build-out. This is essential to ensure that infrastructure development keeps pace with production and demand and avoids a stop-start scale-up.

15. **A funding framework fit for scaling**
    The European Hydrogen Bank should be maintained and strengthened so that public funding is directed to the most mature and viable projects. Project completion deadlines should be made more flexible, so projects are not penalised for delays beyond their control, such as late infrastructure delivery, grid connection delays, or slow national transposition of targets. Governments should also consider pooling unused public funds under the Bank to expand its budget. The sector is estimated to need around EUR 6–8 billion per auction to meet RED III RFNBO targets and close the cost gap with fossil alternatives, which persists because of low ETS prices and incomplete RED III implementation. Where this is not feasible, European and national funding should temporarily be allowed to combine, capped at 100% of the cost gap, so that offtakers can invest now without losing competitiveness.

16. **Enable early market formation through clean hydrogen book-and-claim systems**
    In the early phases, a credible green hydrogen book-and-claim system, inspired by the biomethane sector, can support market development by allowing green hydrogen attributes to be traded independently of physical deliver, on the condition that the certificates must be cancelled when/if physical infrastructure enters into operation. This can enable early offtake commitments and demand aggregation before full transport network connectivity is in place, accelerating market formation while maintaining environmental integrity and transparency.

Notes: 1) The Renewable Hydrogen Coalition's Declaration: A New Deal for A Stronger Europe, December 2025.

4.5 Carbon Capture & Storage and Biomass

In a renewables-led, electrified European energy system, most emissions reductions come from direct electrification. Carbon Capture and Storage (CCS) and biomass play a different role.

They complement the backbone of the transition as critical "problem-solvers" for residual emissions and energy intensive segments where alternatives are limited, costly, or not yet readily deployable at scale. Used well, they help reduce emissions while protecting affordability and system stability through, for example, preserving existing thermalplants and/or permanently sequestrating CO2 emissions. Moreover, captured biogenic CO2 can be utilised as input for e-fuels where direct electrification remains difficult or where the direct replacement of fossil CO2 in industry processes is possible. Similarly, waste and residue biomass from agriculture, forestry or other sectors can be transformed into biofuels which are destined to play a pivotal role in the decarbonisation of especially the transport sector.

Carbon Capture and Storage

CCS is not a new technology. It has long been used in the oil and gas industry. However, in Europe's energy transition, it is politically recognised as a solution for emissions that are difficult to eliminate through electrification or by switching to alternative fuels such as clean hydrogen. In particular, CCS is relevant for energy-intensive industrial processes such as cement production, steel, waste-to-energy where process emissions and limited alternatives make decarbonisation challenging. This political direction is reflected in EU initiatives, including the Industrial Carbon Management Strategy's target of 50 mtpa captured CO2 from 2030, increasing to 450 mtpa in 2050, and the EU Emission Trading System (EU ETS), which could potentially allow EU Member States to purchase Carbon Removal Units (CRUs) to meet any decarbonisation ambitions beyond 2030. In the Competitive & Resilient scenario, full decarbonisation is not the model's target end state, meaning that some sectors will remain reliant on fossil fuels beyond the near term. In this scenario, CCS is prioritised where it delivers the highest system value per euro spent on CCS, and where infrastructure can be scaled efficiently.

Carbon management as an enabler for e-fuels where electrification is difficult

Over time, captured biogenic CO_2, which is just a market subset of projects, can provide inputs to synthetic fuels, or e-fuels, such as eSAF and e-methanol, supporting decarbonisation of aviation and other industries where direct electrification remains challenging. In the absence of supply of such e-fuels, large shipping and logistical companies or companies highly dependent on this sector can purchase Environmental Attribute Credits (EACs) to help offset until they can reduce directly by purchasing the actual e-fuels. This is not the core lever in the Competitive & Resilient scenario, but it is an important option that links carbon management to wider industrial and transport decarbonisation.

The model points to CCS in industry as the economically robust application

The model results highlight a clear prioritisation logic for CCS. Today, fossil power generation with carbon capture is not cost-competitive without subsidies, especially in a system where fossil generation runs fewer full-load hours and more as back-up. Thus, from an overall macro perspective, fossil power generation with carbon capture does not play a role in the Competitive & Resilient scenario. CCS however still provides a strong system value, and when factoring in multiple revenue streams including subsidies, it can be value-creating on a case-by-case basis. Most common use cases include CCS added to waste-to-energy facilities and/or large industrial processes (e.g. cement), as CCS can deliver material emissions reductions without competing directly with electrification or renewables. Much like other technologies, this report acknowledges that there remains a political movement to keep combined-cycle power plants (CCGTs) online longer than what might create most value from an overall European system's perspective. This means that some European governments might offer subsidies, potentially combined with a penalty regime, making some business cases work for this technology.

For CCS, the binding constraint is often not capture technology but the full chain: capture, transport, and storage. Without accessible CO_2 transport and injection capacity, projects simply cannot happen. CCS deployment is therefore inseparable from CO_2 network planning, storage permitting, and coordinated build-out of shared infrastructure. At least governments and industry must jointly take responsibility in aligning the full value chain due to the very high complexity and interdependencies.

Advanced biofuels play a key role in the current and future European energy systems

Bioenergy currently constitutes approximately 10% of final energy consumption in EU, and this share is expected to increase to 14-16% by 2035.
This growth represents both an increased production but also a change in the way bioenergy is applied in the energy system. Historically, bioenergy in Europe has primarily come from Municipal Solid Waste (MSW) and forestry residues that were incinerated for heat and power production. Going forward this traditional use is giving way to a growing focus on converting organic waste into advanced biofuel molecules, such as biomethane, which is well suited to decarbonise Europe's energy-intensive industries.

The growth in the use of advanced biofuels is driven by their attractive intrinsic characteristics. Advanced biofuels are immediately applicable given their compatibility with existing infrastructure, while their cost-competitiveness is growing in a market shaped by strong European regulatory support for energy-intensive industries and increasingly stringent incentive schemes, e.g. via the Renewable Energy Directive (RED) II/III, FuelEU Maritime and ReFuelEU Aviation. In parallel, organic waste volumes are projected to exceed expected biomethane demand 6x by 2030, and their availability is reinforced by regulatory efforts to promote sustainable agriculture, such as the EU Nitrates Directive and the EU Landfill Directive. As a result, the future role of bioenergy in the EU energy system increasingly centres on converting organic waste into advanced biofuels.

5. Implications for Europe: Costs, Resilience and Stability

Europe's energy transition is ultimately defined by the triple challenge: delivering affordable energy, strengthening energy system resilience, and achieving clean energy at scale.

If Europe succeeds, the implications are not abstract. They show up in power prices for households and industry, in system stability, and security of supply. Realising these outcomes at scale depends on whether Europe can put the right market conditions and remuneration frameworks in place to attract private sector investment. As the cost base shifts from a centralised energy system based on fossil fuels to a decentralised and capital-intensive renewable energy infrastructure, market design must increasingly reward adequacy, flexibility, and system services – not only energy volumes to unlock private investment at scale and at the lowest financing cost.

As Draghi argued, Europe's industrial future will increasingly be shaped by its ability to deliver affordable energy. While prices have fallen from recent peaks, European companies still face higher power prices than their global competitors. In this context, the Competitive & Resilient scenario provides the most relevant reference case. It illustrates how Europe can move towards lower and more stable long-term power prices while strengthening resilience and making progress on emissions reductions. At the same time, it is a pragmatic scenario.

It does not realise full decarbonisation in every segment by 2050 and therefore highlights both the upside of coordinated action and the trade-offs that remain.

The sections below assess the implications against the triple challenge, focusing on affordability (energy costs), resilience (imports and system stability), and clean energy (emissions). Delivering outcomes across all three depends on the enabler: market design and remuneration frameworks that mobilise investment and enable delivery at scale.

Ensuring affordable energy for Europe

The power prices forecasted in all three scenarios are set to decrease steadily through 2050.

Combined with the investments in energy system flexibility, the lowest power price point is reached in the Competitive & Resilient scenario at **66 EUR/MWh** in **2050**, compared to **106 EUR/MWh** in 2025. However, should decision makers only want to optimise for price alone, the lowest possible power price could be 59 EUR/MWh, which is essentially realised by adding more solar PV and onshore wind to the energy system. This would come with several concessions, including weaker system resilience and a tougher political stance on not-in-my-back-yard (NIMBY)-resistance to onshore technologies.

As a result, European households and industries could benefit from power prices, which are **40%** less than today's cost levels in the **Competitive & Resilient** scenario.

In 2050, the Slow Transition scenario provides an energy system delivering power prices at **69 EUR/MWh**, and the Net Zero scenario at **75 EUR/MWh**.

The power prices include transmission costs related to interconnection between bidding zones, grid connections for offshore wind and electrolyze plants, and network reinforcement for onshore renewable energy sources. Power prices do not include costs / tariffs for national transmission and distribution grids.

Ensuring secure and resilient energy for Europe

Europe is currently heavily dependent on imported fossil fuels. Today, the region, also including Norway and the UK, imports fossil fuels amounting to ~40% of the primary energy demand equivalent to a cost of nearly **EUR 250 billion**.

Fossil fuel import dependency across all three scenarios will decrease substantially.

By 2050, fossil imports are forecasted to reach **~25%** in the Slow Transition scenario, **~10%** in the **Competitive & Resilient** scenario, while Net Zero has an export share of **~5%** by **2050**.

An integrated European energy system and lowered imports will ensure energy resilience.

In addition, clean fuels for energy-intensive industries are also expected to be imported due to lower production costs in global hot spots, but the dependency on these is purely economic, and the same fuels could be produced in the EU using clean technologies, though expectedly at a higher price.

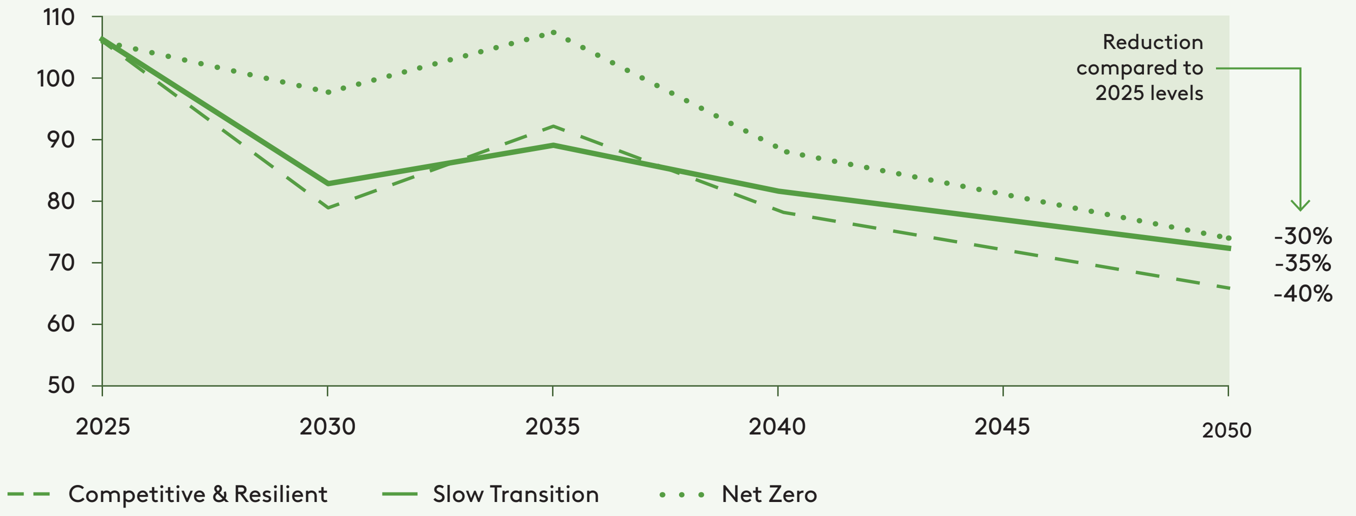
A system with lower import exposure is not resilient by default. As electrification increases, electricity becomes more system-defining, and resilience depends increasingly on operational stability, redundancy, and system flexibility. This strengthens the case for market designs and remuneration models that pay not only for energy volumes, but also for adequacy, balancing, and fast response.

Delivering clean energy and emissions reductions

Across all tested scenarios, gross CO_2 emissions decline significantly towards 2050, aligning with global political agreements but to a varying degree. Full decarbonisation by 2050 is only realised in the Net Zero scenario. The model output is dependent on available and already known technologies. As such, various carbon removal and sequestration (CCUS) technologies may assist across all scenarios in bringing CO2 emissions further down as time progresses.

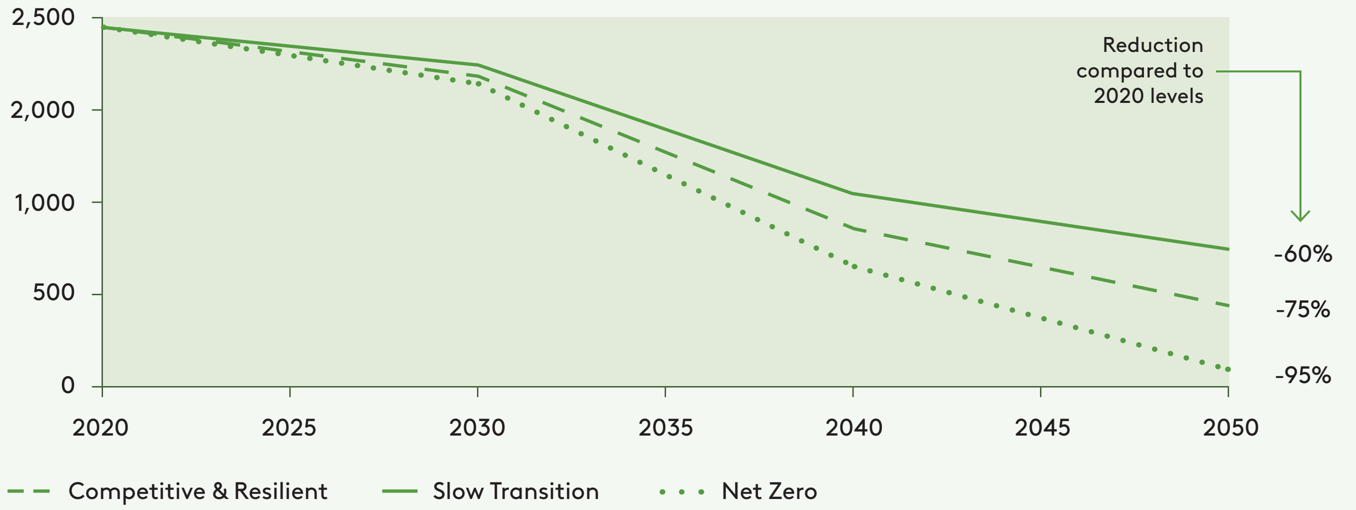
Power Price Development towards 2050

Power price by scenario (EUR/MWh)

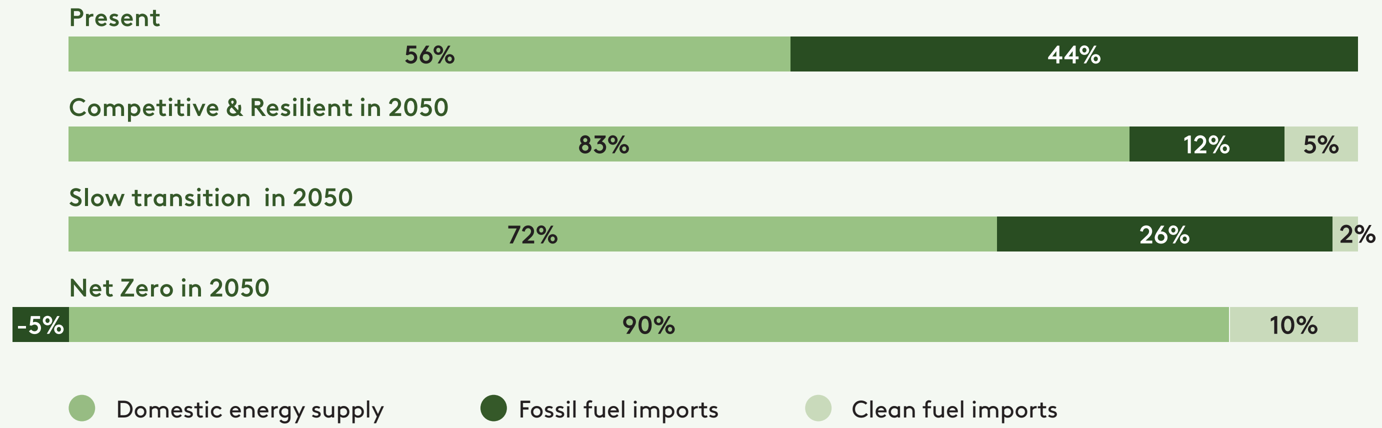


European Emission Reduction Developments

Gross CO2 Emissions (mtpa)



Energy Sourcing in Europe (% of Total Energy)



6. Sensitivities

The Competitive & Resilient scenario is the base case, but the road to 2050 will not be linear.

Demand can surprise on the upside or downside, technologies can cost-out or mature faster or stall, and geopolitics or policy choices can shift assumptions that matter for system design.

The sensitivity analyses that follow test exactly that. Starting from the Competitive & Resilient energy system, the report explores what happens if a few key drivers accelerate, slow down, or take a different direction. The purpose is not to predict outcomes, but to understand where the system is robust, where it is sensitive, and what this implies for investment needs, infrastructure priorities, and the policy frameworks required to keep Europe on track to solve the triple challenge.

Across all sensitivities, a common denominator emerges: electrification continues to be a central driver of the energy system, and renewables remain the backbone of supply. The message for policymakers and investors is clear: Europe needs a build-out model that is resilient to demand uncertainty. That means maintaining a credible development pipeline for renewables and grid capacity, and ensuring that market and regulatory frameworks support both capacity volumes and essential system services.

Sensitivity 01

6.1 What Happens if We Were to Change Track in 2040?

This sensitivity test explores what happens if Europe follows a Competitive & Resilient trajectory in the near- and mid-term but then shifts direction in **2040** to get back on a full Net Zero track by **2050** fuelled by revitalised political momentum.

While global climate momentum has lost pace, the EU has maintained a high level of ambition, most recently signalled by the **2040** EU climate target of **~90%** greenhouse gas reduction. Against this backdrop, it is important to test how sensitive the energy system is to a later, politically-driven acceleration of renewable build-out.

The model results indicate that changing track in **2040** is theoretically possible, but it comes with a clear delivery implication. Most of the adjustment is compressed into the final decade, requiring an unprecedented – and highly ambitious - pace of additional renewable capacity deployment. Offshore wind is the most visible example. Under the Competitive & Resilient scenario, offshore wind reaches **~220 GW** by **2050**. Under the Net Zero scenario, the system builds towards **~390 GW**. If the system only switches to Net Zero assumptions in **2040**, offshore wind needs to reach **~385 GW** by **2050** - requiring a very large build-out from **2040 to 2050** and a sustained annual delivery rate of **~19 GW** per year (which corresponds to a yearly build-out of ~50% of the European offshore wind capacity installed today).

In cost terms, the model suggests that the long-run power price impact is negligible. On one hand, a reduced transmission grid and late-deployed fossil assets (CCGT) increase power cost but on the other hand, deployment of technology at a later stage increases the cost-out, which weighs up for this. As a result ,the average power price in **2050** increases from **~66 EUR/MWh** in the Competitive & Resilient case to **~74 EUR/MWh** in the "changing tracks" sensitivity test, which is similar to **~74 EUR/MWh** if Europe had followed the Net Zero scenario from the outset.

The key takeaway is therefore not about price but about feasibility and timing: delaying the shift compresses the build-out challenge into a single decade, and increases dependency on supply chain readiness, permitting speed, and investment mobilisation at scale.

Overall, this sensitivity highlights a practical trade-off. A late acceleration can still deliver a Net Zero-aligned end-state at similar cost-levels, but it raises execution risk materially. The system becomes more exposed to bottlenecks in supply chains, grid connections, and project delivery capacity, meaning that political ambition in **2040** would have to be matched by high delivery discipline, strong political and regulatory backing to remain operationally credible.

Sensitivity 02

6.2 What Happens if Nuclear Generation Is Increased Significantly Based on Optimistic SMR Cost-Outs?

This sensitivity test explores how the energy system would change if Small Modular Reactors (SMRs) became significantly cheaper than today's expectations, allowing nuclear to compete more directly with natural gas, wind and solar. Under these assumptions, the model ramps up nuclear build-out over time. The increase happens gradually rather than immediately, as SMRs are too expensive by 2030 and 2040 and are not economically viable even under very optimistic cost assumptions.

In the modelled system, total European nuclear capacity is broadly stable through 2030 and only starts to rise meaningfully after 2040. By 2050, nuclear capacity increases to **~175 GW**, driven by SMRs adding roughly **~70 GW** on top of a largely stable conventional nuclear capacity in the base case – the Competitive & Resilient scenario. The practical implication is that nuclear becomes a larger contributor to the European energy system in the final decade but it does not fundamentally reshape the energy transition in the next decade.

As nuclear costs potentially decreases, it partially reduces the build-out of intermittent renewables. Compared to the Competitive & Resilient scenario, the model reduces the required renewables capacity by 2050, with offshore wind decreasing by roughly **9%**, onshore wind by **~5%,** and solar PV by **~11%**.

The point is not that build-out of renewables generation halts, but rather, a larger share of electricity demand is serviced by nuclear instead. This slightly reduces the amount of additional wind and solar the system needs to meet demand.

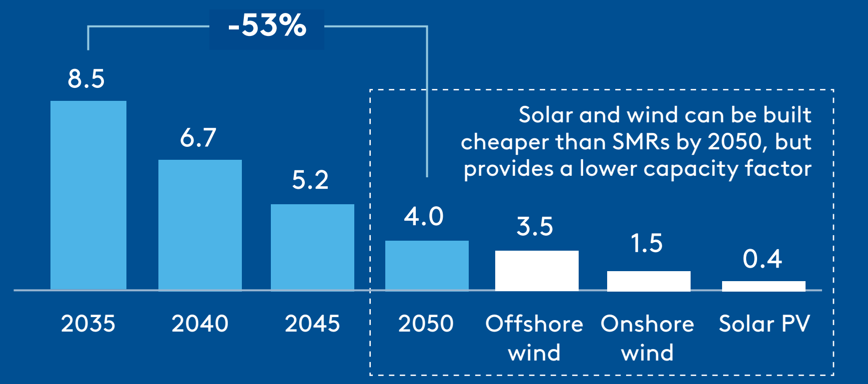
However, the system remains fundamentally renewables-led and infrastructure-heavy. Even with more nuclear, the model still requires a large renewables fleet, reinforced grids, and system flexibility to manage variability, congestion, and security of supply. Nuclear can improve system firmness and reduce reliance on intermittent power generation. However, it does not remove the need for vast investments in transmission, balancing, and market arrangements that make the broader energy system investable and reliable.

Overall, this scenario illustrates a clear trade-off: if SMRs become cost-competitive at scale, they can take up a larger share of long-term supply and reduce some renewable capacity requirements.

Introduction of small modular reactors (SMR's) in the European energy system

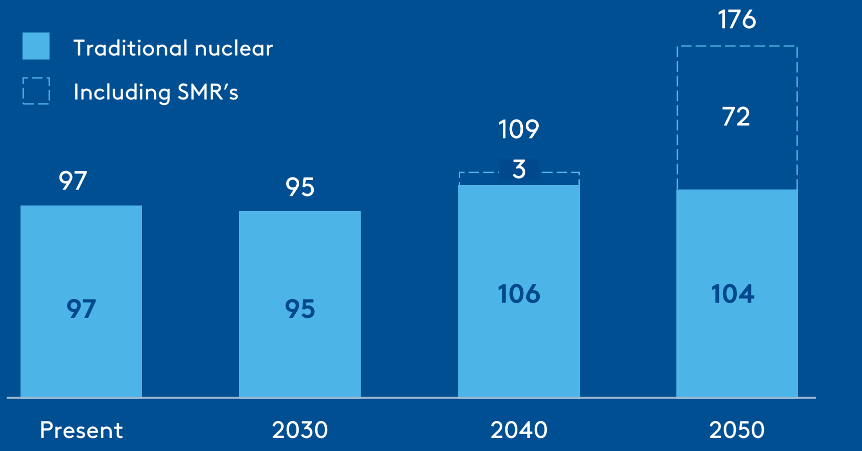
Key changes to assumptions
The model optimises nuclear build-out by investing in SMR's on same level playing field as renewables

SMR CAPEX (mEUR / MW)



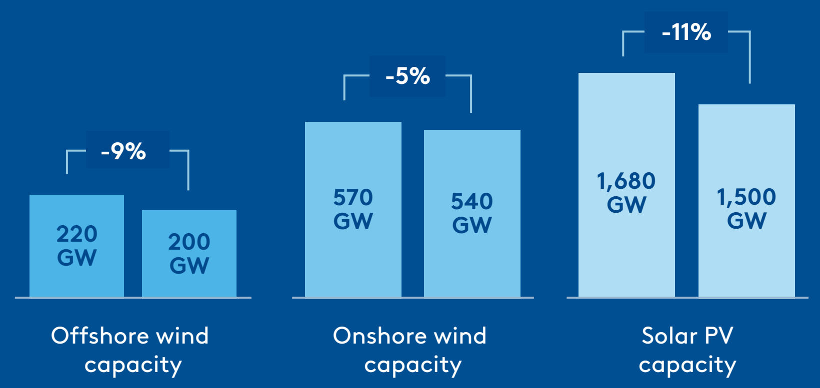
SMR CAPEX is based on 'optimistic scenario' from Danish Energy Agency analysis[1]

European nuclear capacity (GW)



Introducing SMRs is unlikely to have significant impact in the European energy system before 2040...

European renewable production capacity by 2050 (GW)



Nuclear share of total capacity: **3%** ⟶ **6%**

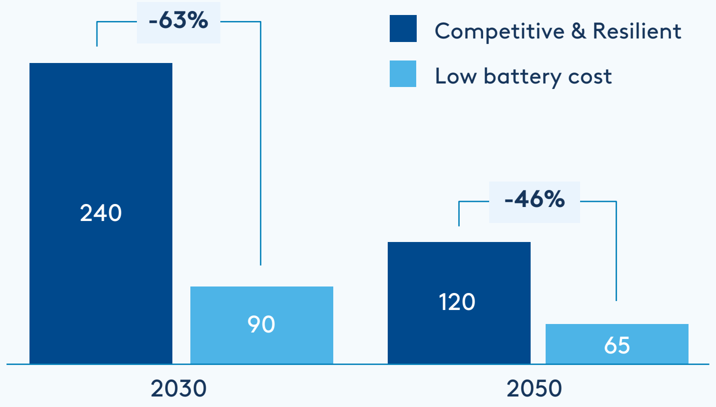
... and is unlikely to significantly replace the large build-out of renewables that is required

Faster cost-out and increasing deployment pace of battery energy storage solutions

Overview of changed assumptions

If battery CAPEX cost-out happens faster than previously assumed...

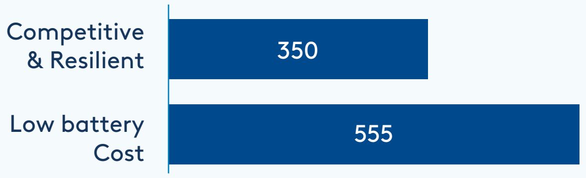
Battery CAPEX (EUR / KWh)



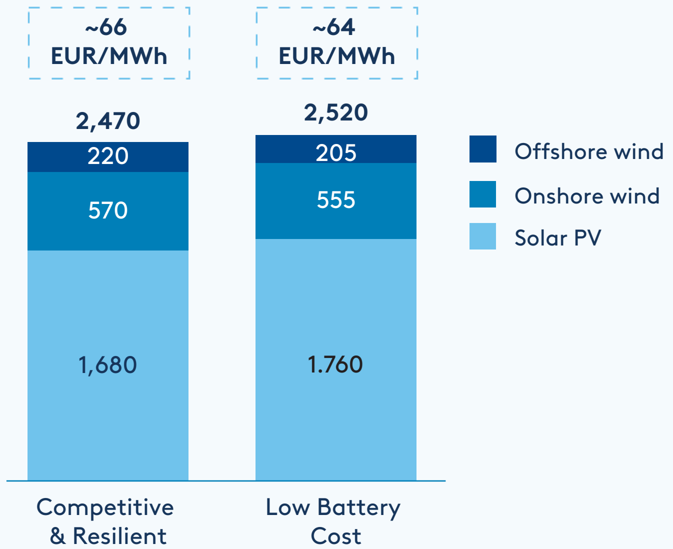
Key changes in capacity build-out

...resulting renewable build-out is similar, with 3% lower power prices

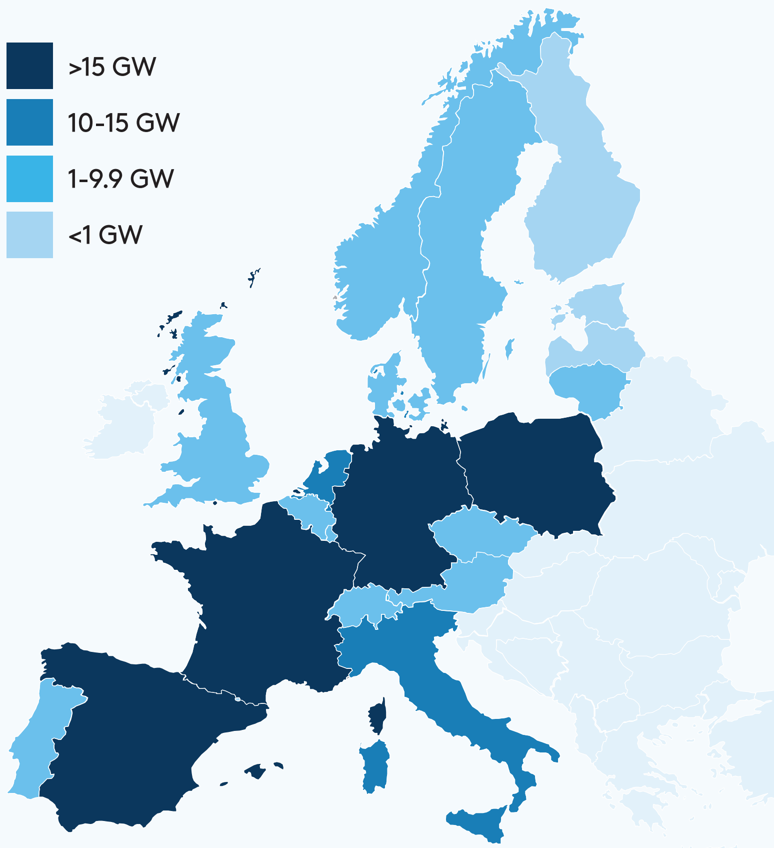
Battery build-out by 2050 (GW)



Distribution of additional battery build-out (GW)



Distribution of additional battery build-out (GW)



Sensitivity 03

6.3 What Happens if Batteries Scale Much Faster Than Expected?

Batteries are already on a steep cost reduction trajectory. With CAPEX falling by around 45% in 2025 alone, the sensitivity is no longer whether costs will decline, but how fast.

This sensitivity tests what happens if battery cost reductions continue at a faster pace than assumed in the Competitive & Resilient scenario. In that case, storage becomes materially cheaper to deploy, enabling significantly higher build-out where it delivers the greatest system value.

The result is not a fundamentally different energy system, but a more efficient one.

Cheaper batteries primarily affect the system through increased flexibility and lowering prices, rather than by changing the overall scale of clean energy deployment. Total battery capacity rises from around ~350 GW in the base case to approximately ~555 GW by 2050.

This additional storage improves the utilisation of clean energy generation. It shifts surplus electricity to periods of higher demand, reduces curtailment, and limits the need for short-run thermal balancing in tight hours.

The price effect is measurable but moderate. Average power prices fall by ~3% in 2050, from ~66 EUR/MWh to ~64 EUR/MWh.

The key point is that batteries do not replace clean energy generation. They make a renewables-led system work better by smoothing volatility, reducing scarcity hours, and increasing the value of low-cost generation.

As a result, the overall scale of renewable deployment remains broadly unchanged. Total clean energy generation capacity increases only marginally, from around ~2,470 GW to ~2,520 GW by 2050. The technology mix also shifts only slightly, with changes of +/- 5% across technologies, primarily reflecting a modest increase in solar PV.

In effect, batteries amplify the value of renewables (particularly solar) without materially reducing the capacity required.

Deployment is distributed across regions and bidding zones, with storage built where it delivers the highest system value, including congestion relief, balancing, and renewable integration.

The question is not whether batteries are needed, but whether the system allows them to scale.

Permitting, grid access, and market design become the binding constraints. If these frameworks are not in place, the system risks under-deploying storage even when it is economically optimal.

Overall, this sensitivity highlights that faster battery cost reductions enable significantly higher storage deployment, improving flexibility and lowering prices, while leaving the scale of renewable build-out largely unchanged.

Sensitivity 04

6.4 What Happens to the Energy System if AI Booms or Busts?

This sensitivity test explores how Europe's power system reponds to one of the most publicly touted demand drivers towards 2050: electricity use from data centres and AI-(Giga)factories. The baseline from the Competitive & Resilient scenario assumes a "conservative" level of data-centre demand ramp-up.

Here, we stress-test that assumption in two directions:

1. An 'AI bust'-case, in which by 2050 we see lower demand and growth of artificial intelligence
2. An 'AI boom'-case, in which artificial intelligence drives data-centre demand and places larger constraint on the 2050 electricity system

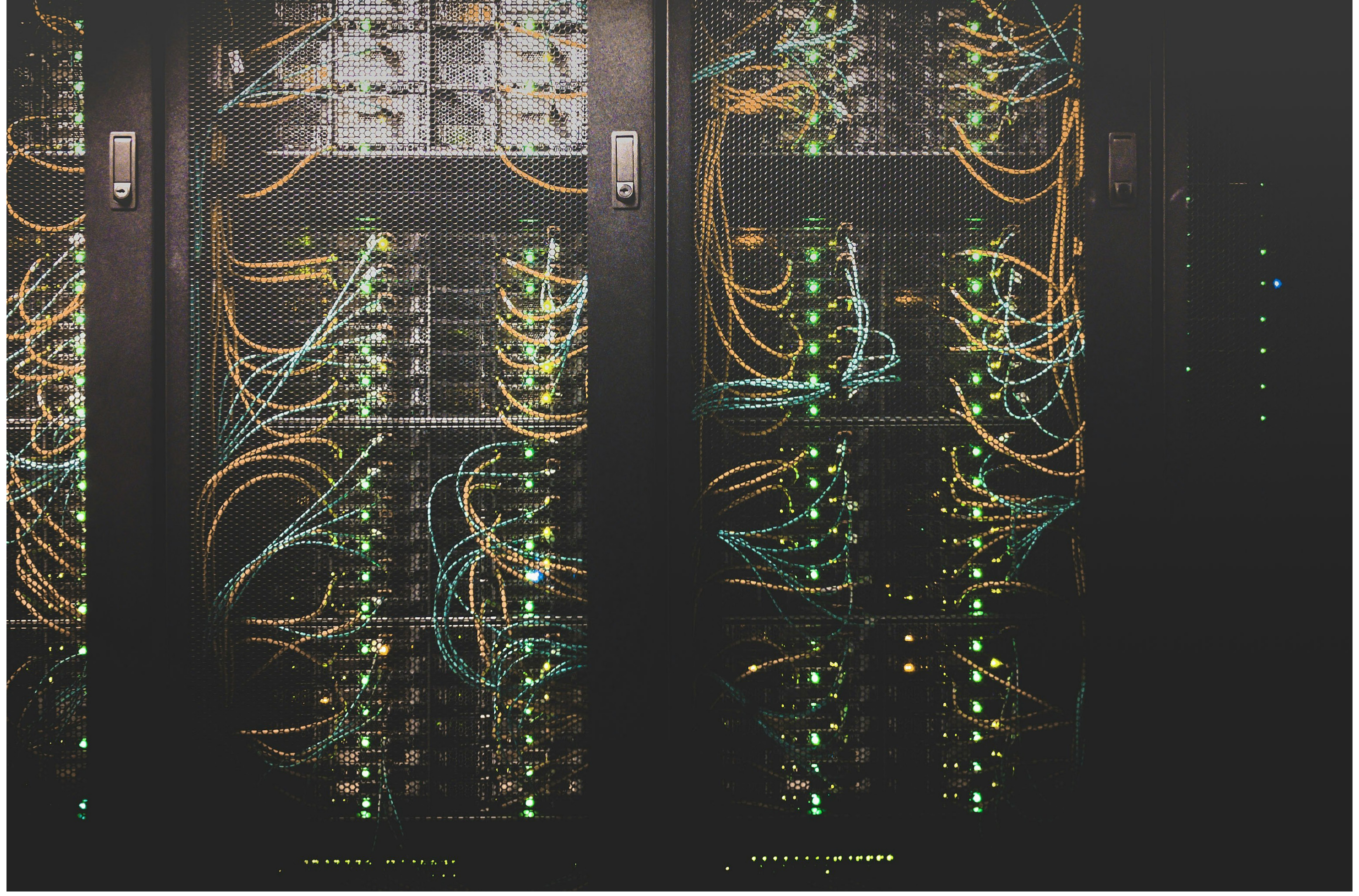
The first takeaway is that data-centre demand across all three scenarios is large enough to move the build-out of renewables materially. In the base case, electricity demand from data centres reaches **~320 TWh** in 2050. In the 'AI bust'-case, the electricity demand is unlikely to exceed **~190 TWh**, while in the 'AI boom'-case it has the potential to reach **~520 TWh**. That swing is not marginal: it changes the required scale of new clean generation capacity, and therefore the investment and delivery challenge across the supply chain.

Offshore wind: AI's power partner

In the model results, offshore wind is the most responsive technology to this demand shift. In the 'AI boom'-case, offshore wind capacity increases by about **~9%** relative to the baseline, reflecting offshore wind's high capacity factor and system value as a large-volume source of clean electricity. In the 'AI bust'-case, offshore wind build-out drops by **~5%**, indicating that lower demand reduces the need for the most capital-intensive parts of the renewables fleet.

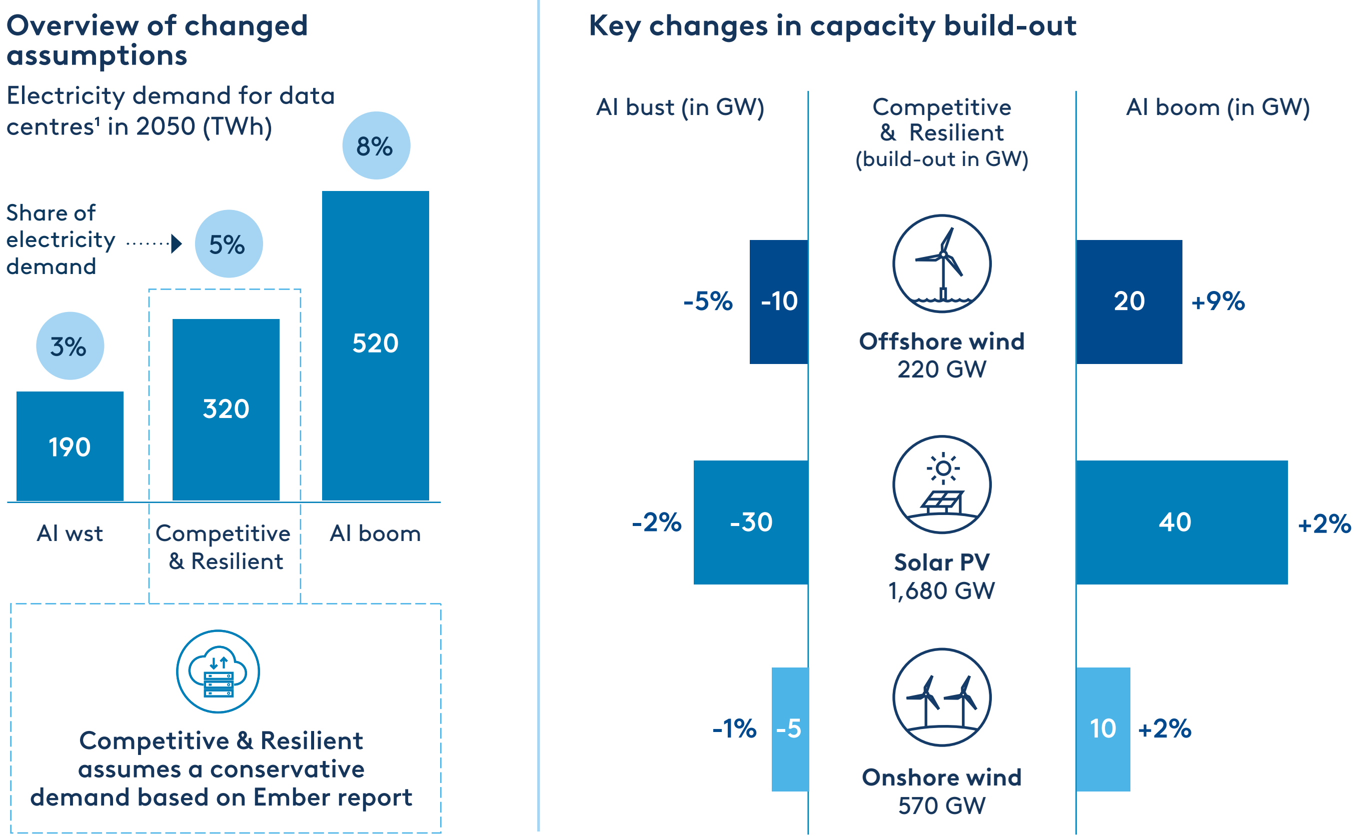
Solar PV also adjusts noticeably, especially on the downside. In the 'AI boom'-case, solar increases by ~2% compared to the base case. In the 'AI bust'-case, the model reduces solar capacity by about **~30 GW**, reflecting that PV build-out is highly volume-driven and significantly scales down when demand is lower. Onshore wind remains largely unaffected in both scenarios, with only minor shifts (~2% up in the 'AI boom' and ~1% down in the 'AI bust'), reinforcing that its role is structural rather than driven by marginal demand changes.

The broader implication is that Europe's renewables-led system remains robust, but the required pace of build-out is highly exposed to demand uncertainty from data centres. If AI-driven demand accelerates, the system can absorb it but only by scaling clean generation faster – particularly offshore wind – and by ensuring that grids, connections, and system flexibility solutions keep pace. If demand growth is weaker, investment needs ease somewhat, but the system logic does not change: electrification still increases the importance of electricity, and renewables remain the backbone of supply.



What happens to renewable energy build-out?

Datacenters have a large impact on offshore wind build-out both in AI boom and AI bust scenarios



Notes: 1) Data centres includes AI driven demand for gigafactories, hyperscalers, etc.

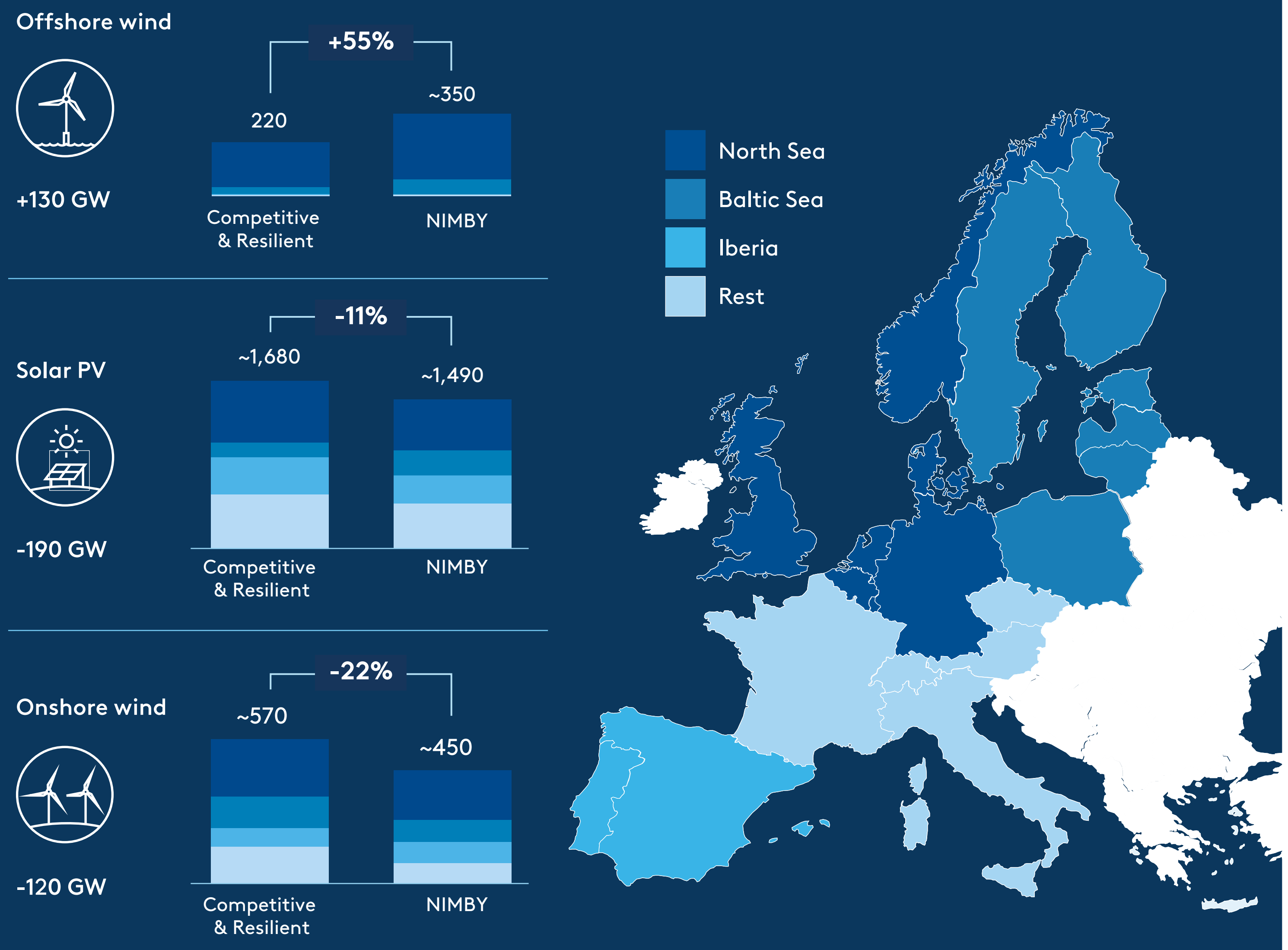
What happens if onshore generation meets increased public opposition

The impact of NIMBYism is higher in areas with dense populations such as Germany, Netherlands, UK and Denmark moving onshore generation away from demand centers – opening the door for further deployment of offshore wind

Overview of changed assumptions

Increasing the "Not in my backyard" philosophy by… | …doubling required distance from assets to nearest buildings | …and protected areas

Key changes in capacity build-out



Sensitivity 05

6.5 What Happens if Public Opposition to Onshore Renewables Accelerates?

Public opposition does not remove the need for energy build-out. It changes where that build-out has to happen. If onshore renewables face tighter constraints, the system compensates by shifting more of the expansion offshore, raising the importance of offshore wind, transmission planning, and cross-border coordination. This sensitivity test explores that dynamic. It assumes that public acceptance becomes a more binding constraint on onshore wind and solar PV than in the Competitive & Resilient scenario. In practice, this means stricter siting and permitting rules, limiting where onshore capacity can be deployed at scale towards 2050.

The modelling reflects this by tightening land-use constraints across countries. Available areas for onshore technologies are reduced through stricter distance requirements for buildings and protected areas, alongside lower caps on land use for both solar PV and onshore wind. In several countries – notably Germany and the Netherlands – these constraints are already close to binding today. In such cases, the model still allows for some onshore deployment, but at levels well below current political targets. The result is not less build-out overall, but a different composition of the energy system. Onshore capacity declines materially. Onshore wind is reduced by around 120 GW (–22%), from ~570 GW to ~450 GW compared to the Competitive & Resilient scenario. The reduction is most pronounced in densely populated regions such as Germany, the Netherlands and Belgium, where land availability is most constrained. Some of this is partially offset by increased deployment in less constrained regions, such as the Iberian Peninsula. Solar PV follows a similar pattern, declining by around 190 GW (–11%), from ~1,680 GW to ~1,490 GW. The gap is primarily filled by offshore wind. Offshore capacity increases from around ~220 GW to ~350 GW by 2050 – an expansion of approximately +55% relative to the base case. A significant share of this additional build-out is concentrated in the Baltic Sea, where sites become more competitive under tighter onshore constraints.

In this sense, offshore wind acts as the system's release valve. It absorbs a large share of the capacity that can no longer be deployed onshore. But this substitution comes with consequences. A more offshore-heavy system requires a step-change in infrastructure. It increases reliance on far-from-shore sites, including the development of offshore energy hubs, and places greater demands on coordinated planning of offshore grids and cross-border interconnectors. Electricity must be transported over longer distances, from offshore generation to demand centres that are often not co-located. It also changes the structure of the offshore build-out itself. In this scenario, around 33% of offshore wind capacity in 2050 consists of hybrid – or "cooperation" – projects, as referenced in the Hamburg Declaration. This corresponds to roughly 110 GW of capacity connected to more than one bidding zone.

The implication is that constraints on onshore deployment do not reduce the scale of the transition, but they shift its centre of gravity. That shift concentrates delivery risk offshore. It raises requirements for grid infrastructure, supply chains, and cross-border coordination, and increases the system's dependence on timely offshore deployment.

For policymakers, this creates a dual imperative. First, maintain social acceptance for onshore renewables – or establish regulatory frameworks that ensure continued build-out despite local resistance. Second, build optionality. Offshore grid planning, auction design, and supply chains must be developed and scaled in parallel, so the system is able to absorb higher offshore volumes if onshore constraints tighten further.

7. Appendices

7.1 Model and Assumptions

The insights and predictions in this report are based on a state-of-the-art energy model that we leveraged to predict the most efficient build-out of Europe's energy system in three scenarios.

This report attempts to answer three fundamental questions about the challenges faced by the European continent:

1. To what extent can Europe lower its energy prices and increase its competitiveness?

2. To what extent can Europe become energy independent?

3. To what extent can Europe reach Net Zero emissions by 2050?

The report's energy model is based on the 'Balmorel'-model, which is developed to optimise energy generation and transmission subject to various constraints. This model integrates the European electricity, heating, and hydrogen systems into one energy model, always ensuring a balanced energy system across Europe. The model area referred to as 'Europe' includes the UK, Norway and the EU with a few country exceptions. The model accounts for hour-by-hour energy generation and transmission from today towards 2050. This approach offers consistency across borders and thus provides a detailed overview of the European integrated energy landscape of the future.

The energy model assumptions were developed in collaboration with Ea Energianalyse, a best-in-class energy economics consultancy based in Denmark, with input from Energinet, the Danish transmission system operator (TSO). They were also peer-reviewed by internal and external industry and political experts. These included, but were not limited to: Brian Vad Mathiesen, Professor in Energy Planning and Renewable Energy Systems at Aalborg University, Hilde Tonne, Senior Advisor at CIP, Chair of the Arup Group and former CEO at Statnett, Robert Habeck, former German Vice-Chancellor and Federal Minister for Economic Affairs and Climate Action, and Henrik Stiesdal, founder of Stiesdal Offshore.

The model has several inputs in the form of economic, technological, and meteorological data. Wherever available, it is based on external sources. To determine the robustness of the model outputs, the analyses tested 19 scenarios with different assumptions (see Appendix for the results of the sensitivity analyses).

In CIP's last European energy systems report (2025), some of the key assumptions were that solar PV was not allowed to take up more than 1.5% of agricultural land by 2050, while onshore wind was based on national targets.

The assumptions were based on what seemed reasonable at that time from a public perspective while keeping in mind the 'NIMBY' (Not-In-My-Backyard) issue.

To strengthen these assumptions, this report has implemented an additional restriction, a GIS ("Geographic Information System") analysis to ensure a more accurate solar PV and wind potential across Europe. The GIS maps out the maximum land available for onshore technologies (compared to the 'agricultural land' used in the old report) and anticipates that only 1.25% and 3% of this land is available for solar PV and onshore wind, respectively. Furthermore, the GIS takes into account that onshore renewables cannot be built within 750 meters of buildings and within 50 meters of protected areas. Introducing these measures provides the model with a more realistic picture of where such assets can and cannot be built.

The implications are that the large capacity build-out of onshore technologies is redistributed from densely populated countries such as Germany, Denmark, Belgium, and the Netherlands towards countries with more abundant areas available, such as Spain, France, and Poland.

Other examples of assumptions built into the model

- A key assumption is that the final energy demand in Europe will decrease by roughly 1/3. The reduction is primarily driven by electrification, which increases energy efficiency and reduces the amount of fossil fuels in the system. Meanwhile, electricity demand will more than double by 2050.

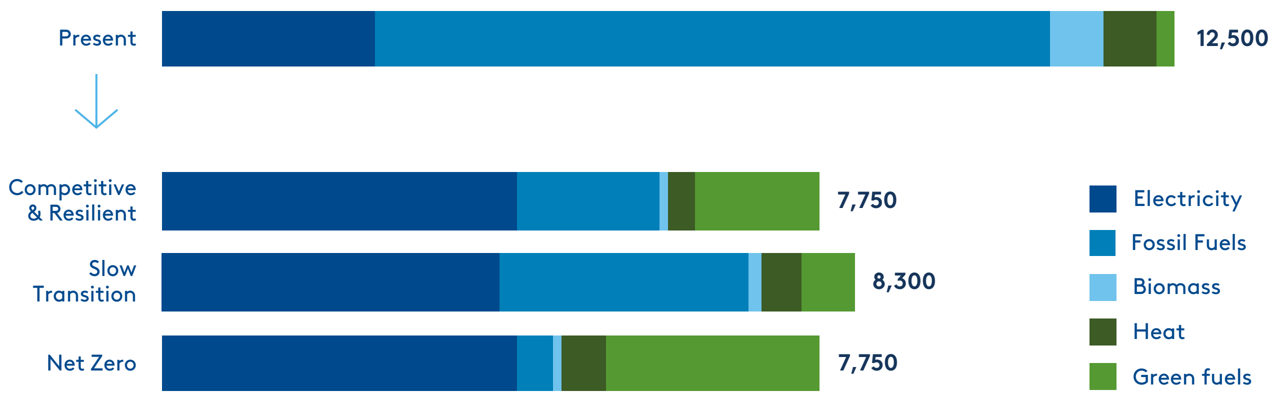
- The model includes economic data on, for instance, fuel and CO2 prices. A central assumption is that the capital expenditures for most technologies such as offshore wind, onshore wind, solar energy, and gas turbines will cost out from 2030-2050 (e.g. -13% for offshore wind and -25% for solar energy).

- The model includes technological data such as wind and solar capacity factors for various locations, and efficiency estimates for electrolysers, gas turbines, and lithium batteries. It also includes meteorological data.

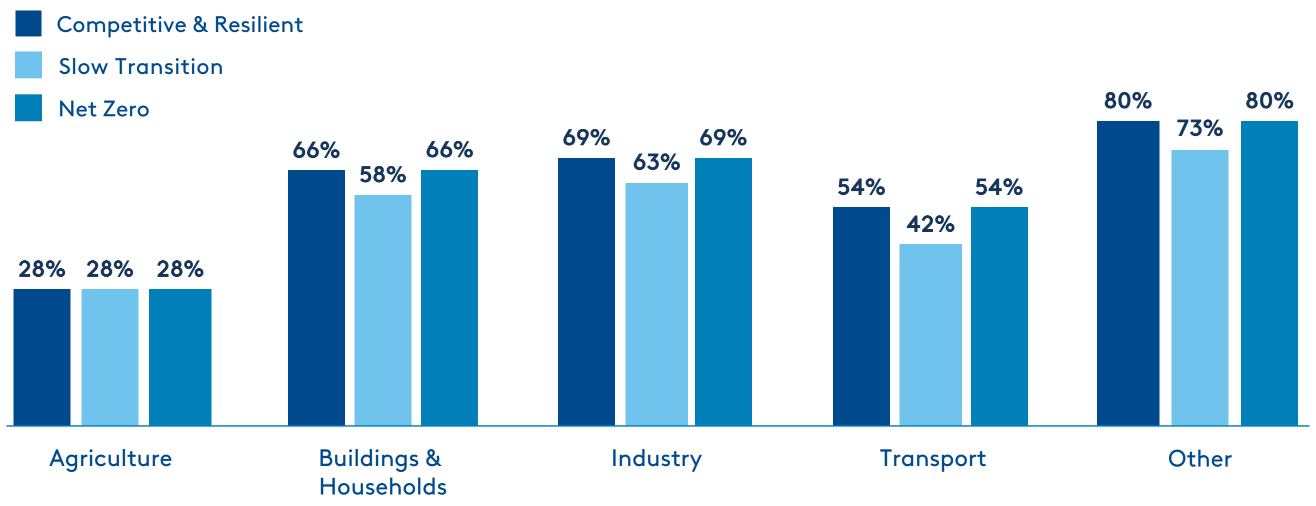
Model input	Diverse sources
Demand: Power, heat and hydrogen demand	European Commission, entsoe
Economic: Fuel and CO2 prices, cost of capital	Energistyrelsen, iea
Technology: Capacity factor, efficiency, meteorology	Energistyrelsen, TGS, 4C Offshore
System constraints: Transmission and RES build-out restrictions	ENERGINET, entsoe

Appendix

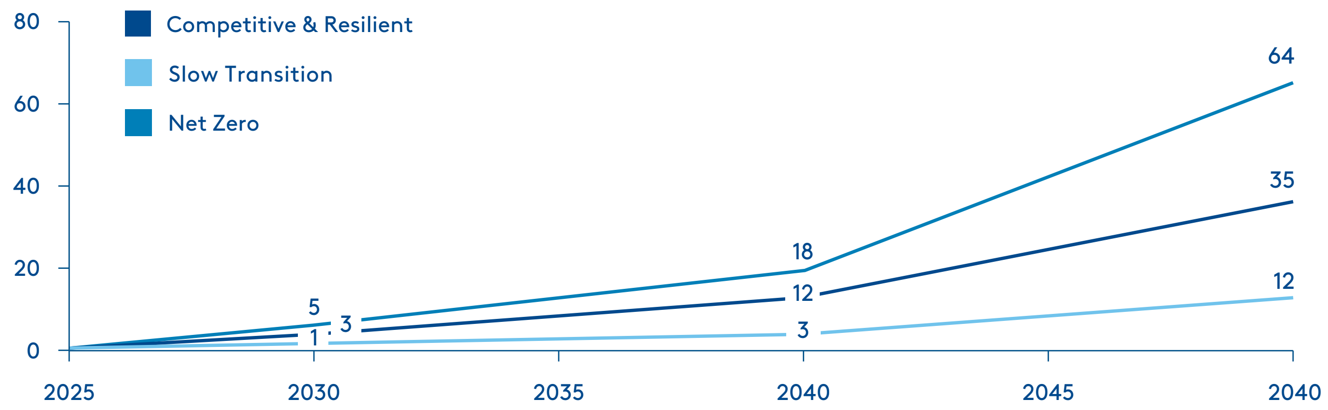
Final energy demand EU+ UK (TWh)



Sub-sector electrification in 2050 (% of total total demand)

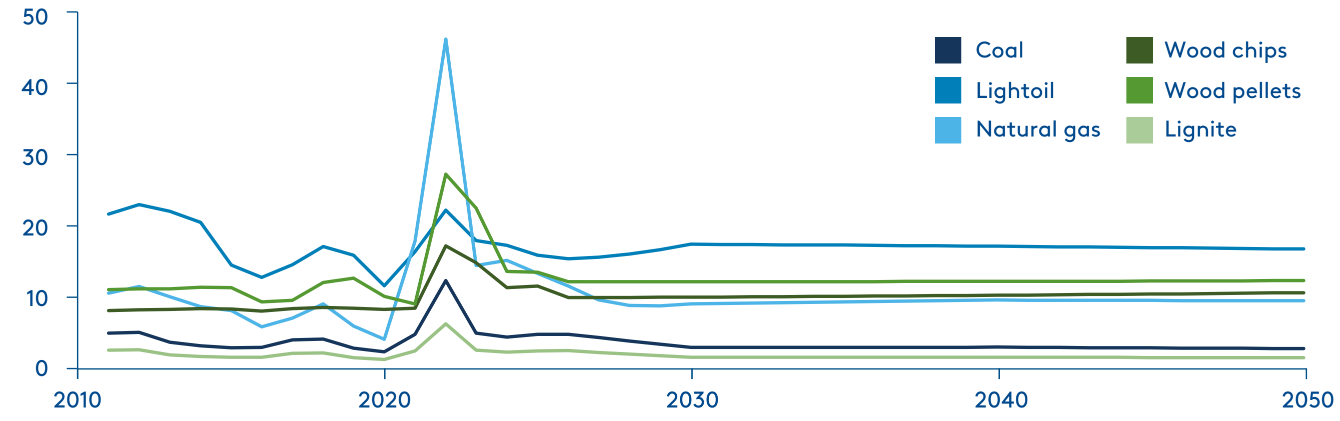


European clean hydrogen demand (mtpa)

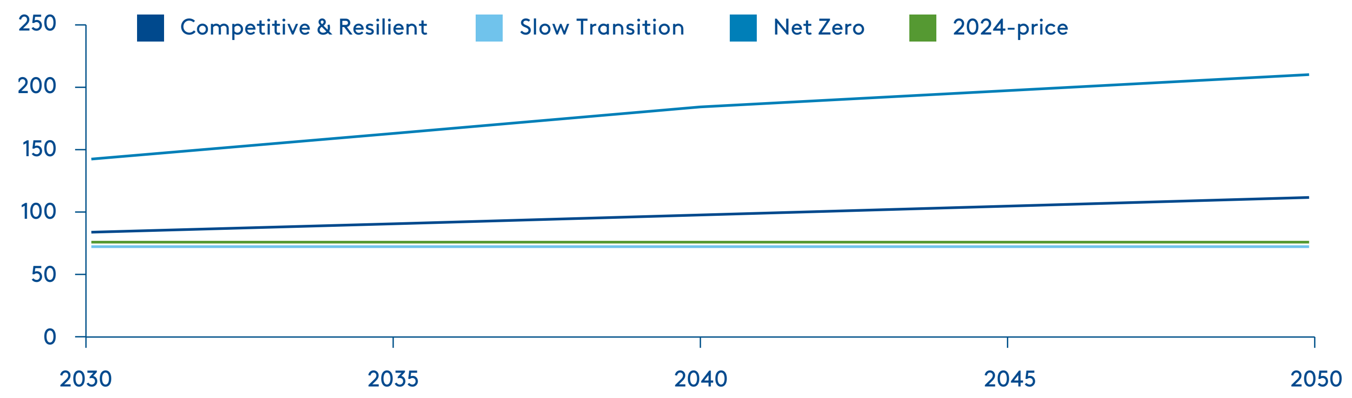


Appendix

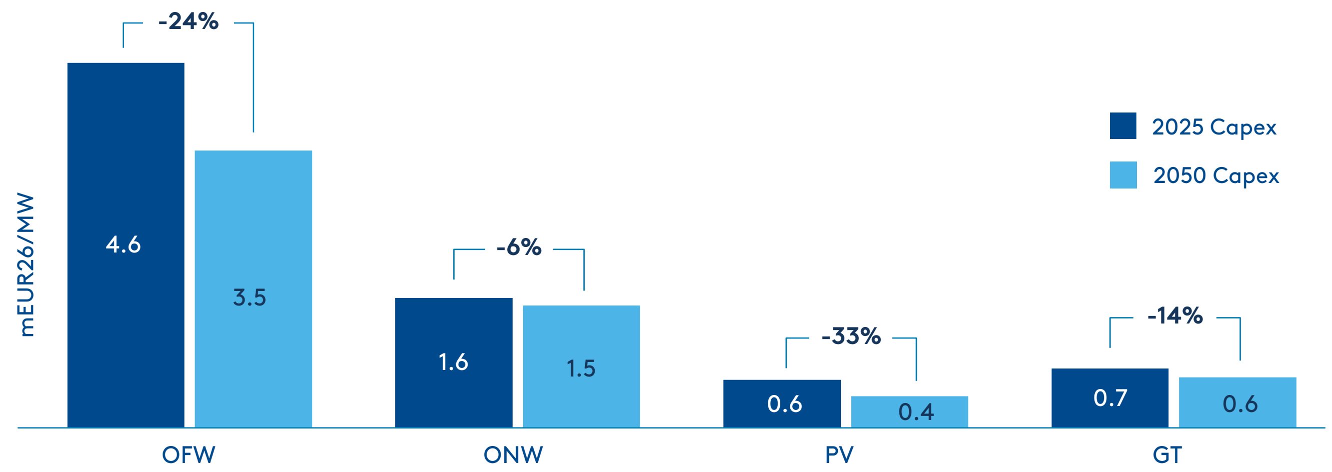
Fuel prices (EUR26/ton)



CO_2 prices (EUR26/tonCO_2)



Technology CAPEX



Appendix

Example of Key Assumptions

Nordsø III

- 91 km from shore
- 40-60 meters depth
- **Capacity factor of 60.0 %**

Nordsø I

- 41 km from shore
- 30-40 meters depth
- **Capacity factor of 57.6 %**

Aegir – Baltic Sea

- 40 km from shore
- 30-40 meters depth
- **Capacity factor of 53.0 %**

Capacity factor

	Onshore wind	Solar PV
DK	44.2%	11.8%
DE	41.4%	11.7%
ESP	38.9%	17.9%

Efficiency

	2030	2040	2050
Electrolyzer (Alkaline)	0.62	0.65	0.70
Gas turbine (combined cycle)	0.58	0.58	0.60
Gas turbine (simple cycle)	0.41	0.41	0.43
Lithium-ion batteries	0.92	0.92	0.92

Appendix

RES Build-out Restriction Assumptions

Solar PV capacity build-out is restricted to 1.25% of agricultural land by 2050 on a national level (~x8 of 2023 PV capacity in DK which covers 0.15% of agricultural land)

Onshore wind capacity build-out restricted by either NIMBY ("not in my back yard") principle or targets on a national level

Offshore wind capacity build-out is restricted by available offshore wind sites based on depth, distance to shore and wind speeds

Grid build-out is restricted to a maximum expansion of each corridor by 500 MW each 5 years

Transmission Grid

- Constructed
- Under construction
- Planned – not permitted
- Under consideration
- Under permitting
- Unknown

ENTSO-E TYNDP planned link towards 2030 (GW)

Interconnector	PT	-	ES	2.3	Under permitting
Biscay Gulf	ES	-	FR	4.4	Under permitting
Southwest-East corridor	CZ	-	DE	1.0	Under permitting
GerPol improvements	DE	-	PL	2.0	Under construction
Reinforcements Ring NL	DE	-	NL	1.2	Under construction
Celtic Interconnector	FR	-	IE	1.4	Under construction
Aurora 3rd AC	FI	-	SE	1.7	Under permitting
Baltic to Continental EU	LT	-	PL	1.4	Under permitting
Greenconnector	IT	-	CH	2.0	Under permitting
St. Peter - Pleinting	DE	-	AT	5.0	Under permitting
CZ Northwest-South	CZ	-	DE	1.0	Under construction
Würmlach - Somplago	AT	-	IT	0.3	Under permitting
Muhlbach - Eichstetten	DE	-	FR	0.6	Under permitting
GerPol Power bridge I	DE	-	PL	1.2	Under construction
Vigy - Uchtelfangen	DE	-	FR	3.0	Under permitting
Osterath - Philippsburg	DE	-	FR	1.6	Under permitting
Project 260	GB	-	NL	4.0	Planned – not permitted
Navarra-Landes	FR	-	ES	3.0	Under consideration
Lonne-Archenne-Gramme	BE	-	FR	2.0	Planned – not permitted
Greenlink	GB	-	IE	1.0	Under construction
West coastline & other	DE (NW)	-	DK (W)	2.0	Under permitting
BRABO II / III	BE	-	NL	2.0	Under construction
NeuConnect	DE	-	GB	2.8	Under construction
St. Peter - Tauern	AT	-	DE	4.0	Under construction
Isar/Altheim/Ottenhofen	AT	-	DE	2.8	Under permitting
Interconnector	DE	-	LU	2.0	Planned – not permitted
ZuidWest380 NL Oost	BE	-	NL	1.0	Under permitting
Lienz - Veneto Region	AT	-	IT	1.0	Planned – not permitted
VanEyck - Maasbracht	BE	-	NL	2.0	Under consideration
Lienz - Obersielach	AT	-	IT	1.0	Planned – not permitted
Westtirol - Zell/Ziller	AT	-	DE	1.2	Planned – not permitted
Beznau - Mettlen	CH	-	DE	0.7	Under permitting
Mettlen - Urichen	CH	-	DE	0.2	Under permitting
Bickigen - Chippis	CH	-	DE	0.5	Under permitting
Niederstedem - Roost	LU	-	DE	0.8	Planned – not permitted

Appendix

Sensitivities Performed on Results from 2050

Highest # Lowest #

	Parameter	Competitive & Resilient	Slow Transition	Net Zero	Introduction of SMRs	Reduced PV build-out	More solar PV and ONW	More solar PV	Low electrolyzer CAPEX	Behind the meter ELZ	High electrolyzer CAPEX	Changing tracks	NIMBYism
Power	Total power consumption (TWh)	6,253	5,107	7,129	6,246	6,226	6,287	6,283	6,284	6,280	6,241	7,119	6,227
	Offshore power capacity (GW)	222	203	388	200	306	185	203	228	204	206	385	344
	Onshore wind capacity (GW)	572	392	608	538	624	615	545	564	578	581	609	448
	PV power capacity (GW)	1,677	1,112	1,887	1,499	1,102	1,826	1,954	1,677	1,732	1,718	1,884	1,492
	Installed power storage (GW)	350	238	441	309	231	350[1]	350[1]	302	296	350[1]	451	323
	Average power price (EUR/MWh)	66	69	74	59	78	59	62	64	65	67	74	73
	North Sea offshore wind capacity (GW)	186	171	305	168	241	155	171	193	172	173	304	272
	Baltic offshore wind capacity (GW)	32	28	74	28	61	25	27	31	27	29	72	64
	UK average power price (EUR/MWh)	65	69	76	59	76	59	64	63	64	66	76	71
	ES average power price (EUR/MWh)	55	56	59	54	68	50	51	53	52	56	59	64
Hydrogen	Total installed ELZ capacity (GW)	247	66	420	225	261	250	263	336	336	223	410	258
	Average H2-production cost (EUR/KG H2)	3.2	3.1	3.4	3.1	3.9	2.9	3.0	2.8	2.9	3.5	3.3	3.7
	European H2-production (Mt of H2)	23	6	41	22	22	23	23	23	23	22	41	22
	External H2-imports (Mt of H2)	6	6	6	6	6	6	6	6	6	6	6	6
	Peak plant consumption (Mt of H2)	0.4	0.1	2.8	0.0	0.0	0.9	0.9	1.1	1.0	0.2	2.9	0.0
	North Sea H2-production (Mt of H2)	13	3	25	13	12	13	12	14	13	12	25	13
	Baltic H2-production (Mt of H2)	3	1	8	3	7	3	3	3	3	4	8	4
Grid	Interconnector investments (billion EUR)	106	107	189	94	137	84	87	104	108	110	179	145
	H2 infrastructure (pipelines) (GW H2)	256	173	344	240	294	251	262	293	273	250	348	279

Notes: 1) Model optimization for Competitive & Resilient shows 350 GW of battery to be optimum, which is used for all sensitivities as the upper limit

Appendix

Sensitivities Performed on Results from 2050

Highest # Lowest #

	Parameter	Competitive & Resilient	Slow Transition	Net Zero	Faster transmission build-out	No pipeline	Reduced gas price	WACC 1%-point higher	WACC 1%-point lower	AI boom	AI bust	Low battery cost	Reduced resilience	Low OFW CAPEX
Power	Total power consumption (TWh)	6,253	5,107	7,129	6,255	6,515	6,237	6,245	6,264	6,452	6,129	6,252	6,237	6259
	Offshore power capacity (GW)	222	203	388	223	236	194	198	238	242	210	205	229	340
	Onshore wind capacity (GW)	572	392	608	574	607	563	568	578	583	566	557	579	507
	PV power capacity (GW)	1,677	1,112	1,887	1,689	1,748	1,691	1,704	1,665	1,718	1,645	1,762	1,658	1479
	Installed power storage (GW)	350	238	441	350[1]	350[1]	350[1]	350[1]	350[1]	350[1]	350[1]	554	350[1]	323
	Average power price (EUR/MWh)	66	69	74	65	66	64	70	61	68	65	64	66	60
	North Sea offshore wind capacity (GW)	186	171	305	187	198	164	166	200	204	177	173	191	263
	Baltic offshore wind capacity (GW)	32	28	74	32	34	26	28	33	34	29	28	33	68
	UK average power price (EUR/MWh)	65	69	76	64	65	63	70	59	67	64	63	63	55
	ES average power price (EUR/MWh)	55	56	59	55	58	55	60	49	56	55	56	55	49
Hydrogen	Total installed ELZ capacity (GW)	247	66	420	247	301	237	243	254	257	243	219	243	259
	Average H2-production cost (EUR/KG H2)	3.2	3.1	3.4	3.2	3.3	3.3	3.5	3.0	3.3	3.2	3.1	3.2	3,0
	European H2-production (Mt of H2)	23	6	41	23	28	22	23	23	23	23	23	22	23
	External H2-imports (Mt of H2)	6	6	6	6	0	6	6	6	6	6	6	6	6
	Peak plant consumption (Mt of H2)	0.4	0.1	2.8	0.4	0.3	0.2	0.3	0.5	0.3	0.5	0.4	0.0	0,2
	North Sea H2-production (Mt of H2)	13	3	25	13	16	13	13	13	13	13	13	12	15
	Baltic H2-production (Mt of H2)	3	1	8	4	4	3	4	3	3	4	3	3	3
Grid	Interconnector investments (billion EUR)	106	107	189	113	107	90	99	112	115	98	103	119	129
	H2 infrastructure (pipelines) (GW H2)	256	173	344	254	268	257	257	256	261	257	258	251	267

Notes: 1) Model optimization for Competitive & Resilient shows 350 GW of battery to be optimum, which is used for all sensitivities as the upper limit

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