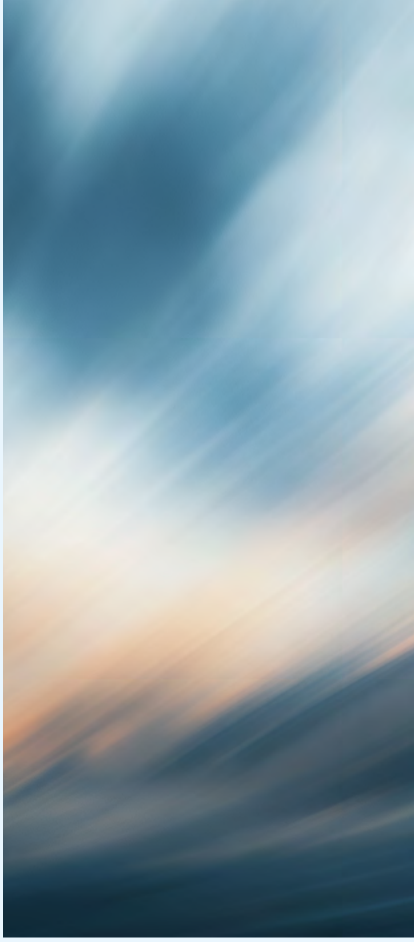
Statkraft

Green Transition Scenarios



2025

Contents

The energy transition endures. Its next phase will be critical for climate, costs, and security.

Birgitte Ringstad Vartdal, Statkraft CEO

What next for the energy transition?

The energy transition is advancing, but not without friction. Its backdrop is one of growing political polarisation, trade disputes, and armed conflict. These shifts are reshaping global energy markets and directly affecting the renewables industry. While onshore wind and solar are becoming increasingly cost competitive and continue to grow at high pace, immature technologies such as hydrogen and CCS have faced setbacks from increased costs.

And while global coal use is expected to peak in the coming years, fossil fuel use remains high. Energy plays an important role in both security and competitiveness, and in many regions, the strong dependency on imported fossil fuels creates dilemmas around energy security and costs for societies and industry.

This report draws on Statkraft's deep market expertise and 130-year history of developing and operating renewable energy in weather-based energy systems. It assesses and quantifies today's realities, and asks one of the critical questions of our time: what next for the energy transition?

Reasons to be optimistic

If you want a reason to be optimistic about the future of the energy transition, just look up. Fifteen years ago, the IEA estimated that solar power would make up 294 GW of the world's electricity capacity by 2030. By the end of 2024, we had already surpassed 2200 GW. This past June, solar was the biggest power source in the EU for the first month ever.

There's optimism in the air, too: an all-time high of 117 GW of wind power was installed globally in 2024. Over the first half of 2025, renewables generated more power than coal globally for the first time in history.

As more intermittent renewables come into the energy system, the need for flexible energy solutions increases. Battery storage solutions play a critical role in solving this challenge, and have, importantly, seen a cost drop of more than 90% since 2010.

When it comes to emissions, there is progress, with Europe registering a 37% drop since 1990, and China potentially soon reaching its own peak of CO_2 emissions. It is, however, clear that further efforts are needed to avoid severe climate damages.

Those realities are in the here and now. But what about the years to come?

How resilient is the energy transition in a changing world?

This is the third year that our analysts have projected the energy transition across not one, but three scenarios – a reflection of the increasingly complex geopolitical landscape. Each scenario reflects varying degrees of ambition, disruption and cooperation, providing different outlooks for the energy future towards 2050.

This year's report identifies key trends consistent across scenarios:

- Solar and wind are on track to become the world's largest energy sources by 2035.
- The remarkable drop in battery costs is unlocking critical flexibility, needed to deploy more wind and solar.
- Electricity consumption will surge while energy consumption will decline as we transition away from fossil fuels.
- Gas will remain in the energy mix for longer than expected, as CCS and hydrogen struggle to scale.

Between the lines, however, there are concerns we can't ignore. While our report projects declines for coal and oil towards 2050, there is a significant difference in the pace of fossil phase-out between the scenarios. The 1.5°C target appears out of reach, while a 2.4°C increase (as our 'Unrest' scenario points to) will bring severe consequences for societies and economies.


Location: Ulla-Førre, Suldal, Norway

The renewable industry also faces challenges in building public support for new developments, especially onshore wind. Central to this discussion is the issue of land use and concerns about energy infrastructure's impact on nature and people. These are concerns that we need to address with care and transparency.

Even a conflicted world can't stop the energy transition

At its core, this report says one thing: the energy transition continues even in a more conflicted world. The market has spoken, and renewable energy is cost effective and reducing emissions at scale. And it's doing it globally.

While the energy transition is delayed compared to three years ago, it is still moving much faster than we thought 10 years ago. In just 25 years, the share of renewable electricity generation globally has nearly doubled. That's a remarkable shift, especially given the complexity of the transition and the challenges we continue to face.

The momentum is real, and I hope the pages of this report offer not just insight into what comes next, but a clear view of how far we've come.

The Green Transition Scenarios in 12 graphs

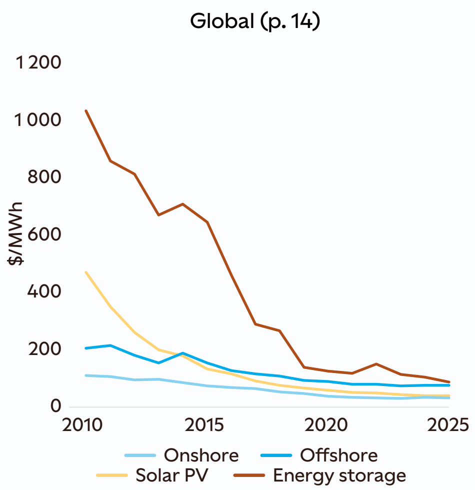
This report features three energy system scenarios to 2050 reflecting varying degrees of ambition, disruption and cooperation, offering insights into how the world, Europe and Norway might navigate the complex path towards a sustainable energy future.

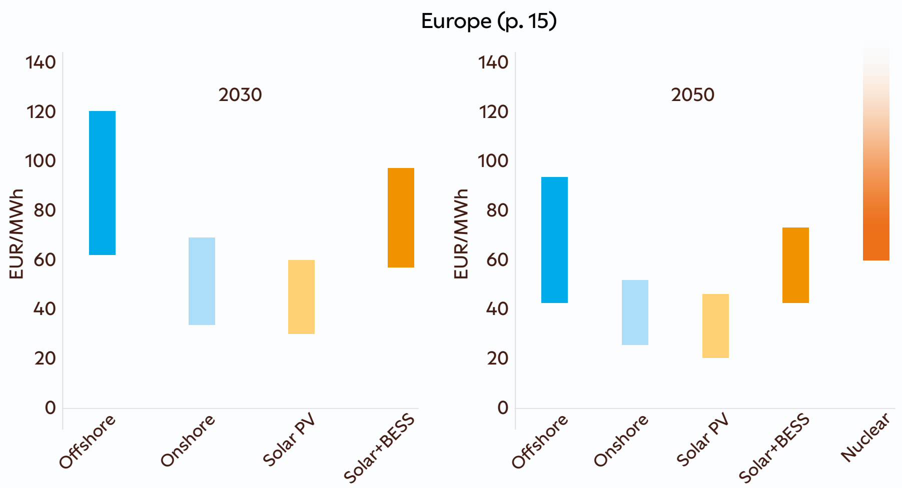
The **Green Transition Scenario** is the most optimistic yet plausible scenario. It envisions a world where technological innovation, market forces, and proactive policymaking converge to accelerate the energy transition efficiently.

In the **Delayed Transition Scenario,** geopolitical tensions persist, but trade remains relatively stable through new alliances.

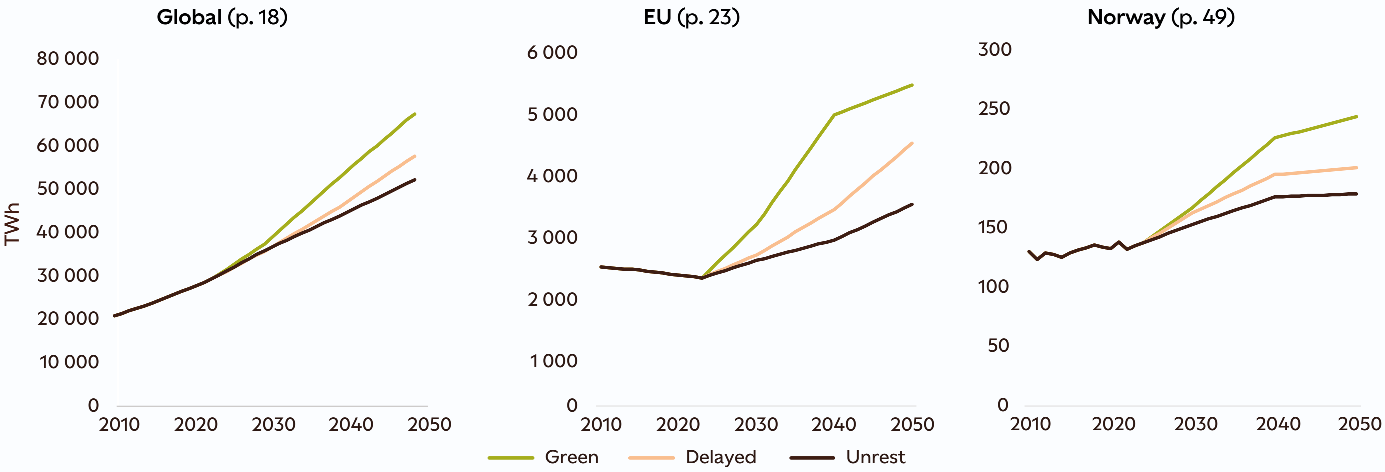
The Unrest Scenario represents a more severe delay. Europe is increasingly isolated. The world moves away from a Western-led rules-based order. Hostile geopolitical threats; cyberattacks, territorial disputes, foreign interference, dominate the agenda.

Cost decreases of mature clean technologies set to continue. Renewable costs are massively reduced since 2010. Costs are expected to decrease further, but at a slower pace to 2050. Levelised cost of electricity and storage (LCOE and LCOS):

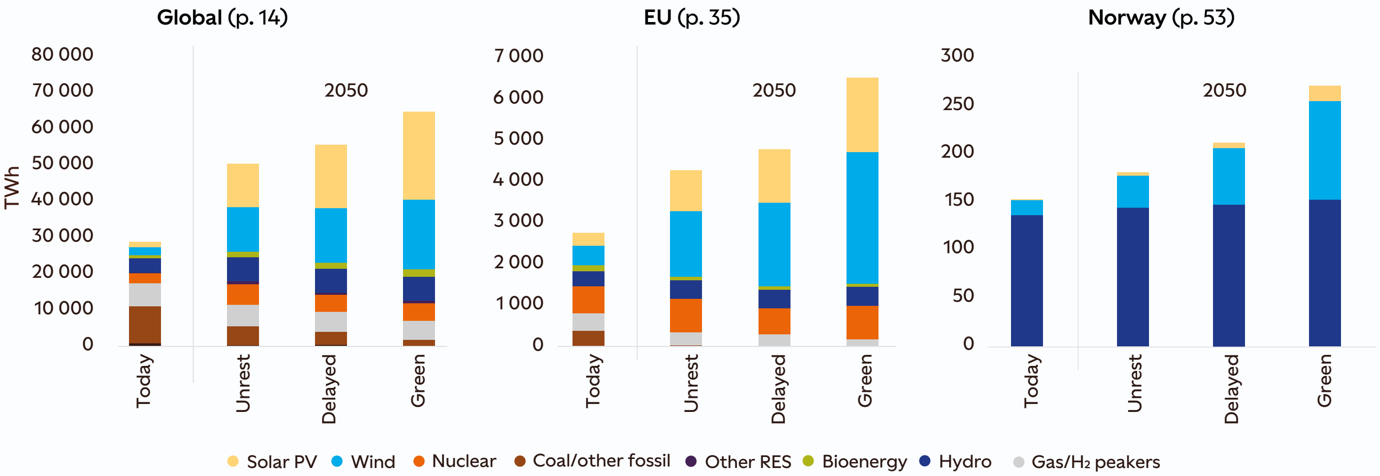




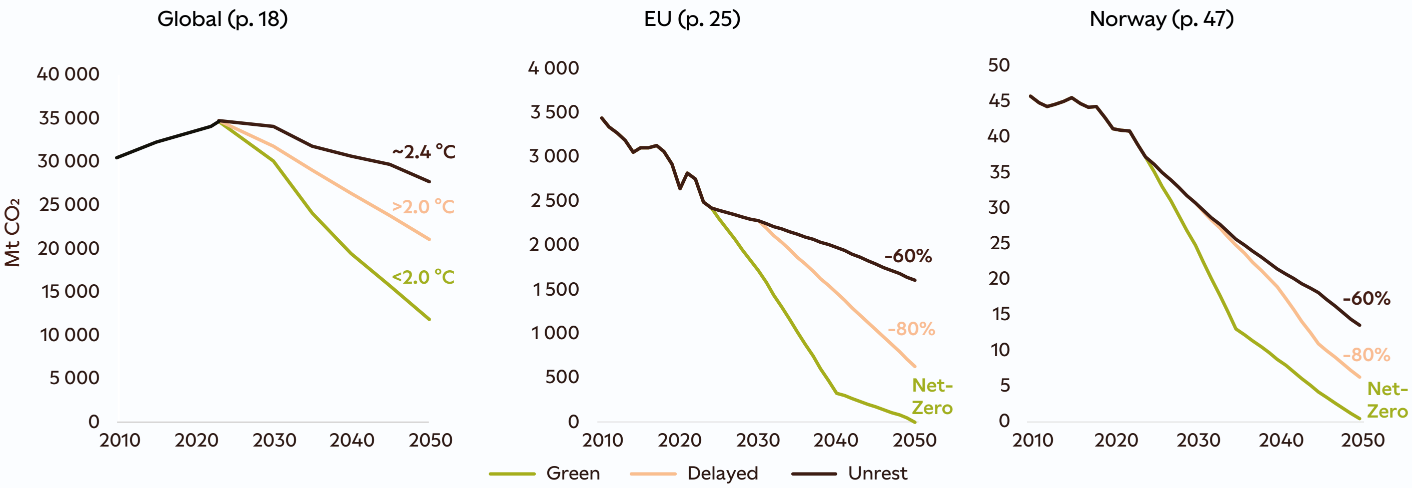
Electricity consumption increases in all three scenarios. At the same time, total energy demand decreases and the energy systems become more efficient and less fossil fuel reliant. Electricity consumption in the three scenarios:



Solar and wind to dominate even in an Unrest scenario and will become the world's largest energy sources. In Norway, hydropower remains the largest to 2050 in all scenarios. Multiple flexibility solutions added to the power system support the integration of intermittent renewables. Power generation in the three scenarios:



Emissions decrease across all the three scenarios as renewable power and other mature clean technologies show strong growth. Geopolitical tension and higher costs for the hard-to-abate solutions add uncertainty to the speed of the transition. More efforts are needed for the Green scenario to materialise. CO_2 emissions in the three scenarios:



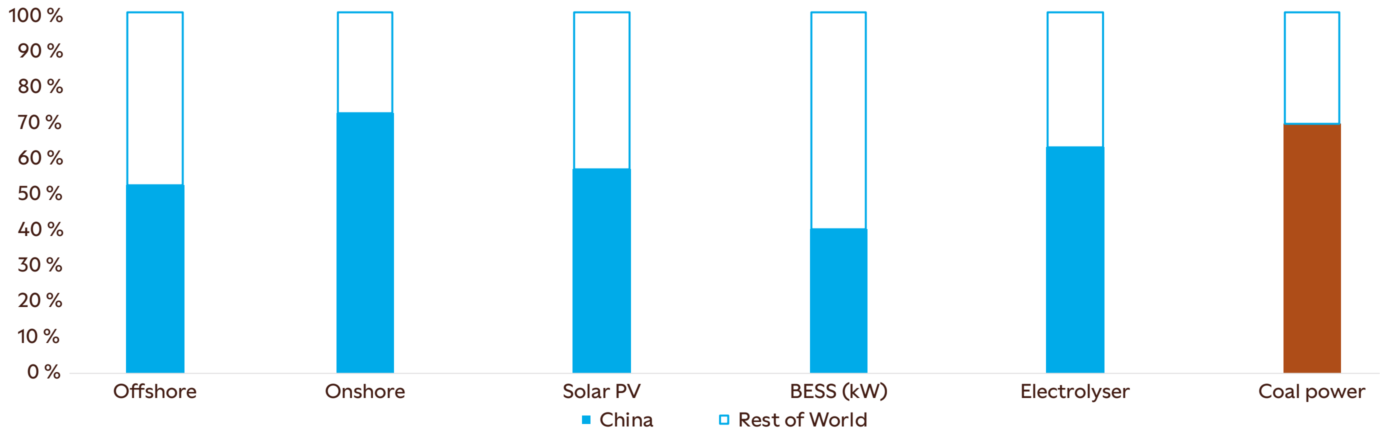
PART 1

The Energy Transition Context

The world is in a phase of geopolitical uncertainty and conflict not seen for almost a century. This shift is characterised by the erosion of the rules-based international order on many fronts, encompassing increased political polarisation, punitive trade policies and increased armed conflict, all amidst a worsening climate crisis. Despite these developments, the energy transition continues to progress. Energy is a crucial part of national security while industrial competitiveness and households' welfare remain dependent on reliable and affordable energy. Within this context of global uncertainty, conflict and climate crisis, we have developed three scenarios that explore potential pathways for the energy transition to 2050.

Location: Ulla-Førre, Suldal, Norway

1 Share of new capacity installed in 2024 in China versus the rest of the world (by technology, %)[2]



The global energy transition progresses despite conflicts

The global energy transition faces new challenges in an era of high tension. The number of armed conflicts in the world is increasing, and 2024 saw the highest number of state-based armed conflicts since the end of the Second World War. The war in Ukraine continues to dominate the political discourse in the West and impacts political priorities and public spending. In Europe – including in Norway - defence and security considerations are driving policy developments in several sectors. In addition to the war in Ukraine, conflicts in the Middle East and elsewhere add to global tension and further strain international cooperation.

The global trading system has entered a period of unpredictability and heightened tension, leading to shifts in trade patterns, pressures on established alliances and weaker economic growth projections. The introduction of variable tariff levels by the US is widely seen as having negative economic effects both for the US and its trading partners. Trade barriers and protective measures could also lead to slower and more costly dissemination of technologies, alongside growing concerns about vulnerabilities and disruptions in value chains. The international trading system will continue to be marked by uncertainty.

The EU is currently striving to balance a fast-paced energy transition, reduced dependence on volatile fossil fuel imports while ensuring the competitiveness of its existing industries. Today, the EU is reliant on imported fossil fuels on the one hand and China's dominant clean tech supply chain on the other.

The 2025 US-EU handshake trade agreement signals that Europe will continue to rely on LNG purchases in the coming years. China's global lead in the clean tech industrial ecosystem including critical raw materials, battery manufacturing, the electric vehicle industry and its dominance in solar equipment adds a different vulnerability to the European energy transition. Within this framework, the EU is currently prioritizing more clean, homegrown energy and energy independence.

Despite current challenges, we continue to see massive growth in clean technologies globally. In 2024, investments in clean energy and infrastructure continued to increase, amounted to almost double those investments in fossil fuels globally.[1] Solar and wind generation accounted for 57% of the increase in global electricity supply in 2024, with generation rising by 17% compared with 2023. While it took a year to add 1 GW of global solar capacity globally in 2004, this volume is now installed in less than a day. China installed 340 GW of solar PV and 80 GW of wind capacity in 2024, representing 59% and 72% of global installations (Figure 1). China has a large domestic market, substantial subsidies and strong domestic manufacturing supporting its energy transition. However, there is also strong growth in renewables in other parts of the world and solar capacity outside China grew by 30% in 2024. Growth has been robust in established markets such as the US, Europe and China, but expansion is increasingly seen in emerging markets such as India, Pakistan and Turkey, which possess substantial renewable potential. Wind generation reached a new record

Location: Renovables del Cierzo, Navarra, Spain

Wind generation reached a new record in 2024, up 8% from 2023. In Europe, onshore wind growth remains steady, while the US experienced a significant reduction in 2024.

in 2024, up 8% from 2023. In Europe, onshore wind growth remains steady, while the US experienced a significant reduction in 2024. The effect of new energy policies in the US remains to be seen, but the uncertainty introduces doubts about the future domestic growth in clean technologies.[3]

The transition to a more renewable and electrified energy system requires significant investments in technology, infrastructure, and policy frameworks to ensure a stable and reliable energy supply. Trade disputes, high financing costs and high conflict levels risk slowing down these investments. Energy security agendas, technology cost developments, geopolitics, public acceptance, economic development and climate priorities will all determine how the energy transition unfolds. We have therefore developed three scenarios for the global, European and Norwegian energy systems from today to 2050. These are described in more detail in the next section and in Annex I.

Introduction to scenarios of possible energy futures

We have developed three scenarios that explore potential pathways for the energy transition in the context of evolving geopolitical, economic, and technological landscapes. Each scenario reflects varying degrees of ambition, disruption and cooperation, offering insights into how Europe and the world might navigate the complex path towards a sustainable energy future.

The Green Transition Scenario (*Green*) is the most optimistic yet plausible scenario. It envisions a world where technological innovation, market forces, and proactive policymaking converge to accelerate the energy transition efficiently. Despite ongoing global tensions, international trade remains robust, supported by resilient supply chains and strong economic growth. Relations between major powers like China, the EU, and the US are governed by clear rules, leading to improved geopolitical stability within a decade. In this scenario, society is better protected against political polarisation and disinformation campaigns. Clean technologies and AI accelerated change will drive industrial innovation, while the declining cost of renewables supports a global shift towards sustainable energy. Energy security and climate goals are largely aligned, enabling a rapid and coordinated global transition.

Due to heightened geopolitical tensions and growing concerns over energy security and supply chain disruptions, this year's analysis includes two more pessimistic scenarios where these issues take precedence over climate action. Inflation, high living costs, limited fiscal capacity and increased defence spending divert resources from clean energy investments. While renewables remain attractive due to cost advantages, progress in decarbonising the hard-to-abate sectors is slow. Fossil fuels persist longer in the energy mix, and public funding for climate initiatives remains limited.

In the Delayed Transition Scenario (*Delayed*), geopolitical tensions persist, but trade remains relatively stable through new alliances and regional blocs. Europe responds with a renewed focus on energy independence and affordability. Investments in renewables and electrification are driven by both cost competitiveness and strategic necessity. In this scenario, the EU pushes for reshoring of key industries. While not as ambitious as the Green Transition Scenario, this scenario still achieves significant emissions reductions and clean tech deployment, albeit at a slower pace.

The Unrest Scenario (*Unrest*) represents a more severe delay. Europe becomes increasingly isolated as the world moves away from a Western-led rules-based order. Hostile geopolitical threats such as cyberattacks, territorial disputes and foreign interference dominate the agenda throughout the analysis horizon. Economic growth slows, and priorities shift toward defence, jobs, and security. Climate policies lose momentum. Clean technologies face higher costs and slower deployment, while populist movements gain influence, leading to erratic policymaking. The growing frequency of disinformation negatively affects decision-making, public opinion and democratic discourse. Social unrest and political instability further hinder progress, resulting in a fragmented and slower global energy transition.

For more details on the methodology, assumptions and key parameters, see Annex I.

There is a growing risk that the energy sector will be exploited by hostile actors to deepen polarisation and erode public trust in governments and the industry.

Security and energy are mutually interdependent.

Facing a new era of risk: Preparing society for hostile state actor attacks. The likelihood of sabotage in Europe and Norway has increased. Energy infrastructure is a potential target for disruption and damage. Such actions aim to disrupt systems, limit energy supply to critical sectors, and create fear and distrust among the population. Digital sabotage, such as cyberattacks, can also disrupt IT and control systems. The use of artificial intelligence (AI) in cyber operations increases the capability, reach, and effectiveness of such attacks.

Reliable access to energy is crucial for society. European energy infrastructure is defined as critical. To strengthen security of supply against threats, safeguarding or improving areas such as decentralisation of energy, securing supply chains for critical equipment, enhancing cooperation between sectors (such as energy, defence and telecoms), and increasing interconnection with neighbouring energy markets, will be essential.[4] In this new geopolitical landscape, the EU has a clear ambition to reduce its dependencies by building more homegrown energy, boosting energy infrastructure, creating new alliances for energy supply and reducing vulnerabilities in strategic supply chains.

There is also a growing risk that the energy sector will be exploited by hostile actors to deepen polarisation and erode public trust in governments and the industry. False narratives around the energy agenda, renewable energy and climate policy can delay critical action. Disinformation may lead to political polarisation, reduced public support for green investments, and increased vulnerability to malign actors influencing the energy-debates.[5]

Underlying energy consumption is also impacted by heightened security focus. To take a larger share of the security responsibilities, European NATO countries have pledged to increase defence and security spending to 5% of GDP while expanding the scope of what constitutes security-and-defence-related spending. This signals continued high investments in these sectors which now clearly include the energy and infrastructure sectors. From 2021 to 2024, the EU's military budget increased by 30% to around €326 billion, while the 'ReArm Europe Plan' calls for an additional €800 billion increase to its military budget by 2030.[6] These military efforts are energy intensive and will affect both GDP and energy use going forward.


Location: Landesbergen, Germany

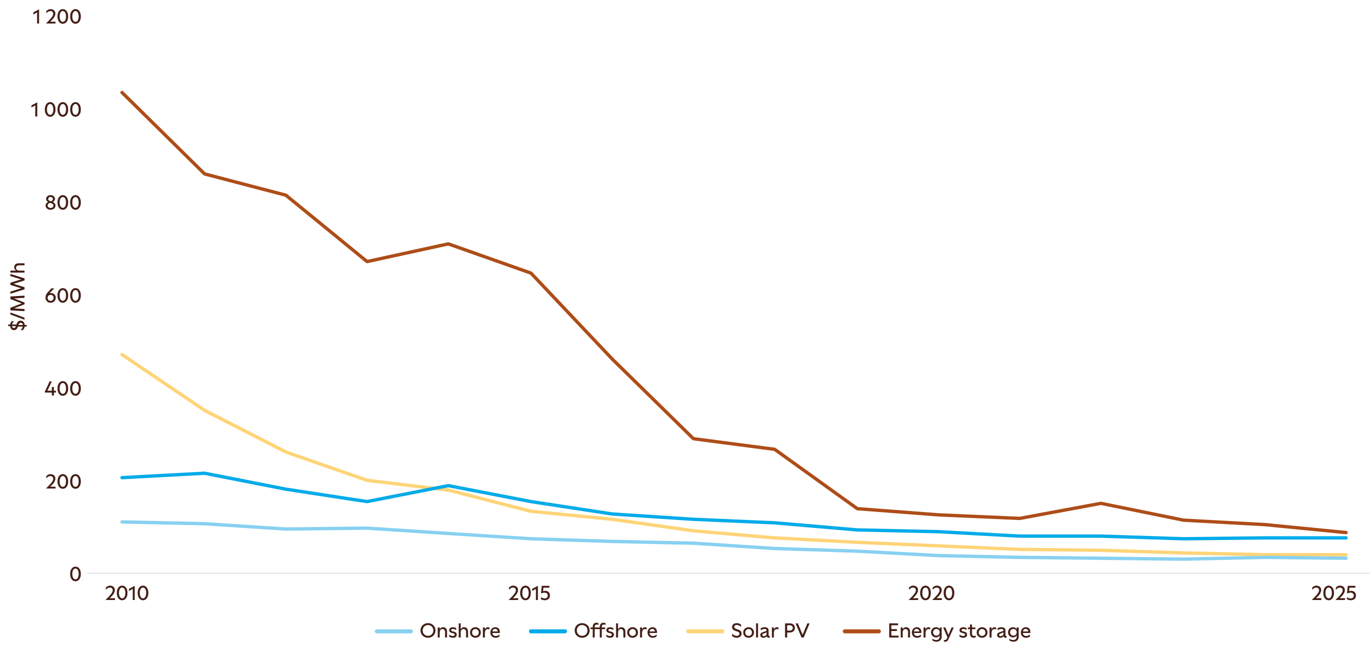
PART 2

Global Energy Scenarios

Economic competitiveness is a major driver of the energy transition, and this chapter starts with an assessment of cost outlooks for the major clean technologies followed by a presentation of three distinct pathways for the global energy transition. Solar PV and onshore wind are already cost-competitive technologies and costs will continue to decline, albeit at a slower pace. Less mature technologies and value chains require policy support for longer and see a larger outcome space. Global energy-related CO_2 emissions will peak before 2030, followed by a decline to 2050 in our scenarios. This will largely be driven by a shift from fossil fuels to renewable energy and electricity, combined with increased energy efficiency.

Location: Talayuela, Spain

2 Global weighted LCOE and LCOS of projects starting operations in the given year from IRENA up to 2023 and Statkraft analysis in 2024 and 2025 ($/MWh, real24)[i,7]



Renewable costs: Holding steady before continued reductions

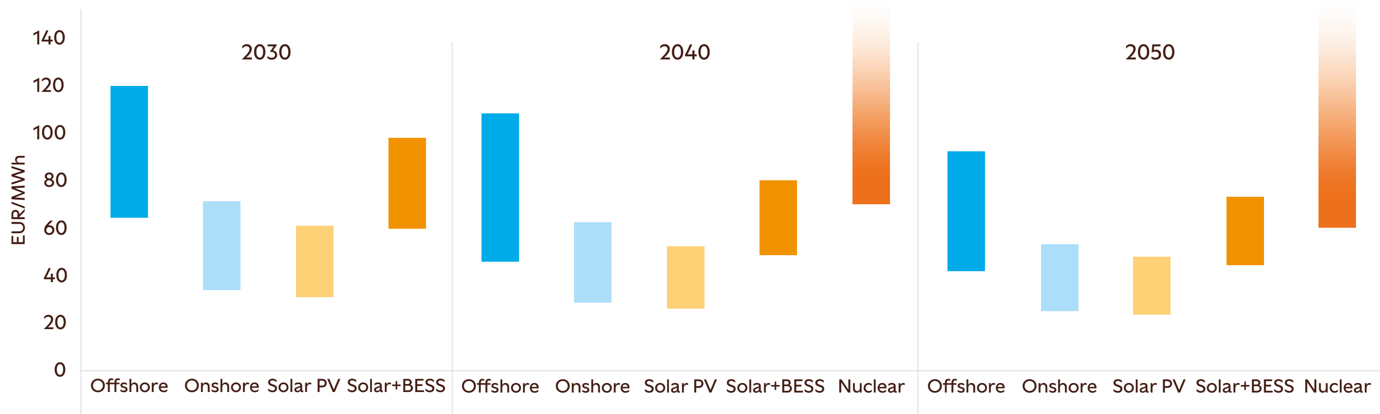
Clean technology cost developments are driven by climate policies, technological innovations and shifting economic dynamics. Each technology faces unique challenges and opportunities that shape its cost development. Mature technologies such as onshore wind and solar PV have established supply chains that are more resistant to the uncertainties of recent years. Solar PV and battery costs are reduced by around 90% the last 15 years, while onshore wind costs are reduced by about 70%. However, cost reductions in these technologies are now slower than those observed over the past 15 years (Figure 2). Less mature technologies such as hydrogen electrolysis and offshore wind are more susceptible to changes in economic conditions and technology development, and these technologies have seen a rise in actual costs and cost estimates recently.

China is the dominant force in the development and manufacturing of clean energy technologies. Solar modules and battery cells are at record low costs due to steady technology progress as well as manufacturing oversupply and strong competition domestically. As current margins in the supply chains of both solar and battery energy storage are squeezed to unsustainable levels, we expect fewer cost reductions over the next few years. Chinese wind turbine manufacturers, facing intense domestic competition, are targeting emerging markets in Asia, Africa, and South America. The lower cost of Chinese technologies is challenging Western manufacturers in these regions.

China will continue to affect global renewable costs, but exactly how this unfolds will depend on the world's willingness to trade without barriers. The Green Transition Scenario assumes a higher degree of geopolitical stability on average in the period to 2050 than we have experienced in recent years, and although manufacturing can shift away from China, global competition and a reduction in trade barriers help keep costs low in this scenario. In the Delayed Transition Scenario, trade is still high, but more within blocs. Energy independence is important, and costs rise due to trade barriers, local content requirements and reshoring of manufacturing. In the Unrest Scenario, technologies become more expensive due to reduced trade and high trade barriers. There will also be slower technological development due to weaker cross-border cooperation and lower economic growth.

[i] LCOE: Levelised Cost of Electricity ($/MWh). LCOS: Levelised Cost of Storage ($/MWh)

3 | LCOE forecast of various technologies in Europe in 2030, 2040 and 2050 (EUR/MWh, real'24)[i]



Long construction timelines, complex logistics, and reliance on specialised infrastructure make offshore wind particularly sensitive to macroeconomic conditions, and since early 2023, offshore wind has faced significant cost increases due to high interest rates, supply chain constraints, and inflation. These factors have made offshore wind less attractive in the short term, especially when competing with onshore wind and solar PV.

Despite current challenges, the long-term cost outlook remains more optimistic for offshore wind. Supply chain maturity in bottom-fixed offshore wind and innovations in floating offshore wind technology are expected to drive cost reductions, while policy support and national targets are fostering continued investment. Offshore wind farms benefit from stronger and more consistent wind speeds than onshore sites, delivering higher energy yields and more reliable power generation while facing less public opposition.

In all scenarios, offshore wind costs decline significantly by 2050, although they remain higher than onshore wind and solar PV in most regions (Figure 3). In the Green Transition Scenario, offshore wind benefits from targeted support aimed at accelerating industry development. This backing contributes to cost reductions driven by improved production efficiency and technological innovation. In *Unrest* and *Delayed*, however, we see significantly higher long-term costs because fewer projects are expected, reducing mass production learning effects. In *Unrest*, we assume less government support for offshore wind. In a world where energy security is valued more highly, offshore wind is likely to be a part of that strategy. This is reflected in *Delayed*, where the LCOE of offshore wind will fall by about 40% from today to 2050.

Onshore wind is one of the most cost-effective and competitive clean technologies. From 2010 to 2025, the global weighted LCOE has fallen by 70%, driven by lower project costs and improved turbine performance (Figure 2). Turbines have increased in size from 2-3 MW in 2010 to 4-6 MW most often used in today's market, and together with higher towers, this has increased the power output of each wind turbine. However, cost increases from 2021 to 2023, driven by higher raw material prices, inflation, and rising interest rates, led to financial difficulties for Western turbine manufacturers, resulting in a strategic shift towards fewer turbine models and longer product lifecycles. Turbine prices have currently plateaued and are beginning to stabilise, suggesting a return to cost reductions in the future.[8]

Chinese turbine manufacturers, with a large domestic market, currently have an advantage in global competition with Western manufacturers. Strong competition, together with standardisation and streamlining of turbine portfolios, is expected to drive cost reductions in the next decade. In *Delayed*, the LCOE is expected to fall by about 35% by 2050. In *Green*, the LCOE is down around 45% in the same period. In *Unrest*, heightened geopolitical tension and lasting financial struggles delay cost reductions, leading to higher costs. However, even in this scenario, onshore wind remains one of the cheapest and fastest power sources to deploy compared with other renewable and non-renewable options (Figure 3).

In many regions, the main challenge to onshore wind growth is not cost but rather access to land, access to grid and local acceptance. Many countries have height and distance requirements for wind turbines near residential areas, and this limits the number of available sites in populated areas. In our modelling, wind power is often the more cost-effective option compared with

solar PV; however, solar energy is often easier to develop and faces less public resistance.

Solar PV has emerged as a frontrunner in the energy transition due to its rapid cost declines, short construction time-lines, and ease of development. Costs of PV modules have fallen markedly over the last years due to efficient mass production, strong competition and oversupply in Chinese manufacturing. Module efficiencies have continued to improve at a steady rate, and larger panel sizes are decreasing balance-of-plant costs. However, as margins for PV modules are squeezed, costs are expected to stabilise, despite continued increases in module efficiencies. With a significant decrease in module costs, other costs such as land and grid connection costs are increasingly becoming more important, which is why LCOE decreases have slowed down, even for solar. Module costs now represent only about 20% of total installation costs.

In the Green Transition Scenario, China will continue to be the frontrunner of technological development of solar modules. There is a limit to how efficient one-junction silicon solar cells can theoretically be, but in this scenario the efficiency improvements continue at a similar pace to recent years as new technology solutions are developed. In the event of a breakthrough in the development of two-junction silicon solar cells, efficiencies could improve even faster than we assume in this scenario. In *Delayed*, we see increasing costs especially in countries that are more likely to develop their own supply chains, such as in the US and Europe. In Europe, there is currently a policy push for EU Member States to prioritise non-price criteria in auctions such as energy security and local supply chains. In *Delayed*, the effect is that costs are moderately higher compared with *Green*. In this scenario, LCOE will fall by about 30% from today to 2050, a smaller reduction than for onshore wind due to the current tight margins of solar. In *Unrest* trade is further limited, and costs are higher as countries are forced to use more locally produced solar modules. There is no complete separation from Chinese technology, but in this scenario energy security is prioritised and most of the production is local.

Site and grid connection availability is limiting cost reductions in wind turbines and solar modules as projects are developed on the most profitable sites first. Later projects are forced to be developed at sites with less solar irradiation or weaker wind conditions, and this will give an increase in LCOE through reduced power output. Weather resources are more important for wind project economics as wind speeds often vary more across locations than solar irradiation does.

[i] LCOE for a representative project per country in Europe across the three scenarios. Outcome space reflecting differences in underlying resources per country but also differences in other cost inputs, for offshore wind, floating offshore is included from 2040, for nuclear, potential technology breakthrough gives larger outcome space. Additional costs or revenues, such as local resistance or achieved prices are not included. It does not reflect differences in project costs within each country.

As onshore wind and solar are land intensive technologies, the cost of land can be a significant part of the total project costs. Another important cost differentiator is the distance of the project to the substation at the grid connection point. Grid connection costs have limited potential for cost decreases over time and will therefore become increasingly important towards 2050. We are currently seeing copper and aluminium prices rise and future grid costs remain uncertain. Today, grid costs account for an increasing share of total project costs, and now account for 5-25% of onshore wind or solar project capex in Europe. The large range reflects significant variation in these costs between projects.

Battery Energy Storage Systems (BESS) are becoming increasingly attractive due to falling costs and high electricity market volatility. These systems are essential for the power system as renewable energy sources such as solar and wind power become more prevalent. Curtailment of solar and wind power is increasing in high-penetration markets, reducing achieved prices and affecting project economics.[9] In many regions, solar power production covers large parts of demand during the day, causing electricity prices to drop or even turn negative. In contrast, prices spike in the evening when demand is high and solar output declines. This creates ideal conditions for energy arbitrage, where BESS charge when prices are low and discharge when prices are high. Battery energy storage is different from solar and wind power in that the revenue stream is much more fragmented. In most markets, however, energy arbitrage is not sufficient for profitability, and alternative revenue streams such as ancillary services and capacity payments are needed.

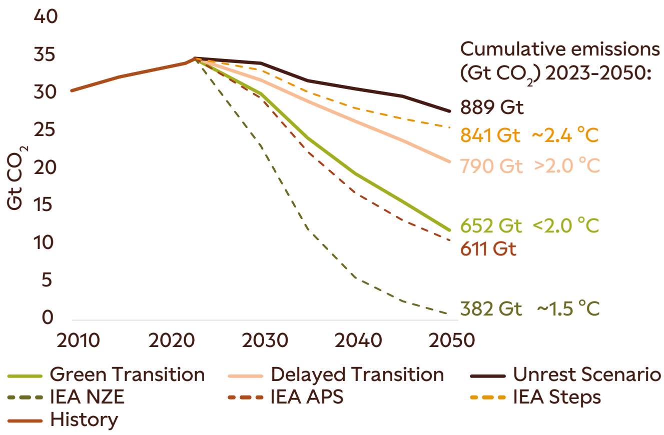
The cost of lithium-ion batteries fell sharply in 2024 due to oversupply in the Chinese manufacturing market and low lithium prices, as electric vehicle sales grew more slowly than expected globally. Technological advancements, including improvements in energy density at both the battery cell level and in the final container system, are contributing to price reductions. There is also progress in other battery types beyond lithium-ion, and notably sodium-ion looks promising for the energy storage industry. In 2024 the first commercial sodium-ion batteries entered the market, but research is still needed before these become mainstream. Possible advantages over lithium-ion include better temperature tolerance, more sustainable materials and eventually lower cost. These batteries are less energy-dense than lithium-ion batteries, but still well suited for energy storage projects.

In our scenarios, battery energy storage is key to balancing and enabling more solar and wind power. Supply chains of batteries are more diversified than for solar power, although costs will be significantly higher outside China with local supply chain requirements, particularly in *Delayed* and *Unrest*. Alternatives such as sodium-ion batteries and using old EV batteries for energy storage reduces the risk of significant price hikes in the future. Overall, capex for batteries will decrease by around 40% towards 2050 in *Delayed*.

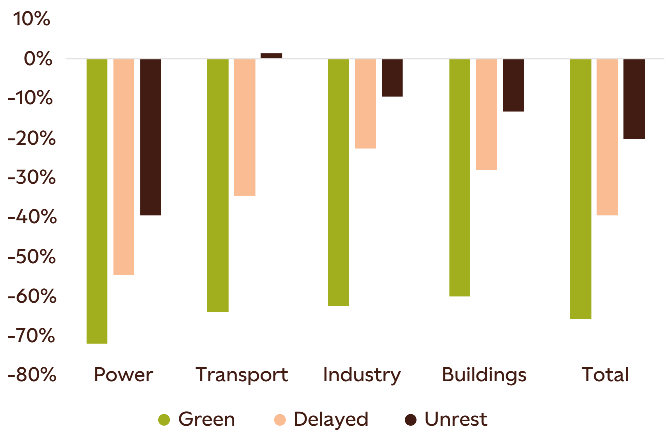
Battery Energy Storage Systems (BESS) are becoming increasingly attractive due to falling costs and high electricity market volatility.

Location: Cushaling Wind Farm, Ireland

4 Total energy-related CO_2 emissions from 2010 to 2050 across scenarios, compared with the latest IEA STEPS, APS and Net-Zero scenarios (Gt CO_2)[10]



5 Changes in global CO_2 emissions per sector from today to 2050 (%)



The path to 2050: Transforming global energy

Across all three scenarios, onshore wind, solar PV, batteries and electric cars show strong and sustained growth reflecting their maturity and increasing cost-effectiveness. Regardless of geopolitical or economic challenges, these technologies remain central to the energy transition. Similarly, coal and oil use will decline in every scenario, underscoring a global shift away from high-emission fuels towards 2050.

Despite progress, if the world develops as in *Unrest*, the current emissions pathway aligns with a global temperature rise of around 2.4°C by 2100. The Green Transition Scenario, which involves more aggressive policy actions and technological advancements, shows the potential to limit warming to below 2.0°C, but this requires much faster and deeper cuts in emissions than are currently being achieved. Energy related CO_2-emissions will reach around 12 Gt in 2050 in *Green*. In *Delayed* and *Unrest*, cumulative emissions from today to 2050 will be 21% and 36% higher, reaching 21, and 28 Gt in 2050, respectively (Figure 4).

All sectors decarbonise rapidly in *Green*, with CO_2 emissions reduced by 66% from today to 2050. There are already scalable and increasingly cost-effective decarbonisation technologies in all key sectors, such as electric vehicles, heat pumps and renewable electricity generation. These technologies will be rolled out fast in *Green*, pushed forward by policy and cost reductions. However, in *Unrest* the adoption of these technologies will be slowed down by uncertain and shifting policy regimes, more disrupted global trade and lagging infrastructure build-out.

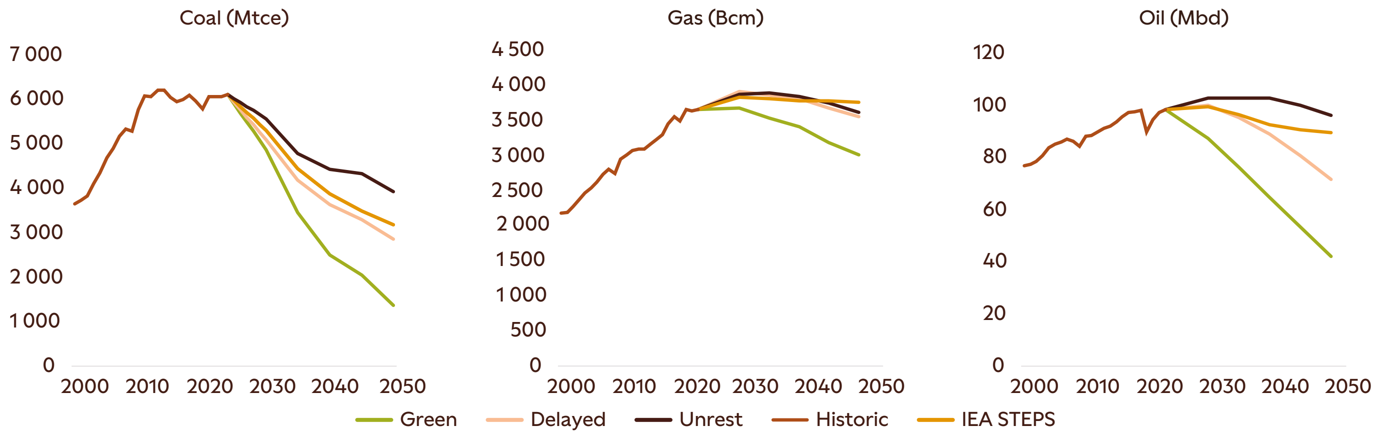
Growth in the more costly decarbonisation solutions, such as carbon capture and storage, clean hydrogen technologies, but also floating offshore wind, will be challenging, with less deployment in *Delayed* and little deployment in *Unrest* due to reduced fiscal capacity and lack of policy support. In these scenarios, total CO_2 emissions will be cut by 39% and 22% respectively (Figure 4 and 5).

Coal and oil together account for more than 50% of the world's primary energy supply today and reducing this dependency will be a massive task. There is momentum in the shift towards cleaner energy, and even in *Unrest* fossil fuels fall to supply 40% of the world's primary energy (Figure 6). In *Green*, the analysis shows that around 20% will be achievable by 2050.[i] In addition to reductions in the power sector, this will be driven by increased electrification of energy end-use, energy efficiency in all sectors, and fuel switching from coal and oil to gas, bioenergy and clean hydrogen.

In *Unrest* the total oil use remains high due to its role in industry and transportation. Coal consumption in power and industry will decline at a slower pace in this scenario largely due to its use in Asia but will nevertheless make up a smaller share of the energy mix. In the Green Transition Scenario coal use falls sharply,

[i] Primary energy supply uses the IEA's methodology assuming zero losses for renewable electricity. With an alternative method assuming the same loss for fossil and renewable electricity (38%), fossil fuels share is reduced to 9% instead of a 20% share of primary energy in *Green* in 2050. The absolute amount of fossil fuels will remain unchanged regardless of calculation method.

6 Global coal, oil and gas primary energy supply from 2000 to 2050 for the three scenarios (in mtce, bcm, mbd)



replaced by gas and renewable energy. China, responsible for almost 60% of global coal consumption today, plays a key role. Since 2010, Chinese CO_2-emissions have increased by more than 40%, but from March 2024 to March 2025 this trend was broken. In these 12 months, CO_2-emissions fell by 1% due to a shift from coal to renewables and nuclear power generation, despite rising energy demand. At the same time, China is continuing to build new coal power plants for energy security reasons, accounting for almost 70% of new global coal capacity in 2024.[11] In all scenarios, the utilisation of the Chinese coal power fleet will decline in the long term and domestic CO_2-emissions will peak and start to decline before 2030.

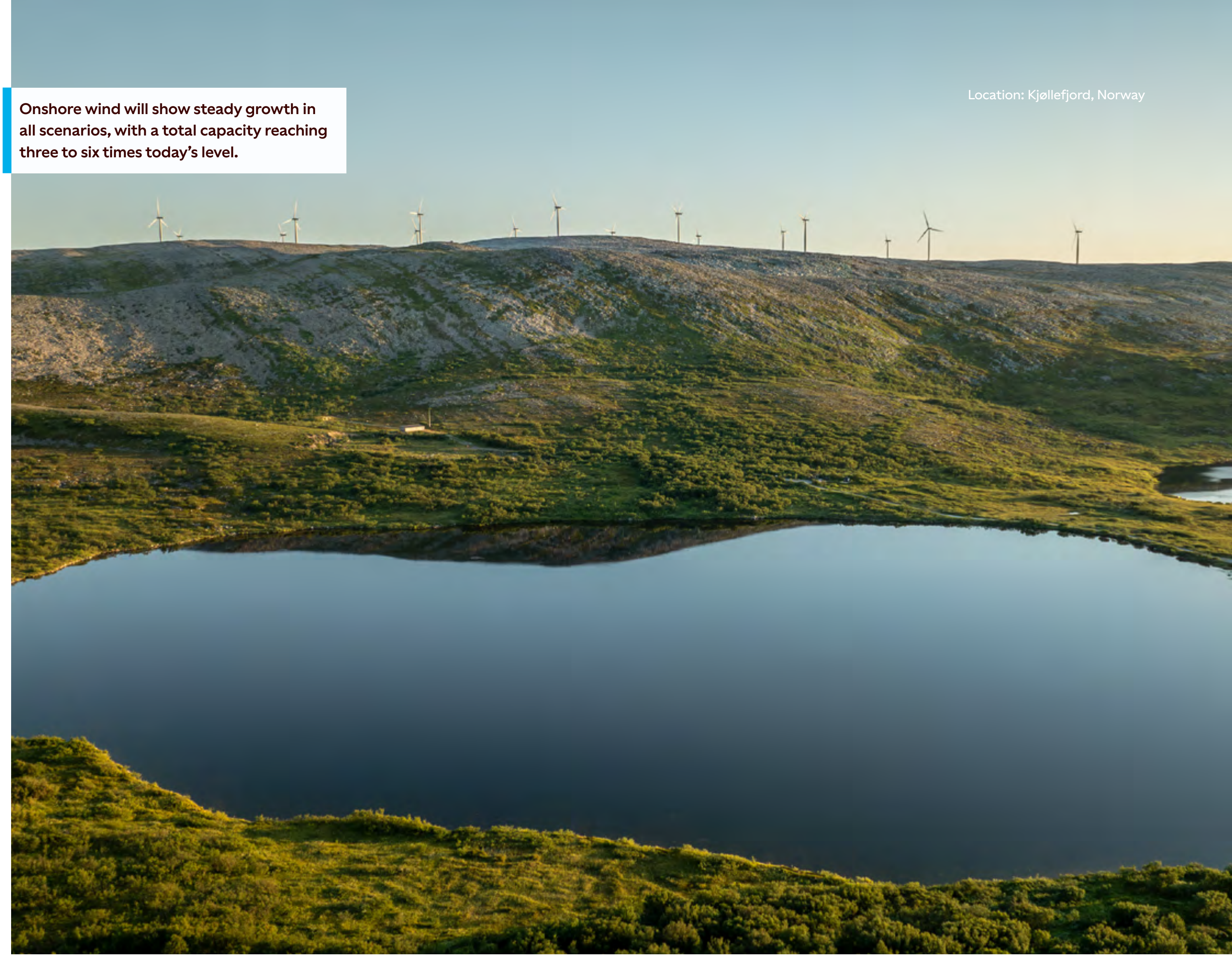
Fossil gas continues to play a transitional role in the power, industry and buildings sectors in all scenarios. Global primary gas supply will increase until around 2030 before slowly decreasing by 2050, with reductions of 18%, 9% and 5% from 2030 to 2050 in *Green*, *Delayed* and *Unrest*, respectively. North America, with firm access to cheap resources, is the region with the highest gas consumption from today to 2050 in *Delayed* and *Unrest*, while the Middle East will surpass North America from 2045 in *Green*. Middle East and Asia see the highest absolute growth from today to 2050 across scenarios, while gas consumption will decline in North America and Europe.

Solar photovoltaic (PV) is the technology with the largest difference between the scenarios and generation is projected to grow between 8 and 16 times from 2023 to 2050. In the Green Transition Scenario, solar receives continued policy support, not only in direct subsidies, but also through support for flexi- bility options like energy storage, grid and demand side response. In the other scenarios, however, the solar and flexibility balance develops less favourably for solar.

Onshore wind shows steady growth in all scenarios, with a total capacity reaching three to six times today's level. Offshore wind saw growth in 2024, and outside the US this technology is expected to further mature, leading to a large increase in installations. Despite recent challenges to the industry, offshore wind accounts for about 20-25% of total wind capacity in 2050.

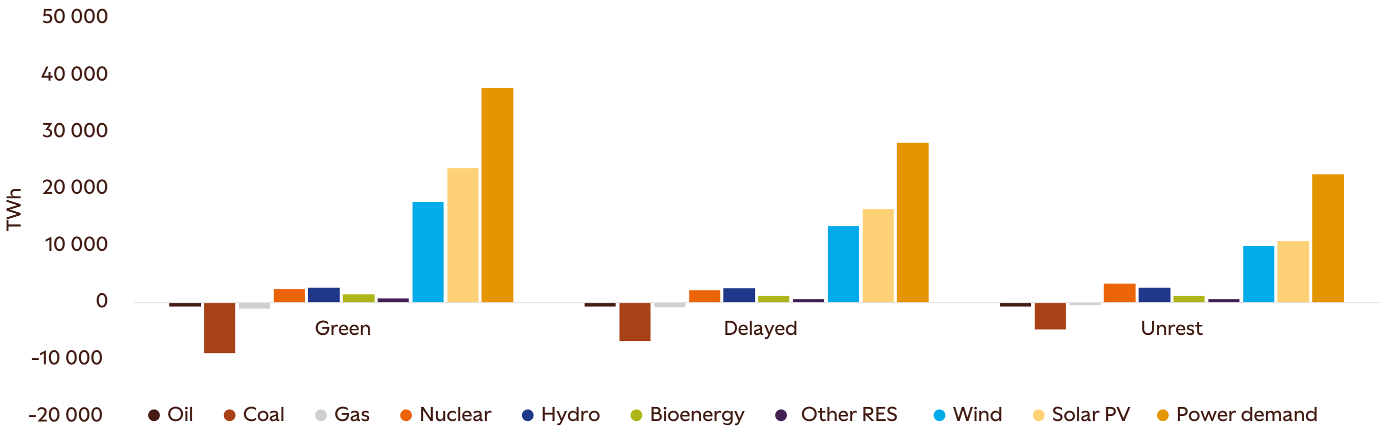
In the scenarios, a heightened focus on energy security and national defence drives increased investment in nuclear power globally, resulting in an approximate 70-110% increase in nuclear capacity from current levels by 2050. Nuclear thereby supports the shift from a fossil fuel-based power system to one dominated by clean energy. However, given that electricity demand is projected to increase by 126% in *Green*, the nuclear share of the overall electricity mix in 2050 remains comparable to its current share of 8-9%. In *Unrest* the share increases to 12% by 2050.

As wind and solar power become increasingly central to the energy system, their weather-dependent and variable nature makes flexibility solutions essential.



In 2024, Battery Energy Storage System (BESS) power capacity grew by over 50% compared with 2023 installations.[12] Annual installations will continue to increase in the coming years, driven by lower costs, rising shares of renewables, greater price volatility in electricity markets, and the growing need for grid balancing. Because of higher-than-expected costs of clean hydrogen, its value for providing flexibility to the power markets globally is expected to be less than previously assumed. As a result, within the time-frame of this report's scenarios, gas will remain a key source of flexible power supply in our scenarios. Still, total gas power production sees a decline in all scenarios due to lower running hours with higher share of renewables in the energy systems (Figure 7).

7 Change in power production per source from today to 2050 (in TWh)



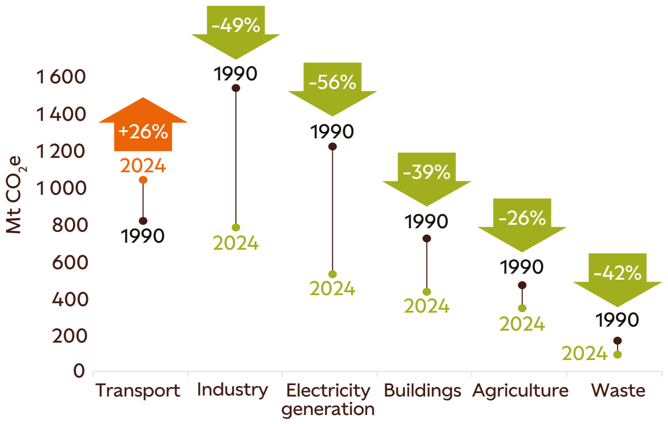
PART 3

The European Future Energy System

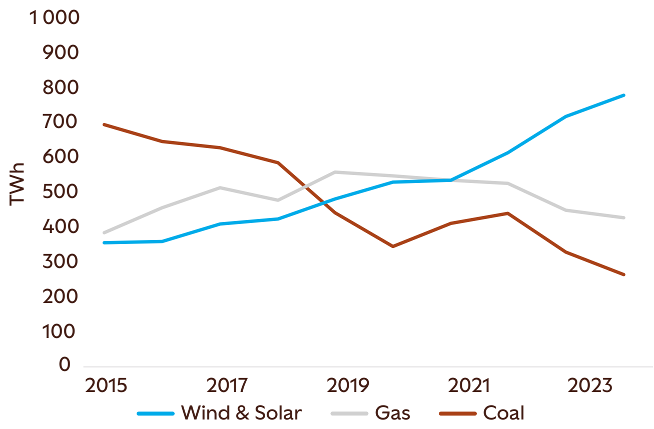
The following chapter presents the state of the European energy system and our scenarios to 2050. The European energy mix is set to undergo significant changes towards a more sustainable, secure, and competitive energy system driven by growth in renewable and clean energy, and electrification. Across the scenarios, the EU's dependence on fossil fuels will peak in the coming years, renewables will dominate the electricity mix, reaching a 73-85% share by 2050, and emissions will decline at different rates.

Location: Roan, Norway

8 EU greenhouse gas emissions per sector in 1990 and changes to 2024 (Mt CO_2e, %)[15]



9 EU electricity generation per source from 2015 to 2024 (TWh)[16]



2025

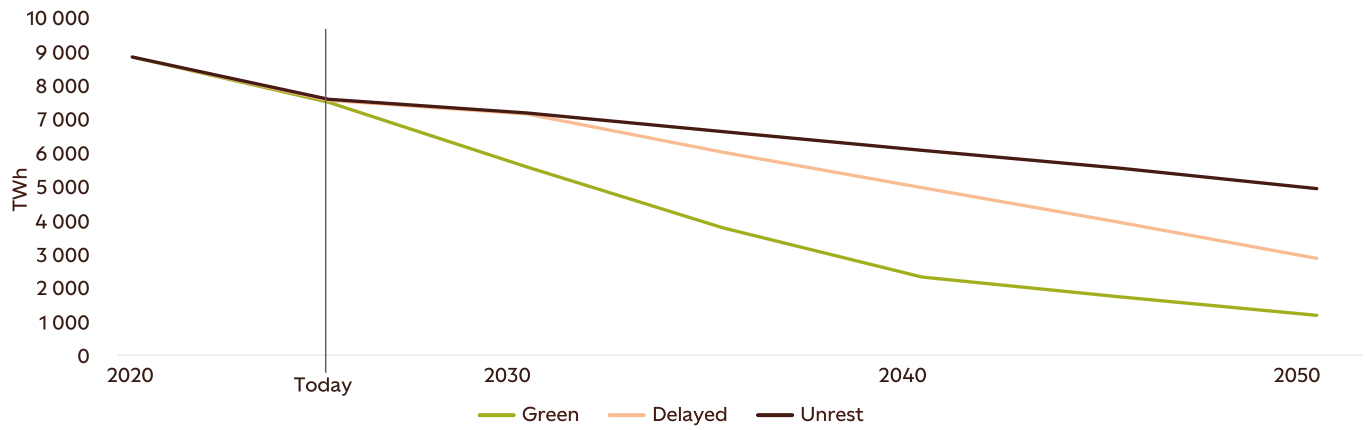
Today's context: Balancing security, competitiveness and climate

Between a shifting US position and a growing Chinese influence, energy security, energy independence and industrial competitiveness are main political priorities for Europe. Still, the EU maintains the lead in climate ambitions and is strengthening it through its flagship initiative the Clean Industrial Deal, with the single market at its core. The key market-based climate instrument, the EU ETS, is being revised in line with a new interim climate target for 2040 and the already agreed net zero target for 2050. At the same time a second EU ETS that covers buildings and transport is due to come online in 2026, albeit with some opposition.[13]

Energy investments in Europe shift from fossil to clean at pace and emissions are declining. In 2024, for every euro invested in unabated fossil fuel power, 35 euros were invested in renewables, compared with a 6:1 ratio in 2015. In 2023, wind power surpassed gas-fired power generation for the first time with 470 TWh annual production. Last year, solar power generation surpassed coal-fired power for the first time, reaching 304 TWh. Renewable energy sources now generate more than 47% of EU electricity. This massive electricity sector transformation is the largest contributor to EU greenhouse gas emissions falling 37% below 1990 levels by 2023 (Figure 8 and 9), while the EU's GDP grew by 68% over the same period.[14]

Technologies are in place for a continued swift transition, but political uncertainty, both within Europe and externally, is significant. In a period where Europe seeks to balance energy security, industry competitiveness, sustainability and climate action, the future energy transition can take many pathways. In this chapter we explore three plausible scenarios for the EU to 2050, consistent with the global scenarios presented in the previous chapter: the Green Transition Scenario (*Green*), the Delayed Transition Scenario (*Delayed*) and the Unrest Scenario (*Unrest*). See Annex I for more details on key assumptions and methodology.

10 EU27. Fossil fuel supply declining in the three scenarios (TWh, excl. oil to non-energy)



Analysis results: EU's energy systems in three scenarios

The energy system: More efficient and less fossil fuel reliant

Security remains a key European priority across the scenarios where electricity consumption increases, fossil fuels decline, and Europe consumes less energy overall. Almost 60% of the greenhouse gas emissions in the EU today comes from final energy use in buildings, industry and transport. Shifting to electricity and improving energy efficiency are the key measures to reduce fossil fuel dependence while cutting emissions going forward. Currently, only 23% of the EU's final energy demand stems from electricity, but the adoption of electric vehicles (EVs), heat pumps, and other electric technologies will increase electricity shares and change the way energy is consumed and produced.[17] As electricity is more energy efficient than fossil fuels in most applications, this switch also leads to a decrease in final energy consumed. The pace of this transition varies across sectors and scenarios.

In *Green*, electricity consumption increases by around 140% to 2050 while coal, oil and gas primary supply fall by 95%, 94% and 74% respectively.[i]
In *Delayed*, there is a new self-sufficiency urgency in Europe and more reshoring of strategic value chains leading to higher energy service demand from European industry compared to the other scenarios. In this scenario, coal, oil and gas primary supply will fall by 95%, 83% and 35% respectively to 2050 while electricity will almost double over the same period. In *Unrest*, Europe and European citizens are worse off, more isolated and with limited fiscal capacity. This scenario sees weaker unity, lower economic growth and high technology costs, resulting in a smaller decline for coal, oil and gas, reduced by 78%, 64% and 10% respectively to 2050 while electricity will grow by 50%. Electricity ends as the largest energy carrier in 2050 also in this scenario covering a 36% share of final energy consumption. In this scenario, the EU remains dependent on fossil fuels for longer, with oil and gas shares of 19% and 18% of final energy consumption in 2050 (Figure 10 and 11).

Gas power plays a key flexibility role by providing peak power in periods of scarcity in all our scenarios, gradually fuelled by either gas with CCS or clean hydrogen in *Green*. However, even if gas capacity increases in *Delayed* and *Unrest*, the actual running hours will decrease with higher renewable share in the power mix. Gas power generation declines by 17% to 2050 in *Delayed*. At the same time, gas share of the power mix will fall from almost 16% in 2024 to around 7% in 2050. In end-use sectors, gas consumption declines by 89%, 48% and 15% to 2050 in *Green*, *Delayed* and *Unrest*. The largest absolute decline is seen in the building sector, followed by industry.

The Green Transition Scenario represents an optimistic yet plausible outlook of a fast and coordinated European energy transition where the pace accelerates significantly. CO_2-emissions fall by

[i] Primary energy supply: the total energy contained in a raw source before it is converted. Final energy consumption: the actual amount of energy consumed to meet demand when excluding energy lost in processing, transmission, distribution or inefficiencies. Energy service demand: the need for the services that energy provides (e.g. lighting a room, moving a car).

The Green Transition Scenario represents an optimistic yet feasible picture of a coordinated European energy transition where the pace accelerates significantly.

Location: Derval, France

11 | Final energy consumption in the three scenarios (TWh)

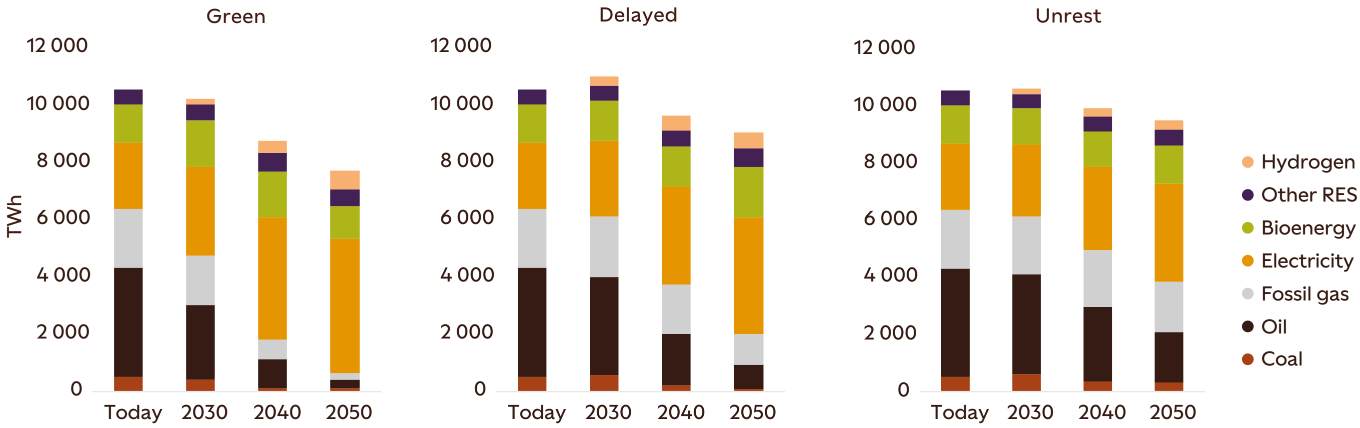


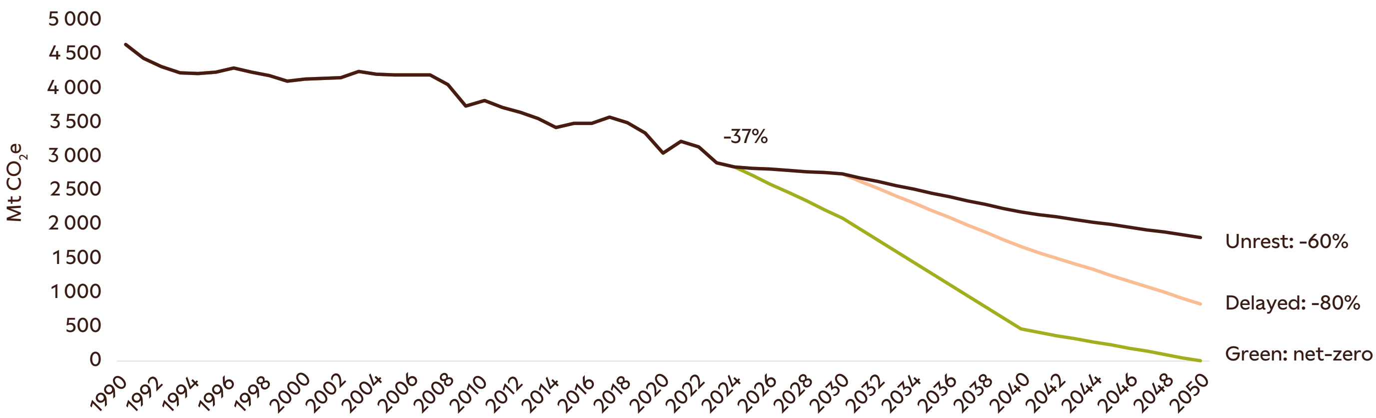
TABLE 1: Share of final energy consumption in the three scenarios (%)

Green				*Delayed*				*Unrest*			
% of TWh	**2030**	**2040**	**2050**	**% of TWh**	**2030**	**2040**	**2050**	**% of TWh**	**2030**	**2040**	**2050**
Electricity	30 %	49 %	61 %	Electricity	24 %	35 %	45 %	Electricity	24 %	29 %	36 %
Oil, coal and gas	46 %	20 %	8 %	Oil, coal and gas	55 %	39 %	22 %	Oil, coal and gas	58 %	50 %	40 %
Other (DH, Bio, H_2)	23 %	31 %	31 %	Other (DH, Bio, H_2)	20 %	26 %	33 %	Other (DH, Bio, H_2)	18 %	21 %	23 %

56% by 2030 from 1990 levels, by 92% by 2040 and reach net zero by 2050. In the Delayed Transition Scenario, Europe keeps its climate ambitions, but with slower implementation and weaker enforcement. Europe's climate targets are not met in time, and CO_2-emissions will fall by 41% in 2030 and 84% in 2050 compared with 1990. In the *Unrest* Scenario, continued short-term priorities, more disrupted global trade, less unity and lower fiscal capacity, lead to a slower decarbonisation, and CO_2-emissions are only cut by 60% in 2050, far from the adopted net zero climate goal (Figure 12).[i]

The transport and buildings sectors see significant electricity consumption growth in all three scenarios as electric passenger cars and electric heat pumps are already close to cost competitive to their fossil counterparts in many segments and countries.

12 | EU net GHG emissions from 1990 to 2050, historic and across three scenarios (Mt CO_2e)[i]



13 Electricity consumption in the three scenarios (TWh)

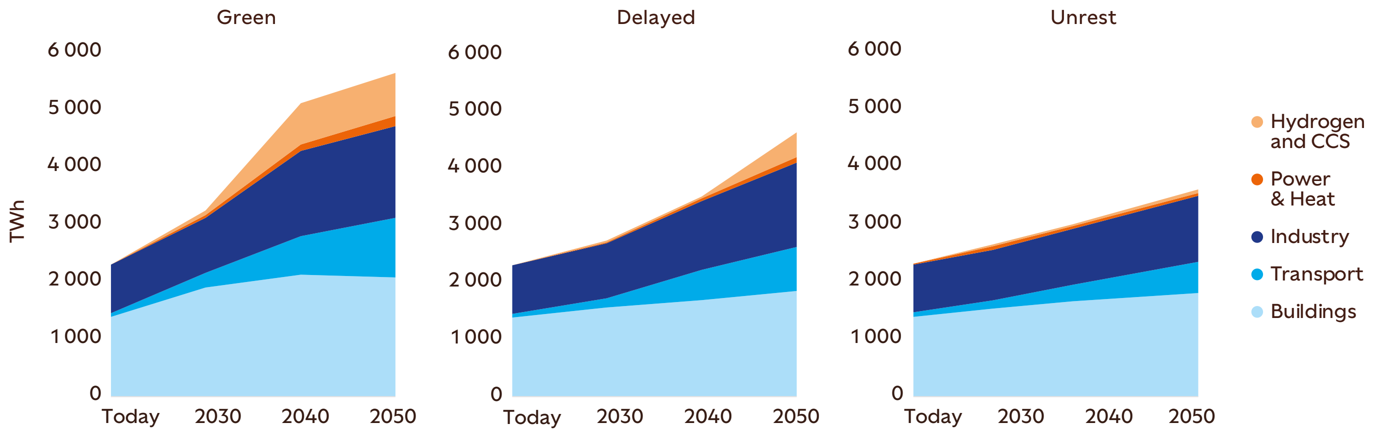
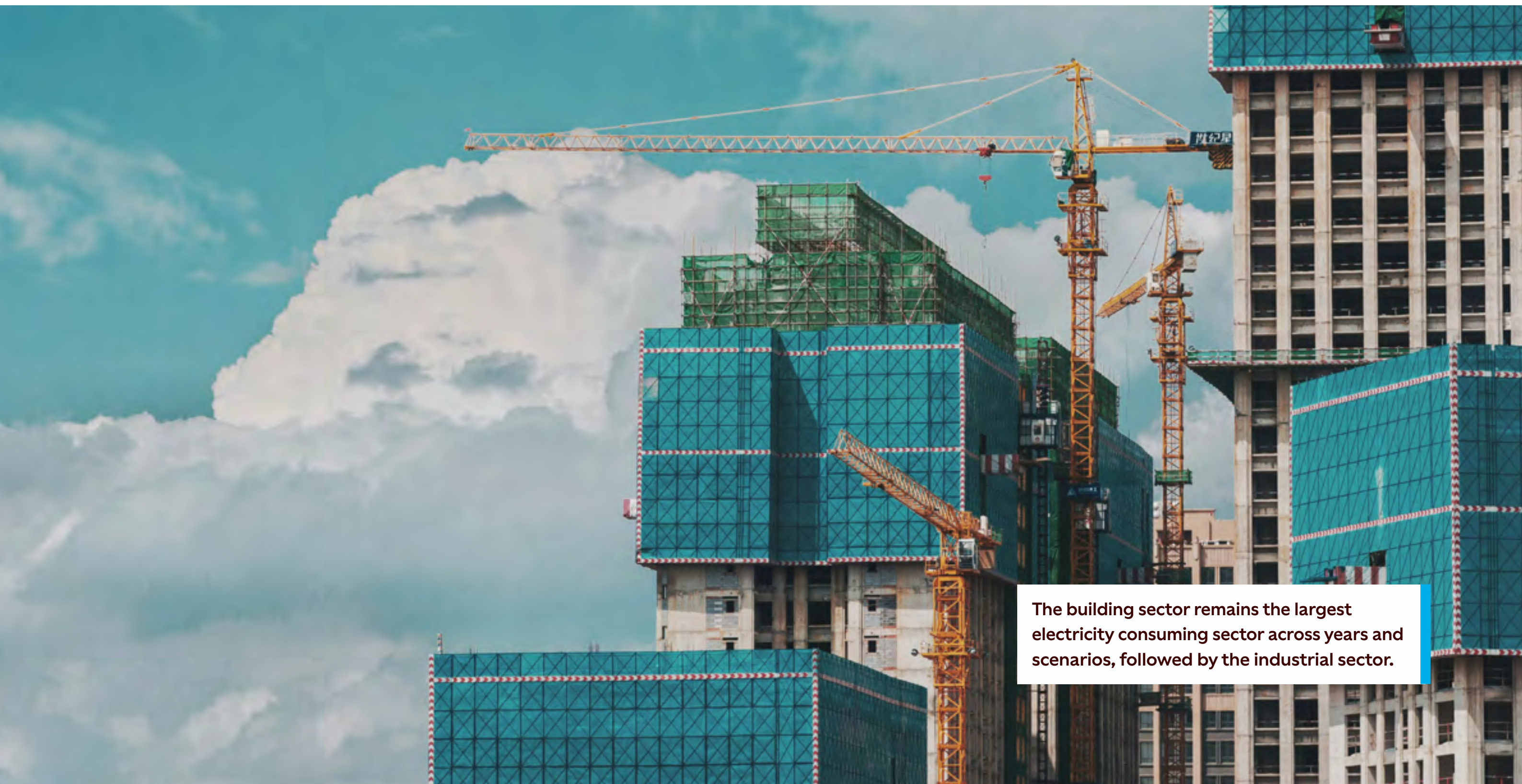


TABLE 2: Electricity consumption per sector in 2030, 2040 and 2050 across scenarios (TWh)

Green				*Delayed*				*Unrest*			
TWh	**2030**	**2040**	**2050**	**TWh**	**2030**	**2040**	**2050**	**TWh**	**2030**	**2040**	**2050**
Buildings	1890	2100	2060	Buildings	1550	1680	1830	Buildings	1520	1640	1780
Industry	950	1480	1590	Industry	960	1190	1470	Industry	860	960	1130
Power, heat, hydrogen and CCS	130	830	920	Power, heat, hydrogen and CCS	50	90	530	Power, heat, hydrogen and CCS	100	70	120
Transport	250	670	1030	Transport	160	530	780	Transport	140	290	550
Grand Total	**3220**	**5080**	**5600**	**Grand Total**	**2720**	**3490**	**4610**	**Grand Total**	**2620**	**2960**	**3570**

The building sector remains the largest electricity consuming sector across years and scenarios, followed by the industrial sector. In *Green* and *Delayed*, the transport sector sees the largest electricity growth from today. In *Green*, electricity consumption in buildings starts to decline from 2040 with more heat pumps and efficient buildings, despite a growing building stock. For the industrial sector and for clean hydrogen, electricity consumption varies dramatically between the scenarios. In these sectors and applications, solutions are generally more complex, and parts of the transition here will need more subsidies and policy support for longer (Figure 13 and Table 2).

[i] Our modelling covers industry process and energy-related CO_2 emissions. Development of other sectors and greenhouse gases are based on the EU 2040 Impact Assessment (more details in Annex I).



The building sector remains the largest electricity consuming sector across years and scenarios, followed by the industrial sector.

The first half of 2025 saw 24% increase in EV sales compared with the same period last year. Still, this is too slow to meet climate targets.

The transport sector: Turning electric due to costs and policies

Today's context

In the EU, around 98 % of transport still runs on fossil fuels, mainly oil. The transport sector accounted for 26% of total greenhouse gas emissions in 2023, of which road transport accounted for about 80%. Despite a decline in transport emissions in recent years, the EU's transport sector is the only sector with increased emissions from 1990 levels.[18]

Electric passenger cars (EVs[i]) are replacing fossil fuel cars in Europe at varying speed across countries, gradually reducing transport emissions and energy use. The first half of 2025 saw 24% increase in EV sales compared with the same period last year. Still, this is too slow to meet climate targets. Achieving near zero-emission cars by 2050 requires replacing more than 10 million fossil fuel cars annually from 2025. This compares with 1.4 million EVs registered in 2024. As the average lifetime of a car is around 12 years in Europe, the 10 million fossil fuel cars sold today will on average be on the road until 2037. Fossil fuel cars sold in 2034, will on average be on the road until close to 2050 unless there is a very high scrapping ratio for fossil fuel cars towards 2040.[19] Consequently, policies made today will shape the car fleet for decades to come.

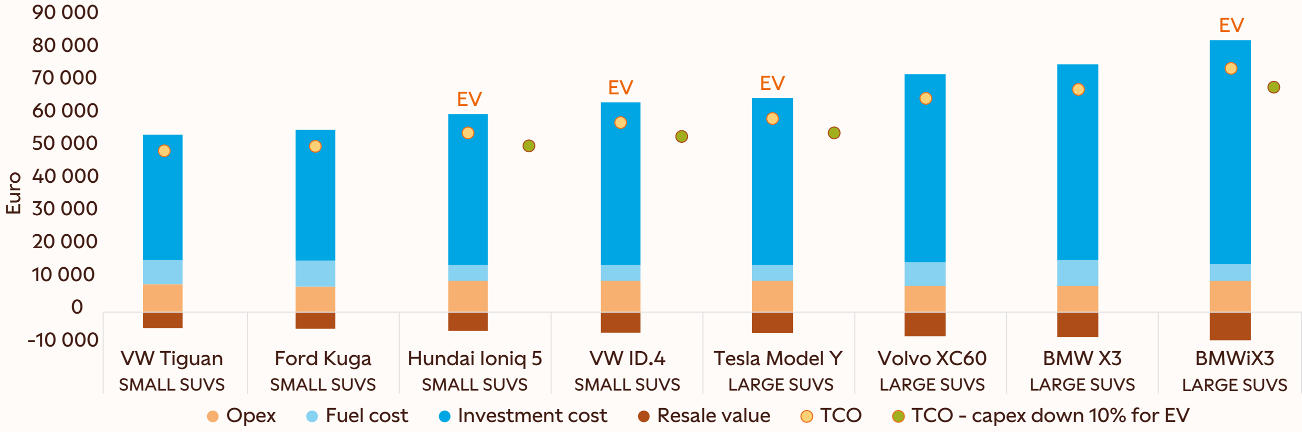
Scenario insight

As a result of technology progress and energy transition policies we expect a significant shift towards electrification in the European transport sector going forward. In our scenarios, there are between 75-132 million electric passenger cars on the road in the EU by 2040 compared with around 16 million EVs today.[23] The shift towards EVs is driven by a mix of policy measures and improved cost competitiveness. In several countries, electric cars are already cost competitive with fossil fuel cars over their lifetime, and this trend is expected to strengthen as the cost of batteries decline and more models enter the market. All scenarios assume the same development in total transport demand for the different transport segments but differ in sales volumes and market shares for green solutions. Across the scenarios, electricity consumption in transport increases by a factor of 8 to 15 by 2050, with the fastest growth in *Green*, already in the 2020s. The development of charging infrastructure and advancements in battery technology is crucial to support the widespread adoption of EVs.

Reaching near zero by 2050 requires faster decarbonisation of the heavier transport segments which face longer investment cycles and lock-in effects. Heavy-duty road transport, aviation, and shipping face more complex decarbonisation challenges. Currently, the large upfront investments and policy uncertainty result in slow progress in these segments.

[i] EVs refer to electric passenger light duty vehicles in this report including battery electric (BEV) and plug-in hybrid cars (PHEV)

14 | Total cost of ownership for small and large SUVs in Germany (EUR total, real'25)[i,22]



Case: Electric cars compared to fossil fuel cars in Germany – cost parity soon to be reached.

We have taken a closer look at the cost difference between electric and fossil fuel cars in Germany which has the EU's largest car fleet today. EVs have historically been more expensive than their fossil alternatives, but the gap is closing. A better understanding of the Total Cost of Ownership (TCO) of EVs compared with fossil fuel cars in Germany today illustrates how the gap can be closed. Even with higher up-front purchase costs, larger EVs have already reached cost parity over their lifetimes in most European countries, while the smaller segments are closing the gap. In Germany, we see the same trend, but due to the high electricity tariffs, the gap is currently wider for many SUV models (Figure 14).[20]

The upfront investment including home charger is the largest component of the TCO. This upfront cost is expected to gradually decline with lower battery costs. However, EVs benefit from much lower fuel costs compared with fossil fuel cars. Even with up to 50% high-speed public charging, the fuel cost of an EV does not exceed that of a fossil fuel car.

There are some differences in the tax and cost levels between EVs and fossil fuel cars in Germany that could more easily be adjusted to increase cost-competitiveness of EVs:

- The VAT tax percentage is the same, but as EVs are more expensive, the absolute VAT tax level is higher.
- The road tax is zero for EVs until 2030 if the car is purchased before the end of 2025. After 2025, EVs will pay 50% of the fossil road tax.[iii,20]
- EVs have lower maintenance costs on average. However, in Germany, EVs pay higher car insurance compared to their fossil fuel equivalents.[21]
  The insurance price is assumed to get closer to the fossil fuel car insurance levels as EV sales increase.

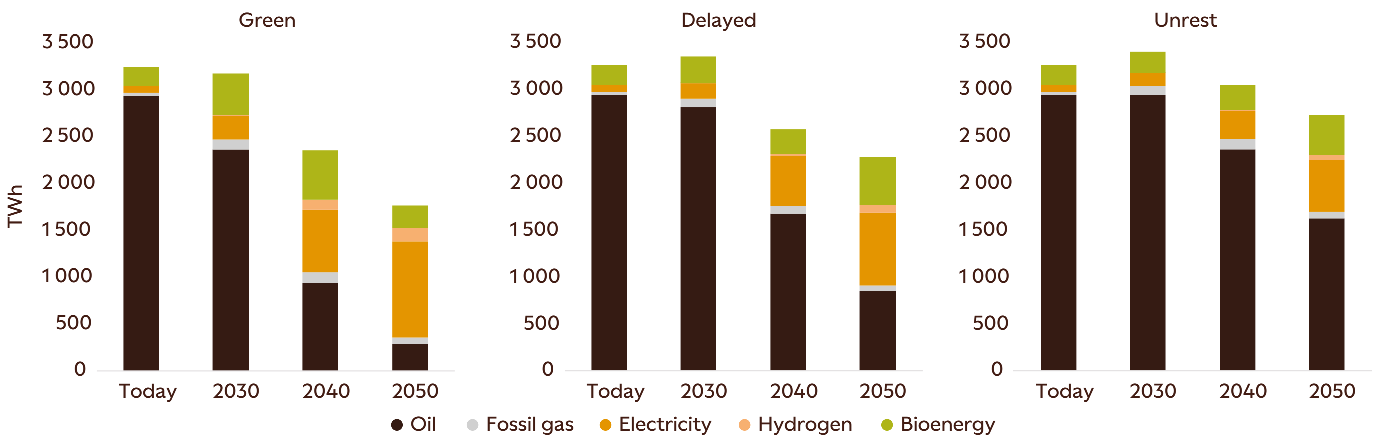
In Germany, the larger electric SUV segment has already cost-competitive models. The investment cost accounts for 70-80% of the TCO, and the EVs are for the most part 15-30% more expensive, except for the Tesla Y. The investment costs have come down in recent years, and if Germany were to subsidise 10% of the upfront cost or forfeit half the VAT for EVs, cost parity would be reached for many of the smaller car segments. In comparison, this is less than the German subsidy level from 2023 (Figure 14).

As the fuel costs impact the TCO, the difference in the absolute tax level between electricity and diesel/petrol is important, such as the carbon tax on fossil fuels. Also, as car dealers face the EU regulation on CO_2 standards for vehicles, this might push the EV purchase prices further down. On the other hand, hurdles like charging points, charging time and driving range remain, but these hurdles are expected to gradually improve, and they do not change the economic viability.

[ii] TCO assumptions: 7 years use and the same sale value percentage, 4% discount rate, fuel price petrol/diesel 1.7/1.6 €/L, home charging 0.40€/kWh, fast charging: 0.6-0.8€/kWh, 12 000km/yr, energy use fossil car 0.06l/km, energy use BEV 0.17kWh/km, EVs 0 road tax. Upfront cost is based on lower range of available cost at the vendors sites and a home charger at around 1 000€.

[iii] The vehicle tax exception will most likely be extended to 2035 for new EVs registered before 31. December 2030

15 | Final energy demand in transport across scenarios from today to 2050 (TWh)



No single clean fuel solution exists for long-distance heavy freight transport, which will likely rely on a mix of electricity, hydrogen, biofuels, and e-fuels. Infrastructure, such as for hydrogen refuelling and high-speed charging, is critical, but underdeveloped. Aviation and shipping contribute smaller shares of EU's greenhouse gas emissions but depend on alternative fuels and efficiency improvements, as electrification is not yet viable at scale. Accelerating infrastructure development and technology adoption across all transport segments will be vital to meet the EU's climate goals.

The Green Transition Scenario will see a full transition to zero-emission EV sales starting already in 2030. Falling EV costs and policy support for infrastructure upgrades and high EV uptake will accelerate the shift. Electricity demand will multiply 15-fold, covering around 60% of transport's final energy in 2050. Hydrogen (including its derivatives) and biofuels will contribute 8% and 14%, decarbonising the heavy-transport segments. Final energy demand will fall by 45%, largely due to replacing inefficient fossil fuel cars with EVs.

The Delayed Transition Scenario follows similar trends as *Green* but with a slower start, reaching near 100% sales of zero-emission EVs later. EV uptake is slower, and fossil fuels still make up 40% of the final energy mix in transport in 2050. Electricity demand will grow nearly 11-fold, covering around 35% of final energy, with biofuels at 23% and hydrogen (including e-fuels) at only 4%.

In the Unrest Scenario, economic constraints and diverging political priorities slow the transition. Although EVs become cost-competitive, adoption lags, with speed picking up only towards the 2040s as infrastructure falls behind and people keep existing cars for longer. Electricity demand will grow eight-fold, covering just 20% of final energy in transport, half that of *Green*. Electrification occurs only in road and rail, with minimal hydrogen use.

The sales rates of zero-emission vehicles strongly influence the transport sector energy mix in 2050. Even though *Unrest* will end with almost the same share of EV sales as in *Green* in 2050, the pace of replacement is much slower. In *Green*, the whole passenger fleet will consist of electric cars by 2050. In *Delayed* electricity will reach a 40% share of passenger transport final energy, while *Unrest* will end up with a 23% share (Figure 15).

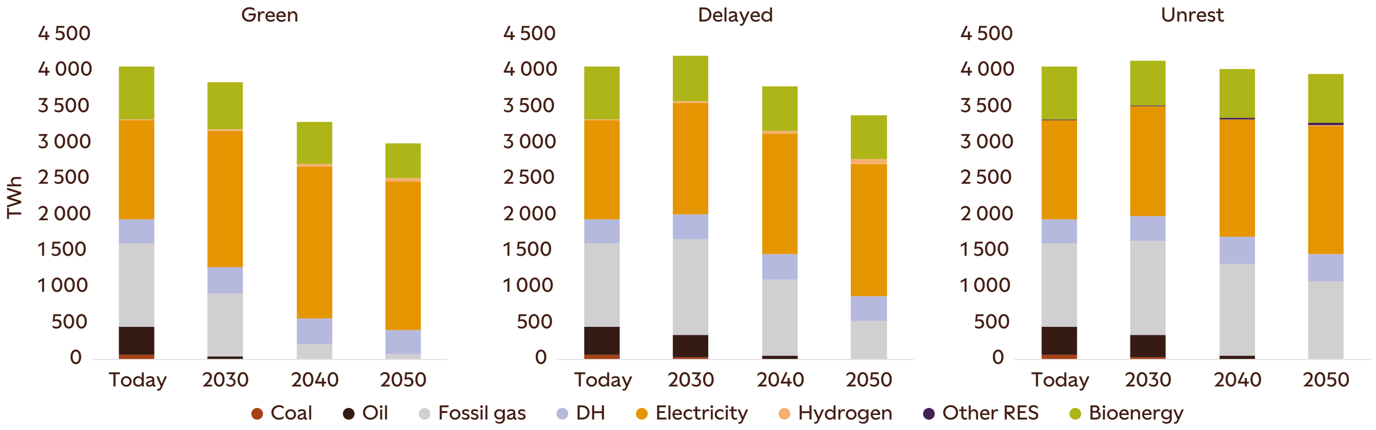
The building sector: Heat pumps reduce fossil dependence and energy use

Today's context

Heat pumps are increasingly replacing fossil fuel-based heating in buildings and industry. Nearly 40% of total final energy in the EU are consumed in buildings today, with over half still reliant on fossil fuels. In 2023, buildings accounted for almost 20% of the EU's greenhouse gas emissions. Since 1990, energy use has risen by 4% in buildings, but greenhouse gas emissions have fallen by about 40% due to efficiency

Reaching near zero by 2050 requires faster decarbonisation of the heavier transport segments which face longer investment cycles and lock-in effects.

16 Final energy demand in buildings across scenarios from today to 2050 (TWh)



upgrades and heat pump adoption.[24] Heat pumps use only about one-third as much energy for heating, compared with gas boilers or direct electricity. The adoption of heat pumps is, in this respect, driven by policy and improved cost competitiveness.

Electrification with heat pumps, and combining with insulation and other efficiency measures, are the most effective decarbonisation strategies in buildings while also reducing gas dependence and energy use in buildings. The Energy Performance of Buildings Directive promotes heat pumps and energy efficiency, mandating zero-emission new residential buildings by 2030 and by 2028 for public buildings. It also aims to cut primary energy use in homes by 16% by 2030 and 22% by 2035, with fossil fuel boilers phased out by 2040.[25]

Despite ambitious goals, 2024 saw a slowdown in heat pump sales in the EU in part due to regulatory uncertainty, reduced support mechanisms, and lower gas prices. Still, the total heat pump stock in the EU grew by nearly 9% over the year, ending at more than 25 million units in operation.[26]

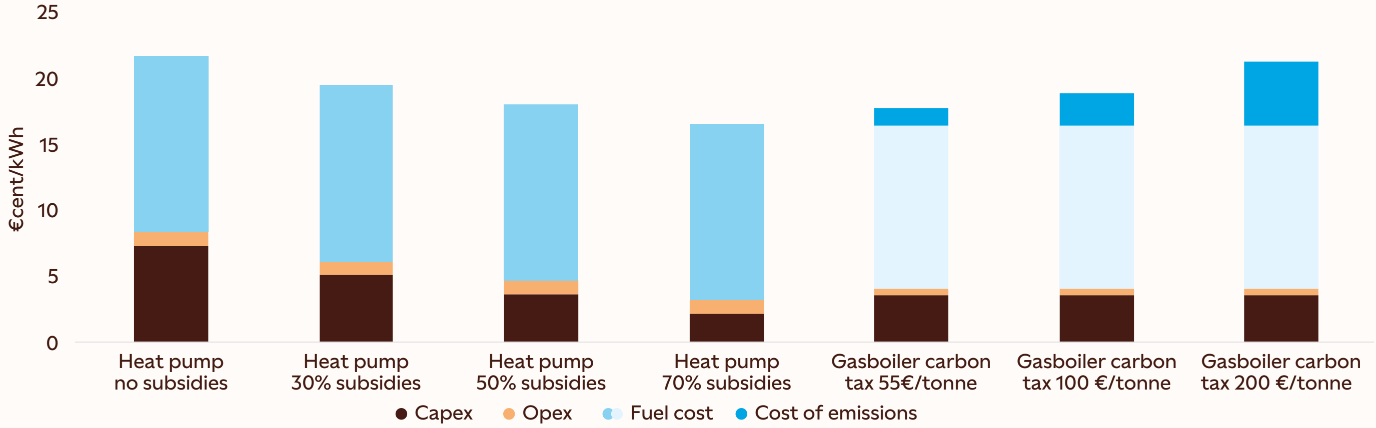
Scenario insights

Further adoption of heat pumps is a key solution to reduce energy demand, cut emissions and reduce fossil import dependency. In the Green Transition Scenario, a strong consensus emerges before 2030 to decarbonise buildings through widespread heat pump adoption and energy efficiency upgrades. This leads to a significant fall in energy demand compared with today – down around 25% by 2050. Deep renovations across Europe are crucial to meeting climate goals. The required heat pump stock will be reached by 2035, followed by a slight decline towards 2050 as systems and buildings become more efficient. Such a steep shift from gas to electric heating by 2035 will require strong and coordinated policy support, followed by grid reinforcements and investments in new power production starting now.

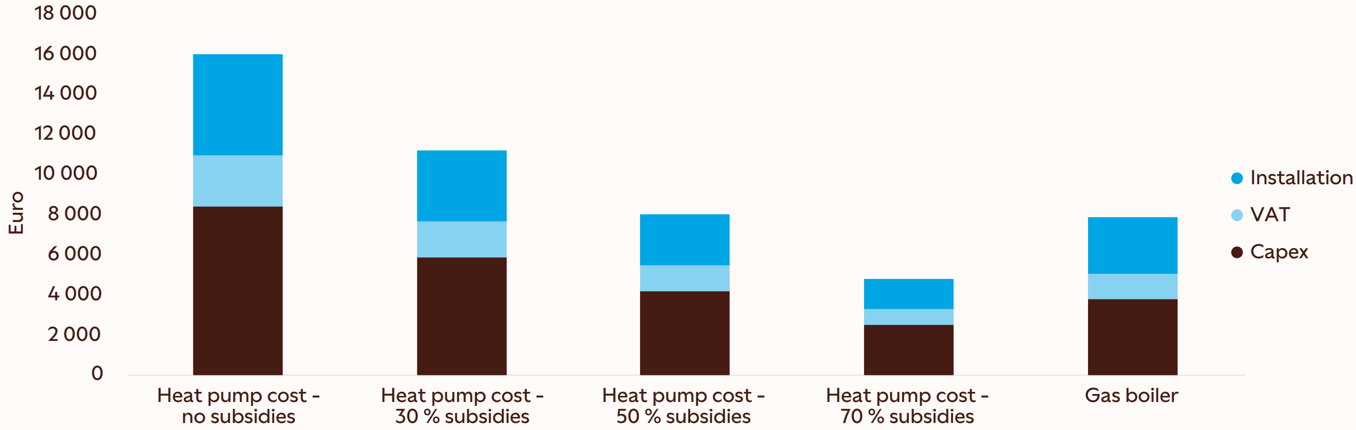
Heat pump growth also occurs in *Delayed* and *Unrest*, but at half the pace due to lower priority and weaker support. After 2035, *Delayed* overtakes *Green* in heat pump stock to compensate for delayed renovation. In *Unrest*, heat pump uptake struggles throughout, constrained by limited support and economic challenges, ending with just about 70% of the level in *Delayed*. In *Unrest*, heat pump adoption is hindered by higher upfront costs and insufficient policy support.

Electricity use in buildings will rise in all scenarios, primarily due to increased heat pump deployment. By 2050, electricity will cover 70% of final energy demand in *Green*, 55% in *Delayed*, and 45% in *Unrest*. This translates to electricity consumption increases of 50% in *Green*, 33% in *Delayed*, and 30% in *Unrest* compared with today (Figure 16). CO_2 emissions will fall sharply in *Green*: Down 97% by 2050 compared with today. In *Delayed*, oil is phased out by 2045, and gas will start to decline after 2035, resulting in about a 50% decline in emissions by 2035 and 80% by 2050. In *Unrest*, oil will be phased out before 2050, but gas will remain steady until 2040 and only drop by 6% to 2050, leaving emissions in buildings at around 40% of today's level.

17 Total cost of ownership for heat pumps at different subsidy levels compared to gas boilers for residential houses (€cent/kWh, real 2024) [i,30]



18 The difference in investment costs between heat pumps at different subsidy levels and gas boilers (EUR, real'24)



Case: Heat pump costs compare to gas boiler in buildings in Germany today

We have taken a closer look at the cost difference between heat pumps and gas boilers in Germany. Germany accounts for 24% of the EU's emissions from buildings and remains heavily reliant on gas boilers. Despite slow initial uptake, heat pump sales surged in 2022–23 before dropping sharply in 2024, partly due to continued high fossil fuel subsidies. In 2025, fossil fuel subsidies in Germany were removed, giving heat pump incentives renewed momentum. Early data suggests a rebound in sales, though still below 2023 levels and short of the 500,000-unit target.[27]

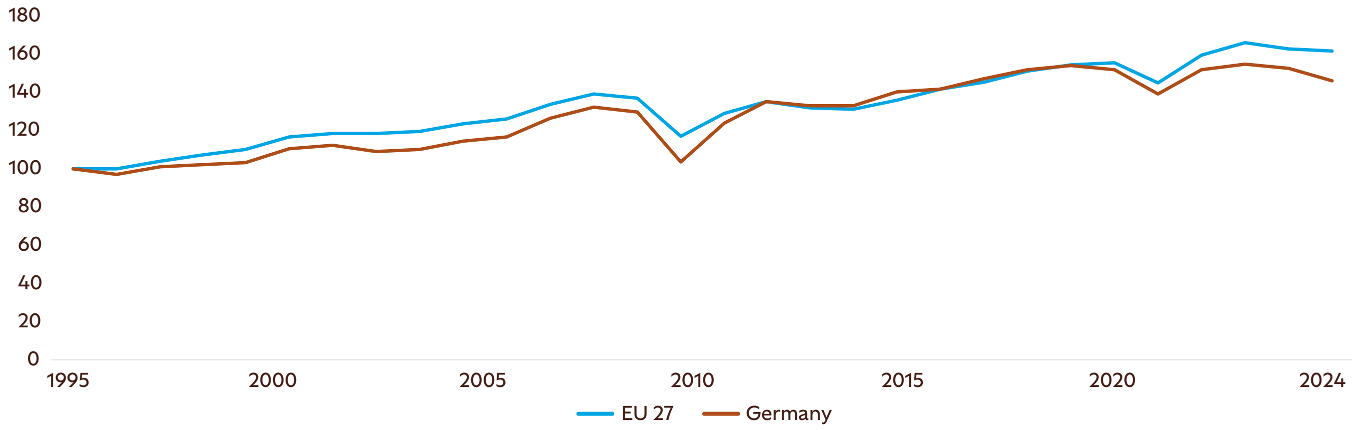
Germany has already introduced a €55/tonne national carbon tax on fossil fuels in transport and buildings.[28]
To evaluate the financial attractiveness of heat pumps, we have looked at the total cost of ownership (TCO) of heat pumps compared with conventional gas boilers. Without subsidies, heat pumps remain significantly more expensive than gas boilers. In our analysis heat pumps become cost-competitive when reaching the maximum subsidy level in Germany which is 70% of capex for low-income households. A 50% subsidy applies for all households when replacing old gas systems.[29] These incentives can make heat pumps cheaper than installing a new gas boiler. However, they are not cheaper than continuing with an existing one (Figure 17 and 18).

At retail level, electricity is taxed significantly more than gas in Germany today, making heat pumps less competitive. The total tax burden for gas is currently approximately 30% of the tax burden on electricity. Both fuels have the same VAT rate, but electricity faces higher levies and taxes in the form of grid tariffs and renewable surcharges.[ii] For households, the electricity bill consists of roughly 25% grid tariffs and 35% taxes and levies including VAT, while the gas bill consist of less than 20% grid tariffs and around 30% taxes and levies. This tax imbalance gives significantly lower gas fuel costs per delivered kWh of heat, making gas boilers more competitive than even the most efficient heat pumps today. In the first half of 2025, €0.236 per kWh of taxes and tariffs were added to the electricity wholesale price, while only €0.062 per kWh for gas.[31] Equalising tax levels between gas and electricity would significantly improve the competitiveness of heat pumps. Lowering electricity taxes to match the gas taxes would reduce heat pump operating costs without increasing the gas heating costs for existing households. In this case, heat pumps would outperform new gas installations on costs already today and approach the costs of continuing with existing gas boilers.

[i] Discount rate 6%, lifetime 20 years, VAT: 19%, air to water heat pump investment cost of 16 000€, power price incl. tax and tariffs 39.7€cent/kWh, COP: 3, gas boiler investment cost: 7 800€, gas price incl. taxes (except CO_2) and tariffs 11.3€cent/kWh, CO_2 tax 55€/tonne. The analyses include heat pumps and gas boilers with minimal system upgrades, only replacing the heating unit. The investment cost would be higher for both cases when other installation costs and local conditions are included.

[ii] Household electricity tariffs and renewable surcharges consist of an offshore grid tariff, KWKG, §19 StromNEV-Umlage, concession fee and grid fees.

19 Gross Value Added from Manufacturing 1995=100%[35]



The industry sector: Restructuring continues towards 2050

Today's context

The EU's industry sector has reduced emissions by about 30% since 2005.[32] A significant share of this decline has been due to changes in Europe's industrial structure, and energy efficiency gains. Going forward we expect a continued industry restructuring with further energy efficiency measures, electrification and recycling being major components in making the European industry cleaner and less vulnerable to fossil fuel import flows.

European industry remains under pressure. Over the past five years, industrial activity in Europe has stagnated, with for example Germany's manufacturing output in 2024 below 2019 levels (Figure 19). This slowdown has raised concerns about the long-term competitiveness of European industries. Going forward, European industry must likely also handle increased trade-tariffs and the uncertainty associated with rapid changes in tariff levels.[33] The current challenges are partly a result of a series of acute crises which have contributed to spur the structural shifts currently observed. Distinguishing between short-term disruptions and lasting trends is key to understanding future industrial energy demand.

For several of the declining industry sectors the key concern is not mainly international competition but rather falling intra-EU demand. As Europe grows wealthier, demand for energy-intensive goods like steel and cement is declining as demand for these goods is saturated and economic growth to a greater degree is driven by services. Despite these structural challenges Europe still has a strong industrial base with production 17% higher than in 2005. The Draghi report points out that the EU outperforms the US in mid-technology sectors like the manufacturing of transport equipment, but lags in IT and professional services.[34]

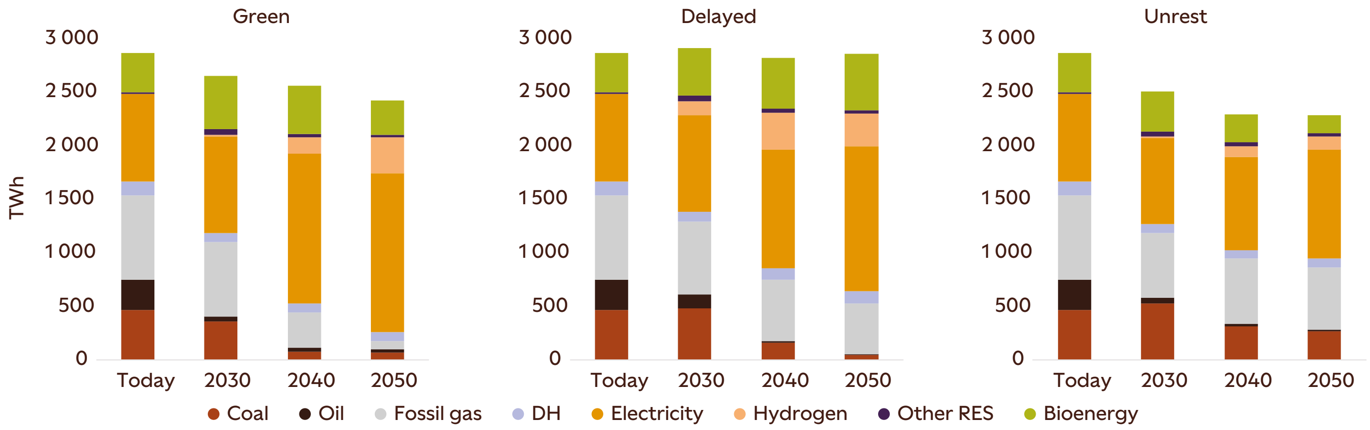
Over time there has been a shift towards high end manufacturing in the EU, and we expect this trend to continue. However, stronger emphasis on resilient supply chains could result in relative higher energy demand from industry as more basic materials are produced domestically. This is the case in the Delayed Transition Scenario where more production is reshored. Despite that GDP growth will be slower compared with *Green*, the total energy demand from industry will be higher in *Delayed*. In contrast, *Green* will see higher GDP growth, but the industry sector will become less energy intensive.

Scenario insights

In all scenarios electricity demand in the EU will grow as electricity replaces fossil fuels for process heat, but the pace and depth of electrification will vary between scenarios. For lower temperature heat processes, industrial heat pumps are cost competitive with fossil alternatives and become viable options. The Unrest Scenario sees only 18% growth in electricity demand from process heat due to weak policy push for electrification, while in *Green*, we find more than a doubling of electricity use for process heat to 2050. The stark difference between the scenarios underlines the degree to which electrification of industry hinges on political ambitions, economic growth and stable regulatory frameworks.

Another key difference between the scenarios for industry is the use of fossil fuels. In *Unrest* the lack

20 Final energy demand in industry across scenarios from today to 2050 (TWh, excl. agriculture and feedstock)



of climate policies will lead to a slow phase out of coal and fossil gas. In *Delayed*, coal will be phased out, but there remains a significant amount of gas by 2050, with a 20% decline from today to 2050. This slow reduction is partly driven by higher industrial activity. In *Green* on the other hand gas demand will fall with around 85% to 2050 as almost all fossil fuels must be removed to meet climate targets. In some subsectors there are other barriers in addition to the cost of shifting to electricity, the so-called hard-to-abate sectors. Here bioenergy, CCUS and hydrogen will have to play a role if emissions are to be reduced (Figure 20).

For medium process heat, switching to electricity is still an alternative, but it is often in the form of direct electrification. As fossil fuel and direct electric heating typically have efficiencies close to 100% there are limited efficiency gains from switching from fossil fuels to direct electricity in these processes. This makes the running costs and profitability of using gas or direct electricity for heat highly sensitive to the difference in electricity and gas prices to industry. As an illustration, at wholesale level, with a gas price of €30 per MWh and a carbon price of €100 per tonne, the resulting marginal cost for using gas for process heat remains at approximately €50 per MWh. For comparison the wholesale electricity price in Germany last year was on average €78 per MWh. This only looks at the wholesale prices. In addition, grid cost and taxes vary between countries and will influence the price difference. One way to accelerate industrial electrification could be by shifting taxes from the electricity bill to the fuel bill, while using electric boilers flexibly and consuming electricity during lower priced hours.

Data centres increase electricity consumption

Driven by high expectations for artificial intelligence (AI) global investment in data centres has nearly doubled since 2022 and amounted to around USD 500 billion in 2024. From now and until 2028 there could be an additional USD 2.9 trillion invested in AI infrastructure.[36]

As data centres are electricity intensive the growth has been followed by rising electricity demand. Data centres currently consume 1.4% of global electricity or 415 TWh, of which 15% is in Europe. The range of possible outcomes for future electricity demand from data centres is huge. Underlying demand varies with different scenarios for growth in AI, storage and processing capacity. There is also uncertainty over how energy efficient the semiconductor used in the data centres will be. Electricity demand from data centres could reach around 945 TWh by 2030 according to the IEA and in a high growth case global demand could exceed 1,700 TWh by 2035. For mature electricity markets like the EU and the US, data centres are the first new sources of rapid growth in electricity demand for decades, testing grid and energy system resilience.[37] However, data centres may also to some extent be flexible in their electricity demand. Google has been able to shift electricity demand at their data centres, reducing the need to invest in grid capacity and enabling better use of intermittent renewable electricity.[38] In Europe, markets close to tech or financial hubs have been the fastest growing so far. But as growth accelerates there is now a lack of access to power and grid capacity in many of the traditional markets. This has given rise to growth in new areas, such as the Nordics and Iberia. In our three scenarios, data centres are responsible for between 5 and 15% of EU electricity consumption growth from today to 2050.

21 EU electricity production today, in 2035 and in 2050 (TWh)

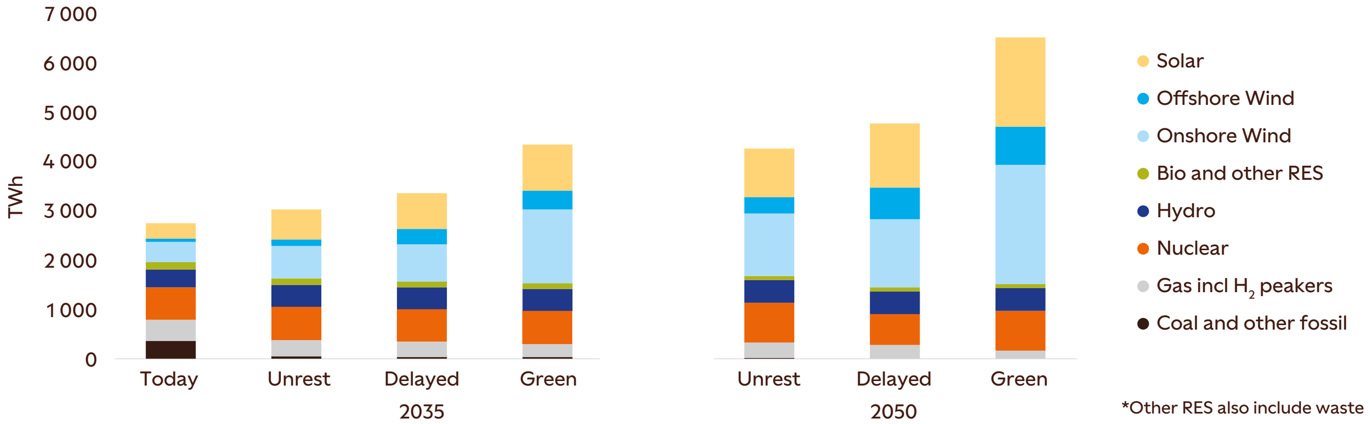


TABLE 3: Renewable share of total generation across scenarios (%)

	Today	2035	2050
Green	47 %	78 %	85 %
Delayed	47 %	70 %	81 %
Unrest	47 %	65 %	73 %

TABLE 4: Total power generation across scenarios (TWh)

	Today	2035	2050
Green	2740	4350	6500
Delayed	2740	3350	4730
Unrest	2740	3020	4100

The power sector: Transforming fast to a renewable dominated sector

Today's context

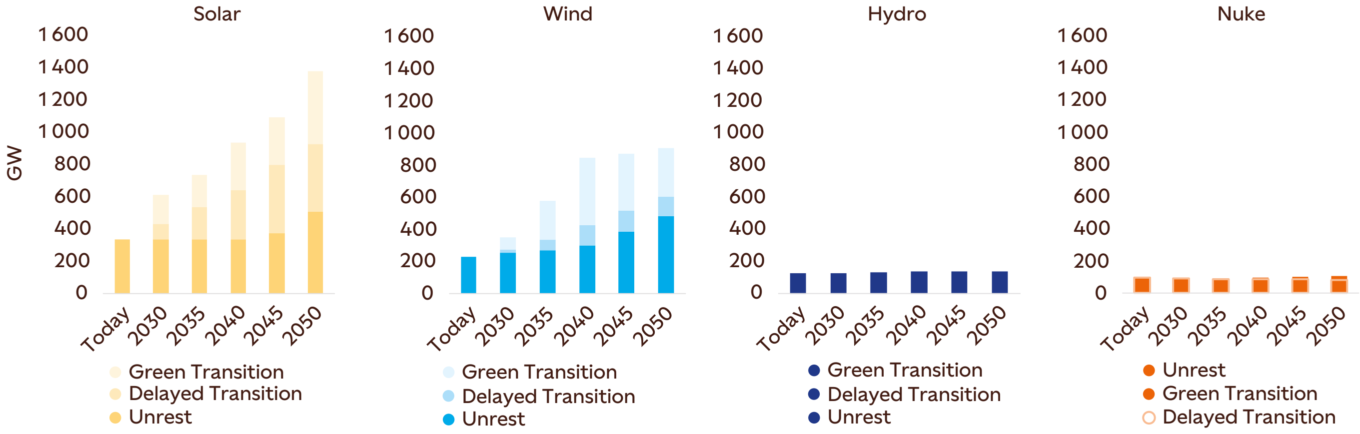
After two years of decline, electricity consumption in the EU increased slightly in 2024, while fossil power generation dropped by 9%. Clean sources accounted for 71% of power generation, with renewables at 47% and nuclear at 24%. This is a massive shift. In 2019, the renewable share of the generation mix was one-third by comparison. Hydro generation increased by 10% in 2024, reaching 13% of the total generation mix, mainly because of higher annual precipitation levels. Nuclear remains the largest electricity supplier in the EU at 650 TWh, followed by wind power at 477 TWh. Coal generation accounted for 10% share of the electricity mix last year, with Germany and Poland responsible for 70%. Fossil gas generation made up 16%, a 6% decline year-on-year, and shifted from baseload towards more peak load. Average electricity prices fell to their lowest levels since 2021, with negative prices rising, although unevenly across regions and throughout the year.[39]

Solar and wind capacity and generation continued to grow in 2024. Europe saw record installations of solar PV capacity, adding over 70 GW in 2023 and 82 GW in 2024, bringing total installed capacity to over 407 GW. Falling costs and short build times make solar PV a frontrunner in the energy transition, with the EU targeting 720 GW by 2030.[i] For onshore wind, positive signs emerged in 2024 after some years of headwinds. Germany, England, and Poland took measures to streamline onshore wind permitting and increase land availability. Germany issued record approvals of approximately 15 GW of onshore wind last year, nearly 90% higher than 2023. England lifted the de facto ban on new onshore wind permits that had been in place since 2015. However, regional challenges persisted, such as in Sweden where 15 of 16 onshore wind project applications in 2024 were rejected by either the local municipalities or the armed forces. Offshore wind remains an important component of Europe's future clean energy mix, despite cost increases and challenges. Awarded tender volumes in Europe increased from 13 GW in 2023 to 19 GW in 2024, and several governments and developers have renewed their investment ambitions.[40]

Scenario insights

The EU's energy mix will continue to change significantly the next decade, with renewables projected to exceed 65% of the generation by 2035. Wind and solar will play a key role, with their share of power generation reaching 60-77% across the three scenarios. By 2050, wind and solar generation will more than triple in *Unrest*, while growing almost 7 times in *Green* (Figure 21). Fossil fuels' share in the power mix will decline from around 30% today to 3-8% by 2050, while shifting from providing base to peak load. Finally, nuclear's share in the electricity generation mix will be between 12-20% from 24% share today.

22 Cumulative installed capacity per technology and scenario (GW)



Wind power will become EU's largest generating technology by 2030 in *Green* and *Delayed*, and by 2040 in *Unrest*. Onshore wind will account for 70-80% of total wind generation in 2050, and the capacity increases to 230-490 GW by 2035 and 395-730 GW by 2050. The EU's measures to reduce bottlenecks such as permitting are contributing to faster build out, while grid constraints and limited tip heights remain barriers. Onshore wind repowering will be increasingly important, benefiting from the use of prime wind spots, existing local businesses and already developed areas. As the first wave of around 20% of Europe's existing wind farms approach the end of their 25-year lifetime, wind developers will seek to extend asset lifetimes. The first action is to replace worn components, but eventually the site must be repowered. On average, repowering reduces the number of turbines by 25%, while tripling the output.[ii,41]

The EU aims to increase its offshore wind capacity to at least 60 GW by 2030, up from 19 GW in 2024. By 2035, offshore wind capacity will reach 35-90 GW and 40-180 GW by 2050 (Figure 22). In *Green*, Chinese turbines becoming increasingly available on the European market, adding downward pressure on costs, and sharp cost reductions are expected within the coming decade. In *Unrest* and *Delayed*, the allocation of government funding is reduced as security is prioritised and fiscal capacity is limited, resulting in slower offshore wind capacity build-out. In *Unrest*, supply chain constraints, such as vessel availability, last longer, while costs decrease at a slower pace with lower volumes, lack of standardisation and heightened trade barriers.

Solar PV will grow substantially with decreased costs and increased efficiency of photovoltaic (PV) systems. Solar capacity is expected to reach 460-735 GW by 2035 and 760-1 380 GW in 2050 (Figure 22). In *Green*, this growth is facilitated by low costs and supportive policies, such as feed-in tariffs, tax incentives, and the removal of barriers to solar deployment, including build out of flexibility solutions. In the short term, we expect the pace of solar GW installations in the EU to decelerate slightly, primarily due to declining profitability and increasing market cannibalization. As more capacity is added, wholesale power prices are depressed during peak solar hours, which in turn affects project economics. This dynamic is prompting developers and investors to reassess timelines and strategies, potentially leading to a more measured rollout of new capacity. In the medium to longer term, price spreads and risk reducing measures are expected to incentivise more flexible solutions, and eventually the day-night spread is expected to converge with the cost of flexibility such as batteries.

Co-locating solar PV and battery storage improves grid stability and is increasingly cost-competitive in many markets as battery energy storage systems (BESS) and solar PV costs have fallen by around 90%.[42] Co-located solar PV and BESS projects offer short-term flexibility by providing more reliable and stable renewable electricity supply. Over 41 GWh of BESS were installed in Europe in 2023 and 2024, with almost 22 GWh added in 2024, tripling the total

[i] GW are provided in direct current terms (DC) if not noted otherwise. E.g. the EU solar PV target of 720 GW would imply 600 GW in alternating current terms (AC). DC refers to the installed nameplate capacity while AC refers to the grid-connected capacity.

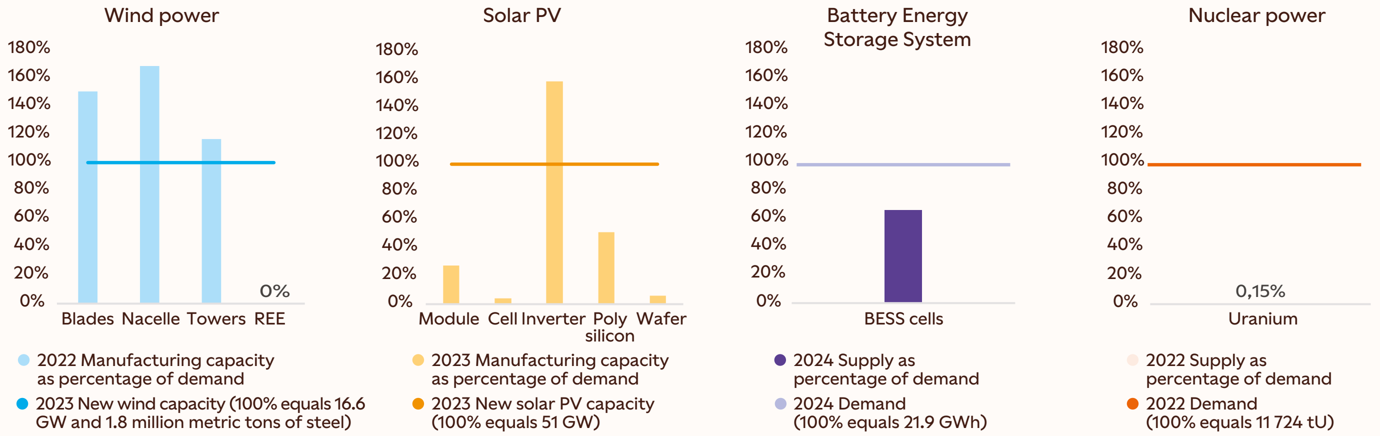
[ii] Currently, about 80-90% of a wind farm can be reused or recycled, with glass fibre wind turbine blades posing the greatest challenge. Wind turbine blades are more challenging to recycle due to the composite material used for constructing the blades. Statkraft supports Wind Europe's call for a European-wide ban on wind turbine blades to go to landfills as of 2025. Repurposing and upcycling wind turbine blades have historically been the most viable options, while recycling will be the longer-term solution.

capacity to over 61 GWh.[43] While BESS can also be co-located with wind power, solar power output is more predictable, which makes it easier to plan battery operation. Batteries can integrate larger shares of solar PV by shifting production from the middle of the day to the afternoon or evening when demand typically is at its peak. By shifting production, batteries optimise on price variations across the day and make the output from the power plant more stable. This offers improved grid stability and helps smooth out fluctuations in solar power generation. Batteries can respond quickly to changes in demand or supply, helping to balance the system and prevent outages. Co-located projects also offer cost-saving benefits in project development, maintenance and grid connection costs. Additionally, co-located systems can reduce transmission losses, as energy is generated and stored close to where it is used.

Nuclear generation in the EU increases by 25% to 2050 in *Green* and *Unrest*, while declining slightly in *Delayed*. Installed capacity will end at 80-110 GW in 2050 across scenarios from 98 GW today as some plants reach their end-of-life, some see lifetime extensions and some new plants are built with government support (Figure 22). More extensive nuclear buildout is constrained by high capex requirements, long lead times, regulatory issues, and other challenges. Still, second-generation reactors could potentially come online in the 2040s at lower costs, benefiting from a more experienced industry. Capex levels as low as those reported in Asia recently are, however, deemed unlikely in Europe, with higher labour and material costs, inexperienced workforce and different regulatory requirements. In our analyses, the construction of nuclear power plants in Europe remains politically driven. Small modular reactors (SMRs) pose an opportunity for the nuclear industry, mainly via reduced project risk. Many designs are under development globally, both with conventional and novel fission technologies. While most aim for commissioning during the 2030s, none have materialised yet and large investments in manufacturing infrastructure to scale production will be required for costs to come down.[44]

Coal will be phased out in two of three scenarios and will account for less than 1% of power generation in 2050 in *Unrest*. Fossil and clean gas will remain important for peak supply, declining by 15%-60% to 2050 and ending with a 3%-8% share of the EU's electricity generation mix, while hydropower's share ends at 7-11% by 2050 despite a 28% growth in generation.

23 Showing current EU domestic manufacturing capacity as a share of EU's domestic demand as of 2023 per technology, fuel and/or sub-component. The strongest European self-sufficiency today is seen in wind technology, followed by solar PV, batteries and finally nuclear fuels.



From fossil dependency to China dependency: European clean tech manufacturing capabilities

While historically a leader in manufacturing clean technologies, Europe has seen China gain dominance in key supply chains over the past decade. To support the green transition, Europe aims to strengthen its industrial base. The EU Net-Zero Industry Act targets domestic net zero manufacturing capacity to meet at least 40% of the EU's deployment needs by 2030 in technologies such as wind, solar PV, batteries and nuclear.[45]

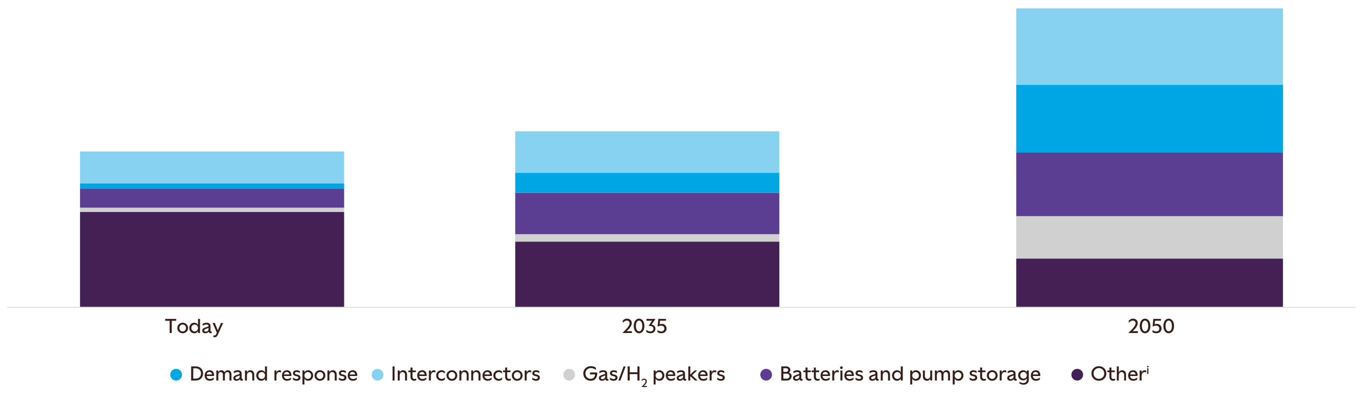
Wind: Europe remains a leading hub for wind manufacturing and innovation and is home to five of the top ten turbine producers in the world. Europe is a net exporter of wind technology, with a €3 billion trade surplus and self-sufficiency in key components. In 2023, 18.3 GW of new capacity was installed in the EU, bringing total installed wind power capacity to 272 GW. Despite strengths in component assembly and materials such as steel and glass fibre, Europe is heavily reliant on imports of rare earth elements (REEs) such as Dy, Nd, Pr, and Tb—essential for turbine magnets. In 2023, China supplied 100% of the EU's Dy and Tb, and 85% of Nd and Pr. The 2024 Critical Raw Materials Act aims to reduce this dependency through domestic mining, substitution, and recycling. Securing REE supply will be essential to sustaining Europe's leadership in wind energy.[46]

Solar PV: Previously, Europe was a forerunner in solar PV manufacturing. Today, Chinese firms dominate the global market. By 2021, the EU's solar trade deficit exceeded €9 billion, and by 2023, 98% of imported panels came from China. While low-cost imports have accelerated deployment, they have also undermined European manufacturers. In response, the EU has launched trade investigations and aims to establish 30 GW of domestic PV manufacturing by 2030. New auction criteria—focusing on sustainability, supply chain resilience, and diversification—are designed to support this objective.[47]

Batteries: China dominates global BESS manufacturing in 2024, producing 77% of all battery cells. Europe accounted for approximately 9%, primarily serving the EV market. Nearly 90% of Europe's battery cell production capacity is allocated to EVs. In China, lithium-ion battery cell overcapacity exceeded 600%, driving prices below production costs and intensifying competitive pressure on European manufacturers. China's dominance in battery manufacturing poses significant challenges for Europe, where production costs are approximately 50% higher.[48] The EU's target of achieving 90% self-sufficiency in batteries by 2030 appears increasingly ambitious, as manufacturers scale back expansion plans amid uncertainty over profitability, market demand, high energy costs, and labour shortages. A 2024 assessment found that over half of Europe's planned gigafactories are at risk of delay or cancellation. The 2025 collapse of Northvolt, once seen as Europe's flagship battery producer, has further deepened concerns. Tackling cost pressures, workforce constraints, and advancing battery recycling will be essential to securing the long-term viability of Europe's battery industry.

Nuclear: Following major nuclear incidents at Three Mile Island (1979), Chernobyl (1986), and Fukushima (2011), the Western nuclear industry has experienced prolonged stagnation. Projects such as Hinkley Point C in the UK, Flamanville 3 in France, and Olkiluoto 3 in Finland—all based on EDF's French reactor design—have faced significant cost overruns and delays. Hinkley Point C remains the only Western-designed nuclear project globally to have commenced construction between 2016 and 2024. Despite recent setbacks, the nuclear industry in Europe is showing renewed ambition to revitalise and expand its capabilities. Several countries have outlined plans for new projects, with the most advanced developments underway in Poland (Westinghouse, US), the Czech Republic (KHNP, South Korea), France (EDF), and Hungary (Rosatom, Russia). However, questions remain about whether the limited number of suppliers can meet concurrent demand across multiple countries, alongside growing concerns over access to skilled professionals. Fuel security is also a key issue, as the EU currently imports over 99.8% of its uranium—primarily from Kazakhstan, Niger, Canada, and Russia (Figure 23). While the industry continues to face significant challenges, its ability to overcome them will be critical in determining the future role of nuclear energy in Europe's energy transition.[49]

24 | Flexible capacity per key category in Germany today, in 2035 and 2050 in Delayed (GW)



Multiple flexibility options will integrate more intermittent power

The EU will need to invest in power system flexibility solutions across production, consumption and grid, such as regulated hydropower, interconnectors, batteries, and demand response. This is to ensure a stable and reliable energy supply with more weather dependent wind and solar PV generation.

Interconnectors, which link the electricity grids of different countries and regions, will help balance supply and demand, mitigate the impact of weather variability, and increase the resilience of the energy system. The EU aims to increase its interconnection capacity to at least 15% of installed electricity production capacity by 2030. In our analysis of Germany under a Delayed Transition Scenario, we see that interconnectors to neighbouring countries will constitute 24% and 26% of total flexible capacity in 2035 and 2050 respectively, increasing from a 20% share today, while the total flexible capacity in Germany almost doubles by 2050 (Figure 24).

Energy storage technologies, such as batteries and pumped hydro plants, which store excess electricity when generation is high and release it when demand is high or renewable generation is low, will increase their share to 21% in 2050 from around 13% today. In addition, adding more synchronous compensators and grid forming inverters will be essential with higher share of wind and solar power. Peakers will play an increasingly prominent role in periods of high demand and low renewable output. These cover 14% of total flexible capacity in 2050 in Germany in the *Delayed* scenario, up from around 2% today. In *Green*, all peakers will run on clean gas, either clean hydrogen or derivatives, biogas or gas with CCS, but at a higher cost, while in *Unrest* and *Delayed*, peakers continue to be fuelled by fossil gas. In addition, other thermal capacity such as combined heat and power will constitute 16% of the flexible capacity in *Delayed* in 2050. In *Green*, these gradually become cleaner, shifting to bioenergy and CCS.

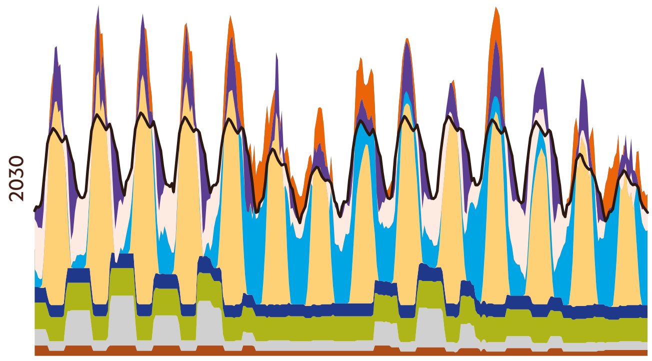
Demand response and smart grid technologies will enable consumers to adjust their electricity usage in response to price signals or grid conditions. Using digital technologies to monitor and manage the electricity flow will facilitate reduced consumption in grid stress periods and increased consumption during periods of surplus, thereby improving the efficiency of the energy system, potentially reducing the need for grid upgrades. Towards 2050, heating, cooling, ventilation and electrical appliances in households and commercial buildings are expected to play a growing role as dynamic tariffs and smart, automated control systems become more widespread. Smart EV charging is expected to have a significant and increasing potential as a flexibility solution at an aggregated level, with power fed back to the grid potentially becoming important. Increasing use of flexible heating systems, in district heating and industries, could significantly reduce power demand during peak periods, such as on cold, windless winter days. Heating solutions that can alternate between

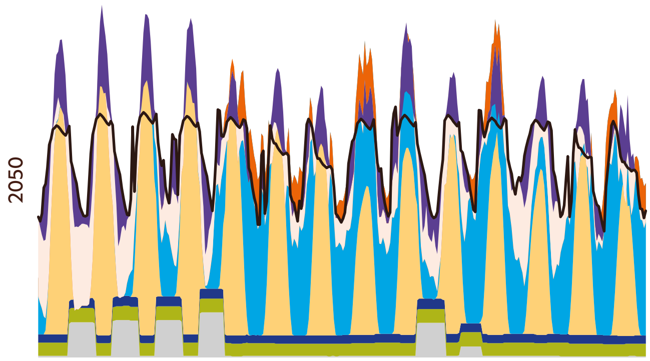
[i] Other: Nuclear, CCGTs, CHPs, coal, waste to power etc. In the Green scenario, these become gradually more clean, including switch from fossil to bio, bio+CCS.

> **The EU will need to invest in power system flexibility solutions across production, consumption and grid, such as pumped hydro plants, interconnectors, batteries, and demand response.**

Location: Ulla-Førre, Suldal, Norway

25 Summer: German electricity generation, 2 weeks, weather patten 2017 (GWh, 2030, 2050)





electricity and other energy carriers will enable electricity to be used for other purposes during periods of low power production and high demand and the use of multiple energy carriers, for example, keeping the old gas boiler when installing a heat pump in industry, could increase the overall efficiency of the energy system. Parts of industry are expected to reduce or halt production during periods of high electricity prices, thereby contributing to solving long-term imbalances over several days. This is economically feasible in some sectors but will often result in reduced industrial production and revenue losses. In Germany, in *Delayed*, demand response at aggregated level is expected to cover 11% of total flexible capacity in 2035, increasing to 23% in 2050 (Figure 24).

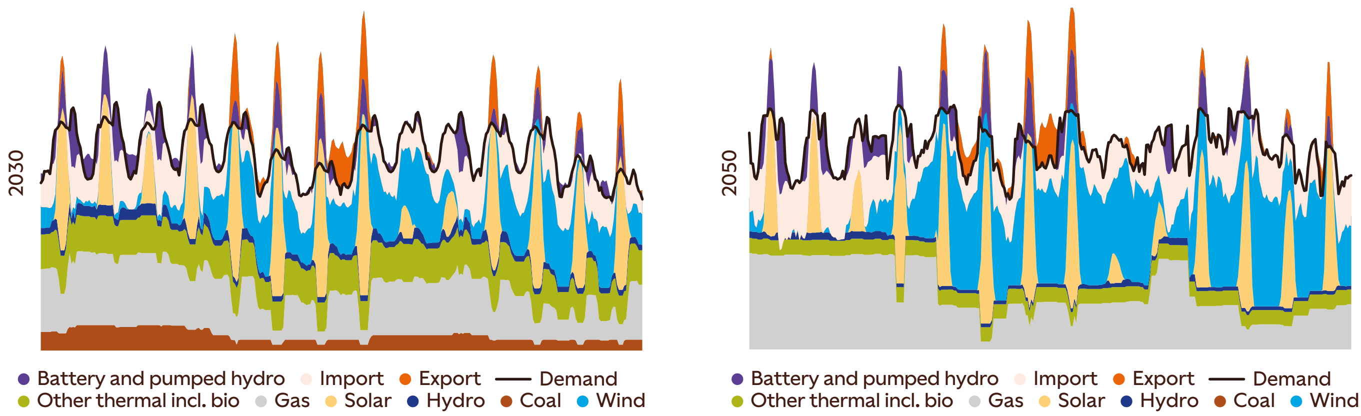
Towards 2050, technological breakthroughs that are not included in our modelling is still possible. Other potential clean technology candidates as we get closer to 2050 could include different long-duration energy storage technologies that are currently in the early stages, new generation geothermal power, small modular nuclear reactors (SMRs), white hydrogen and even nuclear fusion. Technology and cost developments for these solutions are very uncertain and currently they are therefore not included in the three scenarios.

Germany's summer electricity generation mix in *Delayed* highlights the changing role of short-term flexibility. In 2030 we observe that solar dominates midday generation, while wind output fluctuates considerably (Figure 25). Hence, thermal capacity remains essential to balance the system. Already in 2030, batteries and pumped hydro begin discharging strategically during ramps, helping to avoid the activation of high-emitting gas plants. Towards 2050, coal is fully phased out and gas use is minimal during summer. Wind and solar PV dominate the supply stack, supported by an upgraded grid architecture, more flexible EV charging and other demand response. Storage becomes a new backbone in Germany in 2050. Batteries and pumped storage provide most of the intra-day balancing, mitigating variability and reducing curtailment. Flexibility through inter-connectors also increases.

Germany's winter electricity generation mix in *Delayed* highlights the seasonal contrast and the need for solving longer periods of little wind. In 2030, conventional generation is still crucial, with gas and coal power heavily relied upon for base and peak loads. Batteries and pumped storage contribute to evening peaks, while imports support supply during volatile periods (Figure 26). In 2050, power production in winter has increased alongside higher overall electricity consumption. Wind and solar PV dominate the supply mix, while flexible EV charging and price-responsive electric heating are widely adopted. Industrial demand-side response becomes essential. Similarly, fossil gas and cross-border imports provide critical seasonal backup during prolonged renewable shortfalls, especially during cold spells. Still, there will be periods of synchronised stress events across interconnected systems. This underlines the need for development a range of different flexibility solutions for the stable operation of Europe's future grid.

Today, there are several ongoing European collaborative initiatives to ensure sufficient inertia and system resilience as energy systems become gradually more integrated and renewable. Power market price signals reflecting the need to adapt production and consumption are in general the best mechanisms for incentivising flexibility on both the

26 Winter: German electricity generation, 2 weeks, weather patten 2017 (GWh, 2030, 2050)



supply and demand side. Also, developing ancillary markets, capacity mechanisms and procurement schemes that better align with the needs of high-renewable systems will be important. It will also be key to remove barriers and develop new smart solutions. There is potential to unlock more demand flexibility to facilitate higher shares of intermittent renewables. This is reflected in the Green Transition Scenario.

Hard to abate emissions: More costly and challenging

The future for clean hydrogen and carbon capture and storage is uncertain and show large variation across our scenarios. Clean hydrogen and its derivatives are expected to be essential in decarbonising hard-to-abate sectors such as major industries including iron and steel, refineries and chemicals, as well as some long-distance transport segments. In *Green*, clean hydrogen also plays a balancing role in the power markets.

The clean hydrogen market is currently developing more slowly than expected and face high project costs due to often more complex-than-expected system design, high financing costs, and supply chain constraints. A lack of offtake agreements remains a significant barrier to projects reaching final investment decisions. On a positive note, key EU regulations have been passed in recent years, while subsidy schemes are maturing and most projects today are enabled by regulatory push such as the the Renewable Energy Directive (RED III), with binding targets for industry and public funding allocation.

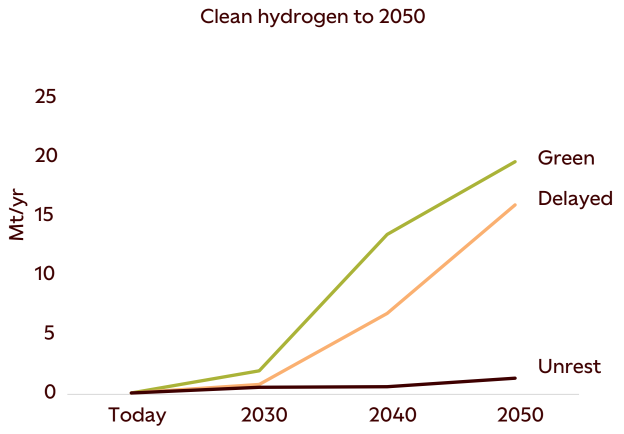
The outcome space for clean hydrogen spans from 1.4 to 20 Mt by 2050 across our scenarios, with the highest volumes reached in *Green*, but the EU does not reach its non-binding 2030 renewable hydrogen target of 10 Mt domestic production in any of our scenarios (Figure 27). To reach the clean hydrogen volumes in *Green*, high climate ambitions combined with fast national implementation of EU regulations, infrastructure build out and future funding schemes will be crucial. The clean hydrogen consumption in *Green* is a prerequisite for the EU to reach its climate targets. For the EU to reach net zero emissions, the majority share of clean hydrogen is produced from electrolysers in this scenario. In *Delayed* there is some use of clean hydrogen and its derivatives to reduce emissions in the chemical industry and steel production, shipping and aviation, but slower uptake and larger share of hydrogen produced from fossil gas with CCS. For peak demand in the power sector, fossil gas remains a solution all the way to 2050. In *Unrest*, the hydrogen infrastructure and storage market fail to develop while *Delayed* will only see limited hydrogen infrastructure build-out.

Sustainable biomass and bioenergy will continue to play a role in the EU's renewable energy mix, particularly in sectors where electrification is challenging. Bioenergy for space heating declines across scenarios, as clean electricity replaces firewood and wood pellets. Instead, bioenergy use is shifted to applications that are hard to decarbonise, such as heavy transport and some industrial processes.
In addition, bioenergy may play a vital role in Northern Europe as a substitute for electricity in flexible heating systems, during periods of low wind power generation and high demand (e.g. 'dunkelflaute').
In our analysis, there is limited import of sustainable biomass and biofuel at reasonable cost, given current expectations of global supply and demand for sustainable bioenergy.

The energy transition is moving forward in the EU across scenarios, with emissions declining. However, the costs of climate inaction grow higher every day as emissions accumulate, and extreme weather events add costs, damage and unpredictability for society and for the energy markets.

Location: Ulla-Førre, Suldal, Norway

27 Clean hydrogen consumption and carbon capture and storage from today to 2050 (Mt/yr)



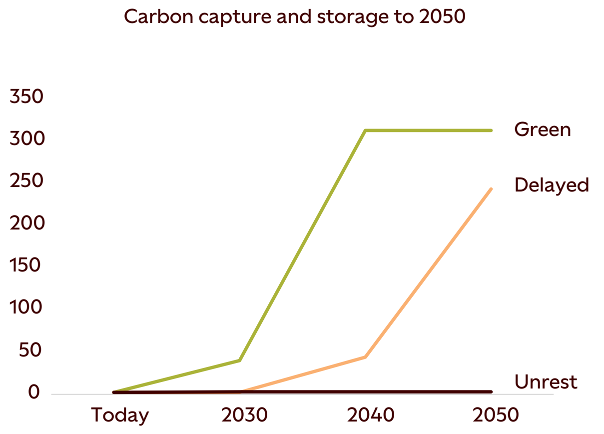


TABLE 5: Clean hydrogen consumption in the EU across scenarios (Mt H_2/yr)

Mt	2030	2040	2050
Green	2	14	20
Delayed	1	7	16
Unrest	0.6	0.6	1.4

TABLE 6: CCS in the EU across scenarios (Mt CO_2/yr)

TWh	2030	2040	2050
Green	40	310	310
Delayed	2	44	240
Unrest	2	2	2

In *Green*, 310 Mt carbon is captured and stored in the EU by 2040 compared with 44 Mt in *Delayed* and close to zero in *Unrest* (Figure 27). Large deployment of industrial carbon removal and carbon capture and storage are needed as soon as 2040 to reach a 90% climate target. CCS is used in applications when switching to other technologies are prohibitively expensive but also in relatively new capital-intensive factories with long expected lifespan. In *Green* and *Delayed*, the remaining emissions in 2050 are primarily concentrated in the hard-to-abate industrial processes and heavy transport sectors. In addition, bioenergy with CCS and some direct air capture result in 130 Mt of carbon removals in 2040 in *Green*. In *Delayed*, there is limited carbon capture in industrial processes and negligible carbon removal deployment, while there is still some consumption of fossil hydrogen with CCS and CCS in district heating. In *Unrest*, the carbon management value chain fails to develop. As with clean hydrogen, the complete carbon management value chain from the capturing plant to a carbon storage site will need to be established in Europe. This will require significant policy support and incentive schemes.

As shown in *Delayed* and *Unrest*, there is currently a significant risk of locking in fossil fuels in all sectors with long lasting negative consequences. The energy transition is moving forward in the EU across scenarios, with emissions declining. However, the costs of climate inaction grow higher every day as emissions accumulate, and extreme weather events add costs, damage and unpredictability for society and for the energy markets. Policy actions to remove barriers to the cost-competitive solutions in the power and end-use sectors are low-hanging fruits with multiple benefits. Clean technologies such as solar PV, wind power, electric vehicles, batteries and heat pumps are increasingly cost-effective solutions and will greatly reduce exposure to volatile fossil fuels markets while also reducing emissions, and the overall energy needs. These mature solutions can contribute to the majority of emission cuts as seen in the *Delayed* scenario. While the last mile to net zero looks increasingly challenging and will require strong policy push and government support, particularly for more complex and less mature value chains, such as developing integrated carbon- and hydrogen infra-structure and storage.

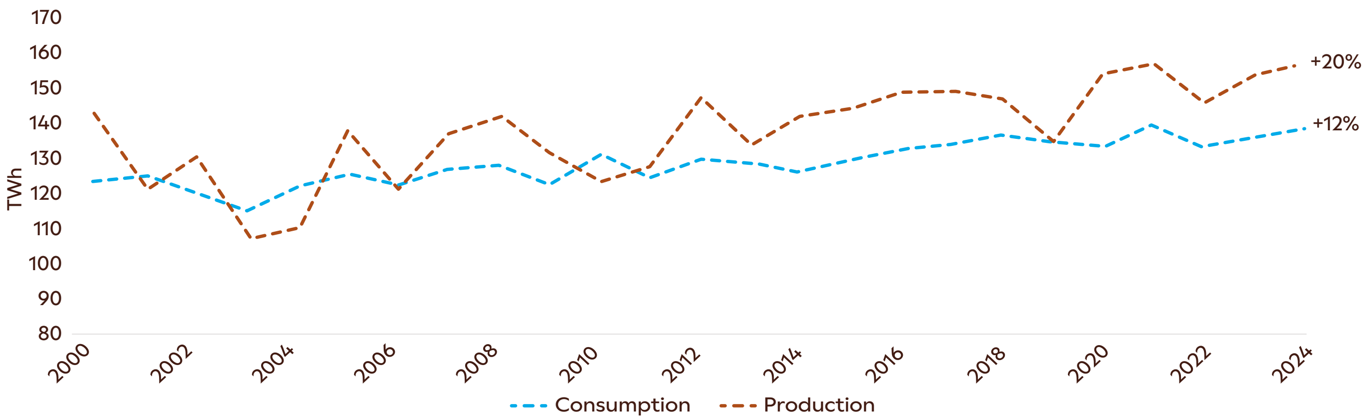
PART 4

The Norwegian Future Energy System

While power production in Norway is already emission-free, energy use is still 50% fossil. Shifting to electricity is the main solution for emission reductions, supported by energy savings, clean hydrogen, CCS and bioenergy. In all our scenarios, Norwegian energy consumption declines as inefficient fossil combustion is replaced by electricity and energy savings. Total electricity consumption, on the other hand, increases across scenarios. Hydropower remains the largest power producing technology until 2050, while wind power experiences the highest growth. Developing a mix of renewable technologies, collaborating with our neighbours and using energy smart are core elements in ensuring a secure, affordable and sustainable Norwegian energy system towards 2050.

Location: Ulla-Førre, Suldal, Norway

28 Historical annual electricity consumption and production in Norway from 2000 to 2024 (TWh)[52]

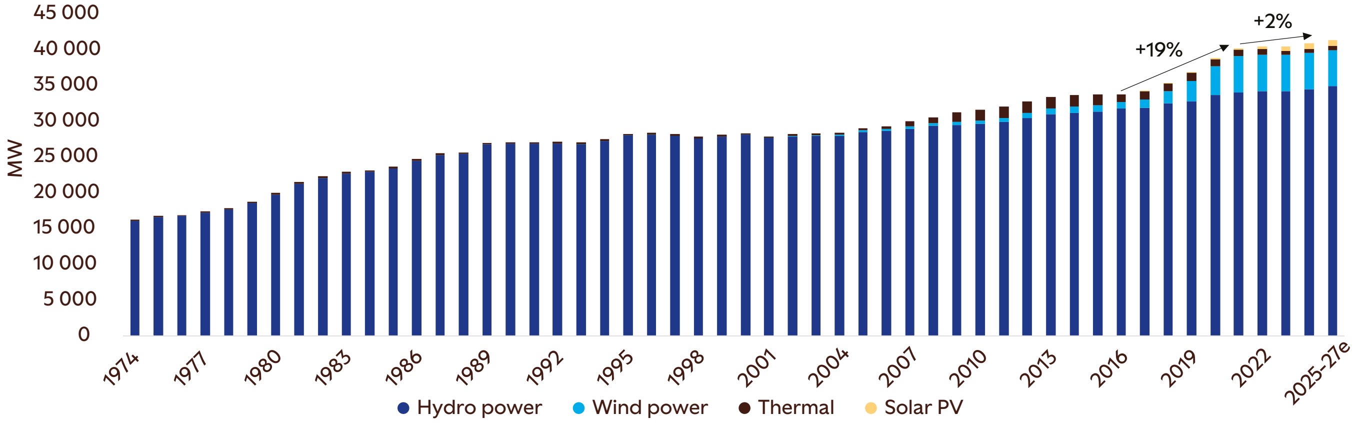


Today's context: The energy mix is 50% fossil and new electricity production lags

Energy use in mainland Norway and on the continental shelf amounted to 316 TWh in 2023 of which 49% was fossil fuels, 43% electricity and 8% bio energy and district heating. Total energy use declined by 3% since 2021 due to electrification of the transport and the petroleum sectors and somewhat lower activity in energy-intensive industries.[50]

Since the millennium, Norwegian electricity production has grown faster than consumption, by approximately 20% and 12%, respectively (Figure 28). During these 25 years, consumption has increased in the petroleum sector, buildings and transport, while industry saw a small decline. Wind and hydropower accounted for 99% of growth in electricity production with 57% and 42% shares respectively, while only 0.4% of the growth came from solar PV. From 2016 to 2021, total installed production capacity increased by nearly 20%, caused primarily by a rapid expansion of onshore wind power. In terms of installed capacity, this growth was comparable to the major hydropower development phases of the 1950-70s. Since 2021, however, the development of new power capacity has slowed markedly, with minimal additions to the system (Figure 29). According to the NVE project pipeline, most of the new capacity expected by 2027 will come from hydropower, with around 1 TWh currently in the project pipeline. No new onshore wind capacity is expected to be commissioned in this period. Temperature corrected electricity consumption, on the other hand, increased by 4 TWh from 2024 to 2025.[51] The coming years we expect continued consumption growth from electric vehicles, electrification of offshore fields, new data centres and other users, resulting in consumption growth outpacing production growth towards 2027 and hence a tightening of the power balance.

29 Historical and projected installed electricity production capacity in Norway (MW). 2025-27 are estimated as per NVE new power report[53]



Scenarios of possible energy futures for Norway

To describe the possible development of the Norwegian energy system and address the political trade-offs that need to be made, we have developed and quantified three scenarios for the Norwegian energy system. The starting point is today's global, European and Norwegian energy situation. The three scenarios represent possible energy system trajectories and energy-related CO_2 emissions towards 2050. The three scenarios - the Green Transition Scenario (Green), the Delayed Transition Scenario (Delayed) and the Unrest Scenario (Unrest) - are consistent with the European scenarios described in the previous chapter.

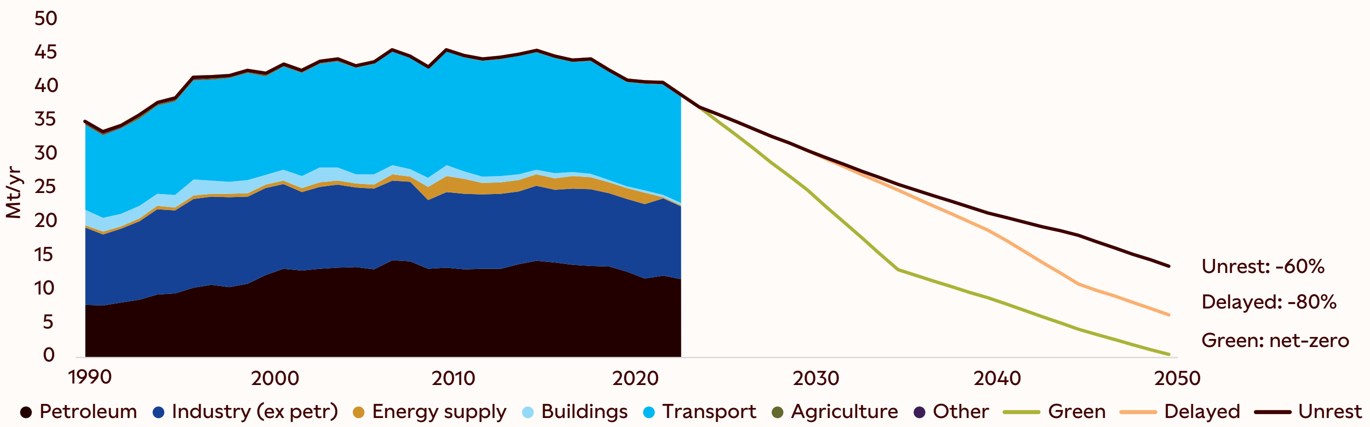
In the Green Transition Scenario, Norwegian CO_2 emissions reach net zero in 2050. Climate is a top priority and Norway transitions its energy production and consumption rapidly. Increasing energy efficiency in buildings is a high priority. In this scenario, the strong and rapid development of new clean industry in Europe and strong global trade provide substantial industrial opportunities for Norway. Norway reduces its energy-related CO_2-emissions domestically by 63% by 2035 compared with 1990 levels and reaches net zero CO_2-emissions in 2050. Technological solutions are known and available to cut emissions in all sectors, but many measures have long lead times of several years, some are less mature, and most require additional electricity.[54] Immediate, fast and coordinated actions are prerequisites in this scenario.

In the Delayed Transition Scenario, climate ambitions are maintained but implementation and enforcement of compliance is lagging. The energy transition encounters more barriers in the coming years, including public resistance to various climate measures, and delays in value chains for certain clean technologies. Global tension remains higher for longer and priorities shift to affordability and security. The transition is primarily driven by more cost-competitive clean technologies, such as wind and solar, redesign of hydropower, batteries, heat pumps and electric vehicles, while less mature solutions lag behind. New industrial development is supported by Europe's desire for better control of value chains for strategic technologies. This push for self-sufficiency leads to higher industrial activity in Norway as well. Overall, Norwegian emissions decrease at a slower pace than in *Green*, leading to around an 80% reduction in CO_2 emissions by 2050 compared with 1990. In this scenario, neither the EU nor Norway reaches its 2050 climate goals.

In the Unrest Scenario, Europe becomes more isolated, the world is even more unpredictable than today, and global trade is more disrupted. Overall, clean technologies are more expensive, and economic growth in Europe and Norway is weaker compared with the other scenarios. Hybrid threats intensify, security and social stability top the political agenda, and the climate and energy transition receive less attention in Norway, in Europe and in the rest of the world. The energy transition slows, and emissions fall more slowly than in the other two scenarios. Neither the EU nor Norway reach their climate targets. In Norway, electrification of transport and industry progresses more slowly, and new industrial growth is lower due to weaker economic growth. There is also more social unrest and political instability adding to the uncertainty in Europe and Norway. Norwegian CO_2 emissions fall by 60% by 2050 compared with 1990 levels (Figure 30).

The key assumptions and variables used for the three scenarios are listed in Annex 1.

30 Historic CO_2 emissions and forecasted CO_2 emissions in Norway for the three scenarios (Mt/yr)[55]



Location: Ulla-Førre, Suldal, Norway

Climate remains a top priority and Norway transitions its energy production and consumption rapidly in the Green Transition Scenario. Energy efficiency in buildings is a key priority.

31 | Final energy consumption in Norway for the three scenarios from today to 2050 (TWh) [56]

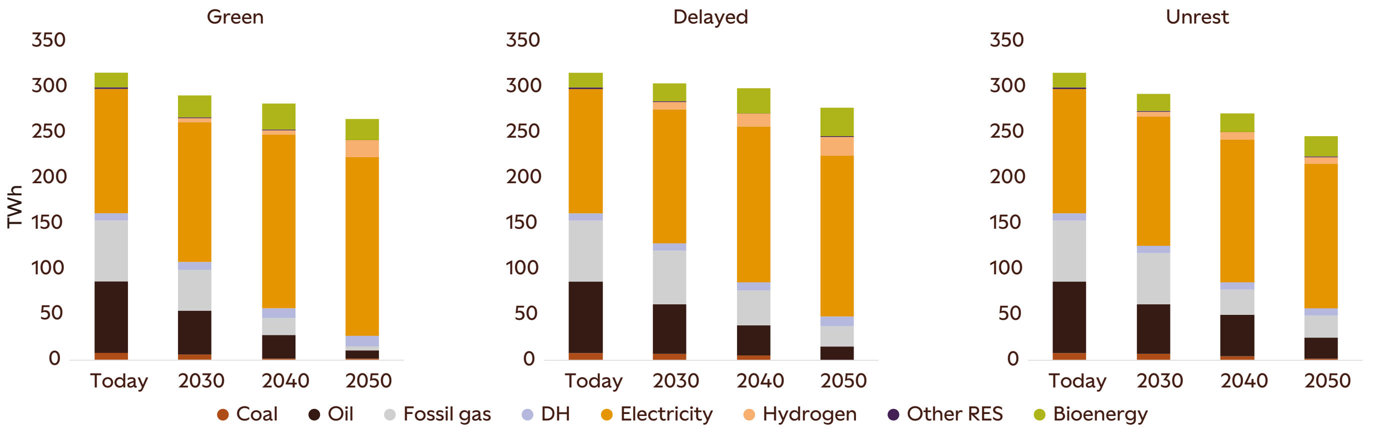


TABLE 7. Share of final energy consumption for the three scenarios in 2030, 2040 and 2050 (%)

Green			
% of TWh	2030	2040	2050
Electricity	54 %	68 %	74 %
Oil, coal and gas	33 %	16 %	6 %
Other (DH, Bio, H_2)	13 %	16 %	20 %

Delayed			
% of TWh	2030	2040	2050
Electricity	49 %	58 %	63 %
Oil, coal and gas	39 %	25 %	14 %
Other (DH, Bio, H_2)	12 %	17 %	23 %

Unrest			
% of TWh	2030	2040	2050
Electricity	49 %	57 %	64 %
Oil, coal and gas	39 %	29 %	20 %
Other (DH, Bio, H_2)	11 %	14 %	16 %

Analysis results: Three scenarios for the Norwegian energy system

The energy system to 2050: More electricity, less energy and lower emissions

Norwegian energy consumption decreases by 12-20% to 2050 across the three scenarios as a result of greater energy efficiency combined with effective electric applications replacing fossil combustion. The share of electricity in final energy use will rise from 42% today to 63-74% by 2050 while the fossil share of final energy will drop from around 48% today to 6-20% by 2050 (Figure 31 and Table 7). In *Unrest*, the decrease in energy consumption and fossil fuels is driven partly by low economic growth and low industrial production, and partly due to electrification and more efficient energy use. Bio energy, district heating and hydrogen in final energy use increase from 24 TWh today to 38-62 TWh across the three scenarios by 2050.

Electricity consumption growth is larger over the coming 10 years than during the previous 10 years in the three scenarios. Electricity consumption grows by about 25-40% to 2035 and by 30-75% to 2050 in our three scenarios as industry and transport shift from fossil fuels to electricity, while new users including data centres—driven by cloud services and AI—also contribute to rising demand. In addition, several offshore oil and gas facilities are expected to electrify, replacing fossil gas. In contrast, electricity use in buildings is expected to remain relatively stable or slightly decline through energy efficiency measures and retrofitting although the underlying building stock increases. Electricity consumption in 2024 was around 140 TWh, while in the three scenarios, it will increase to 173-196 TWh by 2035 and 181-246 TWh by 2050. *Unrest* sees the lowest growth, while *Green* sees the highest due to faster decarbonisation and stronger economic growth (Figure 32 and Table 8).[57]

The largest percentage growth is seen in the transport sector where electricity consumption increases three-to fivefold by 2050, but from a low starting point of around 4 TWh today. In *Green*, final energy consumption in transport is down 38% to 2050. In this scenario, electricity covers 44% of the transport sector's energy demand by 2050, while biofuel, hydrogen and synthetic fuels cover 53%. Electricity consumption in industry including petroleum and data centres sees the largest growth in absolute terms. Future electricity consumption from the industrial sector is highly uncertain, depending on the pace of decarbonisation and the underlying industrial activity. When including electricity to produce clean hydrogen, electricity consumption in industry increases from around 60 TWh today to 77-127 TWh by 2050 (Figure 33).

32 Norwegian electricity consumption historic and across scenarios and sectors to 2050 (TWh)

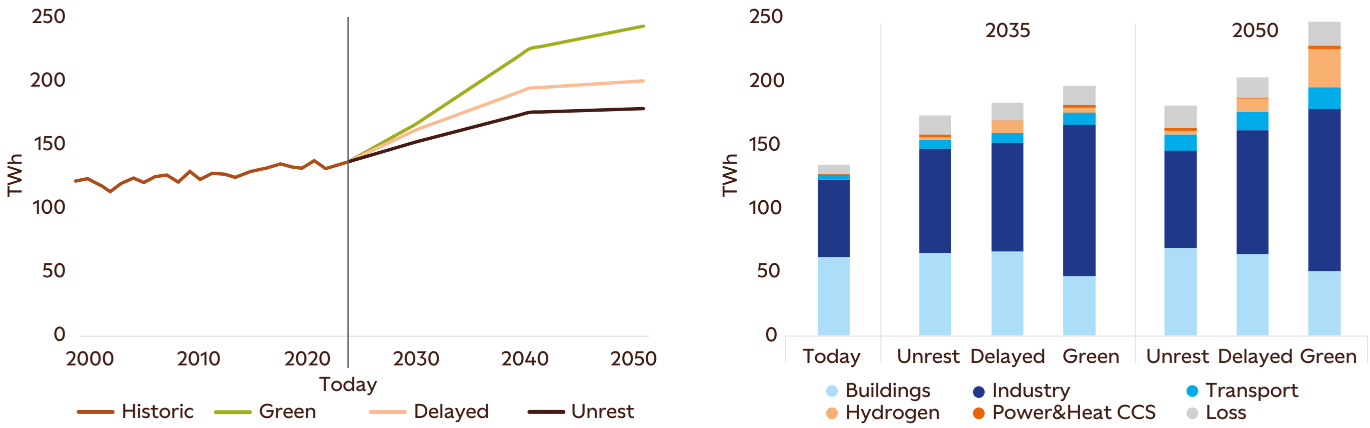


TABLE 8. Power consumption per sector in 2030, 2040 and 2050 across the three scenarios (TWh)

Green			
TWh	2030	2040	2050
Buildings	46	50	51
Industry (onshore)	73	88	88
Transport	7	12	17
Data centre	10	22	25
Petroleum	18	18	14
Other (H_2, DH)	5	20	30

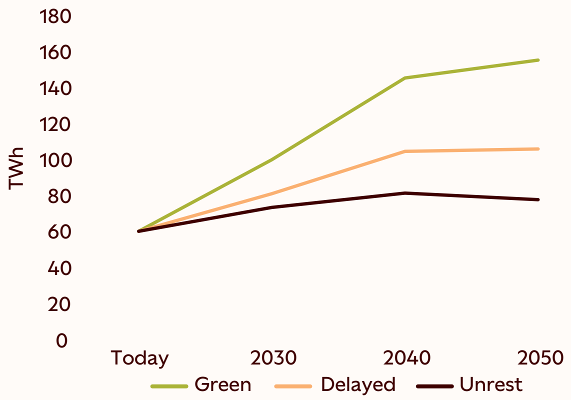
Delayed			
TWh	2030	2040	2050
Buildings	64	65	64
Industry (onshore)	55	60	60
Transport	6	10	15
Data centre	10	22	25
Petroleum	13	15	13
Other (H_2, DH)	3	10	10

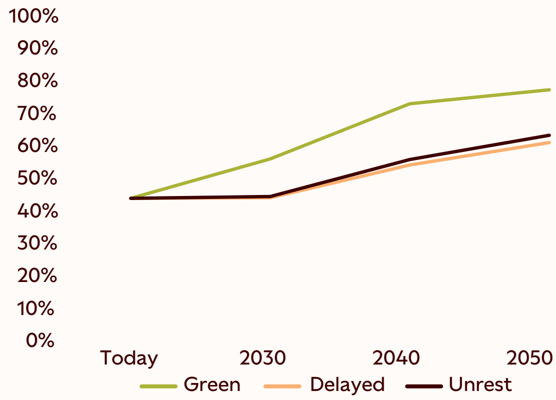
Unrest			
TWh	2030	2040	2050
Buildings	63	67	69
Industry (onshore)	53	58	51
Transport	5	9	13
Data centre	7	10	13
Petroleum	13	14	13
Other (H_2, DH)	4	5	5

Norwegian energy consumption decreases by 14-24% to 2050 across the three scenarios as a result of greater energy efficiency combined with effective electric applications replacing fossil combustion.

Location: Eidfjord, Norway

33 Industry electricity consumption in Norway (left, TWh) and as share of final energy demand across scenarios (right, %)





The energy transition entails significant industrial opportunities

The underlying industrial activity varies across the three scenarios. In *Green* and *Delayed*, Norway's industrial sector experiences positive growth, driven largely by stronger European economic growth and increased nearshoring of critical supply chains. In *Unrest*, final energy demand in existing industry remains fairly stable as weak economic growth and disrupted trade in Norway, Europe and globally results in muted industrial activity, while the share of fossil fuels is higher.

In *Green*, total industry electricity demand more than doubles by 2050, rising from around 60 TWh in 2024 to 127 TWh in 2050, while in *Delayed* and *Unrest* the corresponding figures are 97 TWh and 77 TWh.[i] One key reason for the differences lies in the pace of electrification in heat processes and production of feedstock. As industrial growth is a significant driver for future demand for electricity in Norway, we have also assessed electricity consumption growth needed to reach the climate targets in *Green* without new industries, such as data centres and battery manufacturing. In this case, the growth in industrial power consumption is 39 TWh from today to 2035 and further 6 TWh to a peak in 2045. While in *Delayed*, the growth is only 6 and 13 TWh over the same period, if new industry is excluded.

Electricity consumption in the petroleum sector is expected to increase. Across the scenarios, electrification of the continental shelf will increase demand from about 11 TWh in 2024 to a peak around 2035, before declining, due to reduced production and activity in the fields.[58] The increase is most pronounced in *Green*, where demand reaches roughly 20 TWh by 2035 before declining to 14 TWh in 2050. In *Delayed* and *Unrest*, the peak is lower, at around 15 TWh, reflecting slower electrification and weaker policy signals.

Clean hydrogen has gained much attention as a decarbonisation solution for hard-to-electrify sectors such as maritime transport and some industrial processes. While the potential is strong, challenges when it comes to costs and competitiveness have added uncertainty to the potential of clean hydrogen, and many industrial actors have delayed or cancelled their initiatives. Yet, some electrolyser projects have nonetheless moved forward and have started or are about to start constructions. In *Green*, policy support continues, electrolyser costs fall, and demand drives large-scale uptake. In this scenario, hydrogen production reach 29 TWh by 2050. In *Unrest*, cost pressures persist, infrastructure lags, and political attention shifts elsewhere. Clean hydrogen production remains closer to 2 TWh in 2050.

Across all scenarios, data centres contribute to consumption growth, expanding from less than 1 TWh in 2020 to 13-25 TWh by 2050. This amounts to a compound annual growth rate of 9-11%. Norway and the Nordic regions are by many expected to become important data centre hubs in Europe. With access to clean power, stable grid infrastructure, low ambient temperatures, and high geopolitical trust, the region offers good conditions. As Europe intensifies its digitalisation and AI ambitions, demand for scalable, green, and secure data infrastructure is surging.

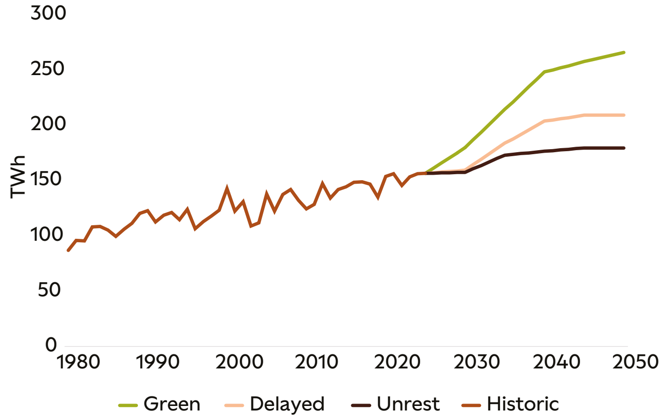
Industrial process heat in Norway takes very different paths across scenarios, reflecting diverging levels of climate ambition, investment, and technological adoption. In *Green*, electricity use for industrial process heat, including aluminium, increases by 6 TWh by 2050. In process industries such as steel, ferro, aluminium and silicon, which commonly use high temperatures in their processes, fossil fuels are progressively replaced either by electricity or, when that is unfeasible, by hydrogen and bioenergy. In medium- and low-temperature segments, electricity becomes dominant, primarily through heat pumps and electric boilers. As variability in electricity generation from wind and solar increases, flexible electric heat technologies are deployed at larger scale to take advantage of low-price periods and contribute to system balancing. This strategy is already evident in Finland, where district heating and industries plan to deploy up to 2 GW of electric boilers in the coming years – to be used primarily during low-price periods. In the Unrest Scenario, industrial demand declines by 6 TWh, but the shift away from fossil fuels still proceeds, though more slowly. In high-temperature applications excluding aluminium, gas becomes the largest single source, while medium-temperature processes are supplied mainly by electricity, but also with some fossil gas and some contribution from bioenergy. In low-temperature segments, electricity continues to play the central role.

Beyond the big energy-intensive sectors, Norwegian industry includes among others non-ferrous metals, chemicals, defence manufacturing, the maritime and seafood value chains, and other industries. These sub-sectors may seem fragmented, but together they matter for electricity demand, and their future diverges sharply across scenarios. In *Green*, electricity consumption in this group more than doubles by 2050. Strong climate policy and competitive renewable power make electrification the default choice. Companies modernise to stay competitive in a Europe focused on low-carbon value chains. In addition, new electricity demand may arise from technology-driven aquaculture, as for example Norwegian salmon producers are moving towards closed or land-based facilities that are more energy intensive than traditional production. Also, CCS retrofits at waste-to-energy and cement plants further increase demand through capture systems. In *Unrest*, the picture reverses. Electricity consumption in these industries falls by about 60% by 2050. Instead of driving growth, industries will shrink, reflecting a world where security concerns and cost pressures overshadow decarbonisation. The contrast highlights what is at stake: in a *Green* scenario, diversified industries become a major source of electricity consumption and industrial resilience; in a fragmented world, they risk long-term decline.

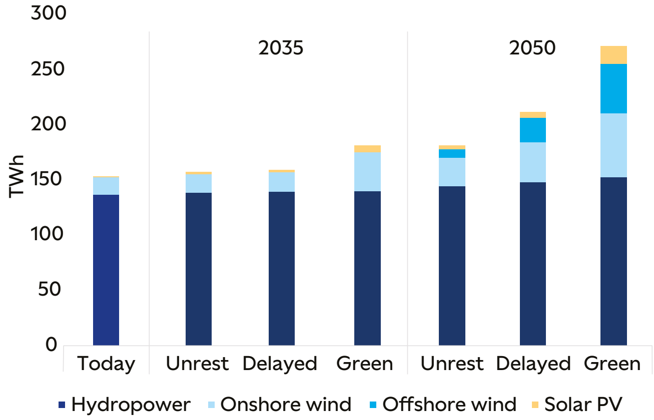
In *Green*, total industry electricity demand more than doubles by 2050, rising from 61 TWh in 2024 to 127 TWh in 2050.

Location: Landesbergen, Germany

34 Annual growth in Norwegian power production from 1980 to 2050 (TWh)



35 Power production in Norway across the three scenarios today, in 2035 and in 2050 (TWh)



Power production: Utilising Norwegian comparative advantages

Norwegian power production increases by 24-115 TWh by 2050 across the scenarios. Hydropower remains the dominant source through 2050, while wind power experiences the largest growth. Hydro, wind, and some solar power complement each other well in Norway's energy mix, supporting competitive electricity prices compared with neighbouring markets, and contributing to emissions reductions in industry, transport, buildings and petroleum production. For the period to 2035, onshore wind and some hydropower are the only viable solutions for delivering large volumes of cost-competitive electricity in Norway (Figure 34 and 35).

In the three scenarios power production in Norway increases from 157 TWh today to 181-272 TWh by 2050.[59] The hydropower share is projected to range between 56-80% by 2050, with the lowest share in *Green* and the highest in *Unrest* (Figure 36). Onshore wind sees the largest growth from today to 2035 in *Green* and *Delayed* while almost stalling in *Unrest*, growing by 10-42 TWh by 2050 across the three scenarios. These volumes represent a 14-21% share of total production in 2050 compared with 10% today and installed capacity of 7-15 GW compared to 5 GW today. In our three scenarios, Norwegian offshore wind production in 2050 varies from 7-45 TWh. This corresponds to 1.5-10 GW of installed capacity, a significant increase, but far from the 30 GW target for 2040.[60] Solar PV reaches 3-16 TWh in 2050, up from 0.5 TWh today. This equals a generation share of 2-6% (Figure 35).

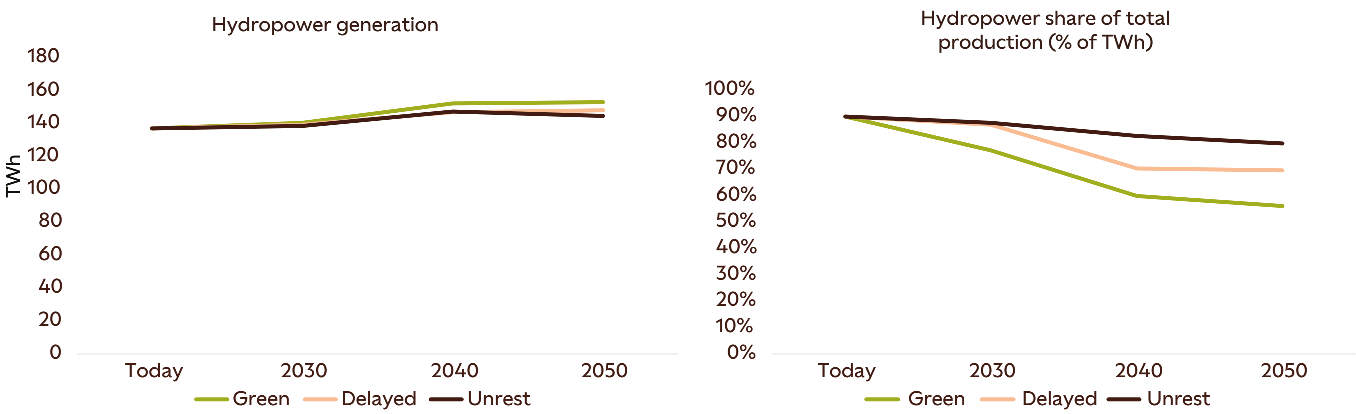
The value of flexible hydropower increases

Conventional hydropower plants with reservoirs can store energy across various time scales, offering flexibility and reliability in an energy system with more intermittent sources. Norway has more than 1,790 hydropower plants with a total installed capacity of 34,000 MW. Over the past 20 years, upgrades and expansions at about half of Norway's hydropower plants have increased hydropower production by nearly 5 TWh. In the coming decades, several major plants are nearing the end of their technical lifetimes and will require reinvestment. Although most of Norway's hydropower potential when it comes to energy generation has already been developed, considerable untapped potential remains to provide additional system flexibility. In all our scenarios, hydropower production and installed capacity increase. By 2050, annual electricity production from hydropower rises by 5–11% from today's baseline of 138 TWh (a normal weather year). The largest gains occur in *Green* (Figure 36).

Driven by increasing electricity consumption and competitive renewable resources, Norwegian power production will increase significantly in all our scenarios. Hydropower remains the largest source until 2050, while wind power experiences the highest growth.

Location: Roan, Norway

36 | Hydropower generation and share of production across the three scenarios to 2050 (TWh, %)



Utilising hydropower in the best possible way

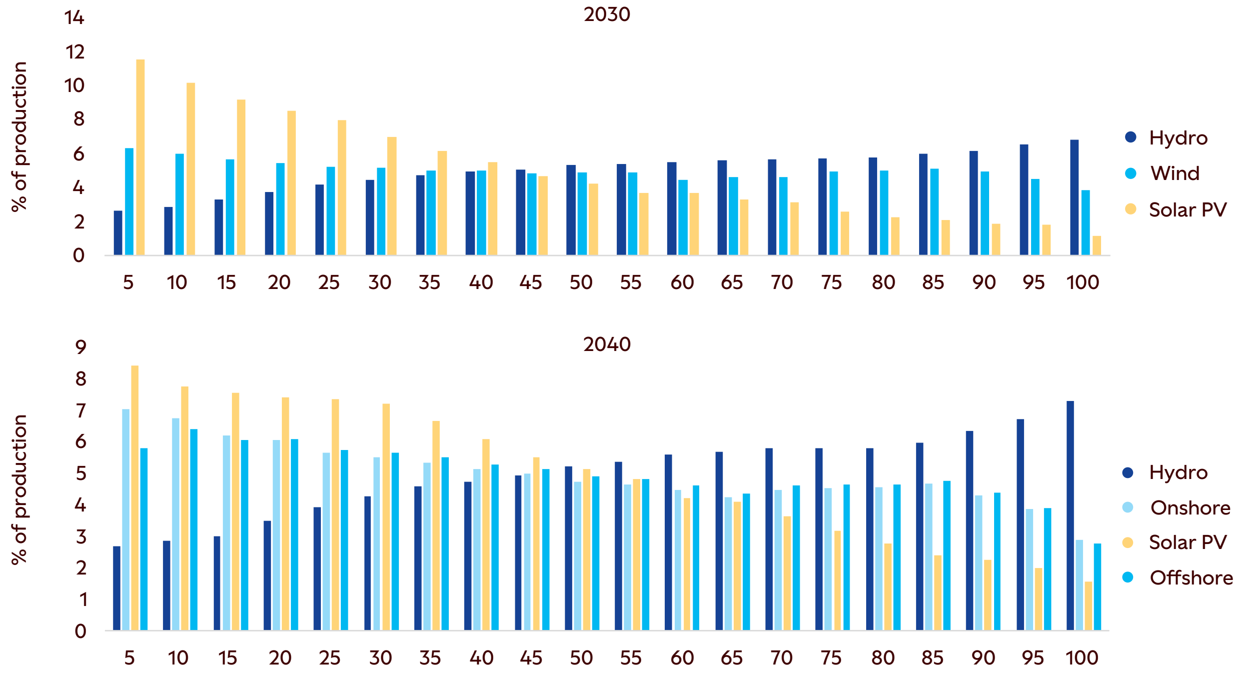
The flexibility of hydropower enables the Norwegian power system to integrate large quantities of wind and solar energy. To illustrate this, we have assessed power production in the southernmost part of Norway (NO2) under the *Delayed* scenario for 2030 and 2040 in greater detail. Figure 37 shows the modelled prices in percentiles at which different technologies supply electricity to the grid. The x-axis represents sorted electricity prices in percentiles (lowest to the left), while the y-axis shows the percentage of total production from each technology corresponding to those price levels. Solar PV generates most of its output during summer, with low prices, and contributes less to the power mix when prices are high, challenging the profitability of PV installations. Increased flexibility in the power system, such as batteries co-located with solar PV, can partly compensate for this challenge. Onshore wind shows a relatively stable production profile across price percentiles, though wind tends to produce slightly less during very high-price periods, reflecting reduced output during low wind periods in winter, which in turn cause prices to rise. Offshore wind, introduced towards 2040, follows a similar pattern to onshore wind when it comes to production at different price levels, although the off-shore wind generation profile over the year sees less variation. In general, wind power has a production profile throughout the year that is relatively well aligned with the consumption pattern as it is windier in the winter when consumption is also high.

Hydropower by contrast produces a smaller share during low-price hours and the majority when prices are high (Figure 37), demonstrating its ability to time power production to periods of high demand. In our simulation of NO2, 60% of Norwegian hydropower is generated during hours when prices are above the 50 percentiles in 2040. Without this supply flexibility provided by hydro power, price volatility in Norway would have been significantly higher.

Redesign of hydro power: Adapting to changing energy markets

Many of Norway's major hydropower plants were originally designed for base load production in the 1950s to 1970s to serve local and domestic consumption and with limited interconnectivity. With deregulated energy markets, strengthened transmission infrastructure, and more intermittent power production, societal needs have shifted. Hydro-power redesign projects now aim to adapt to these changes by focusing on increasing installed capacity and/or integrating pumped storage units . Increasing capacity allows the plant to concentrate production during periods of high demand and high electricity prices, rather than operating continuously. Pumped storage units enable the plant to store energy by pumping water from a lower to an upper reservoir during periods of surplus electricity, typically when intermittent generation is high and demand is low and to generate electricity when the system experiences scarcity.

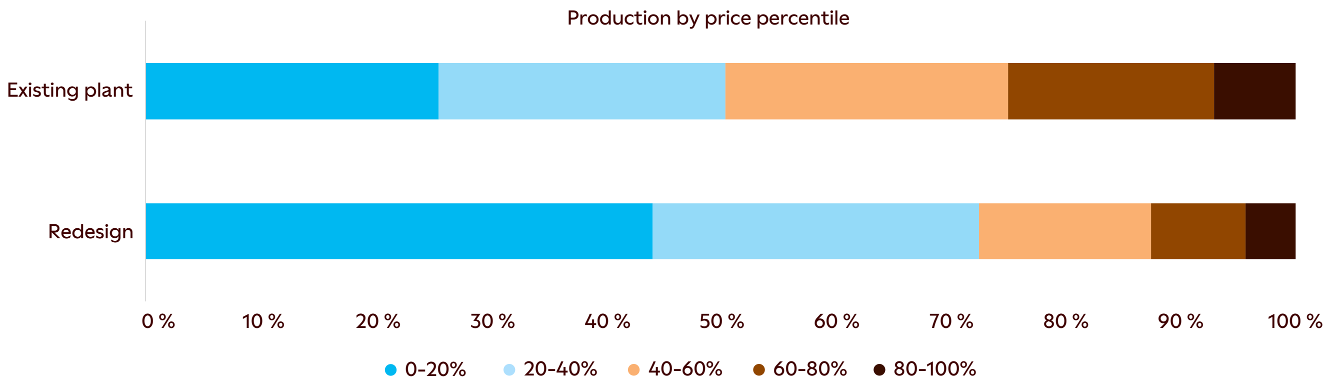
37 Production according to price percentile in 2030 and 2040 for different technologies in NO2 (% of GWh)



Location: Alta, Norway

Many of Norway's major hydropower plants were originally designed for base load production in the 1950s to 1970s to serve local and domestic consumption and with limited interconnectivity.

38 Illustration of price dependent production. Percentage of production in different price percentiles over a year for an existing plant and a redesigned plant. The highest price segments are shown to the left and the lowest to the right.



Redesign and pumped storage projects may alter hydropower's role in the electricity market by reshaping the merit order curve as more capacity becomes available during peak demand, reducing the highest prices. A redesigned plant may run up to 50% fewer full-load hours during the year, with a higher share of its production concentrated to periods of high demand and corresponding high prices.

Figure 38 illustrates how production in a redesign project may be distributed across different price segments represented by colour bands and compared with the plant prior to the redesign project (existing plant). Dark blue on the left represents the 20% of hours with the highest prices, while purple on the right represents the 20 % with the lowest prices. In the given example, approximately 25% of the existing plant's annual output occurs during the 20% of hours with the highest electricity prices (dark blue). This existing plant operates around 6,000 full-load hours per year. The redesigned plant in this example operates about 50% less, at around 3,000 full-load hours annually, concentrating production in periods with high demand and corresponding high prices. As shown in the figure, more than 40 % of the redesigned plant's output occurs during the hours with the highest prices, when electricity is most needed by society (dark blue).

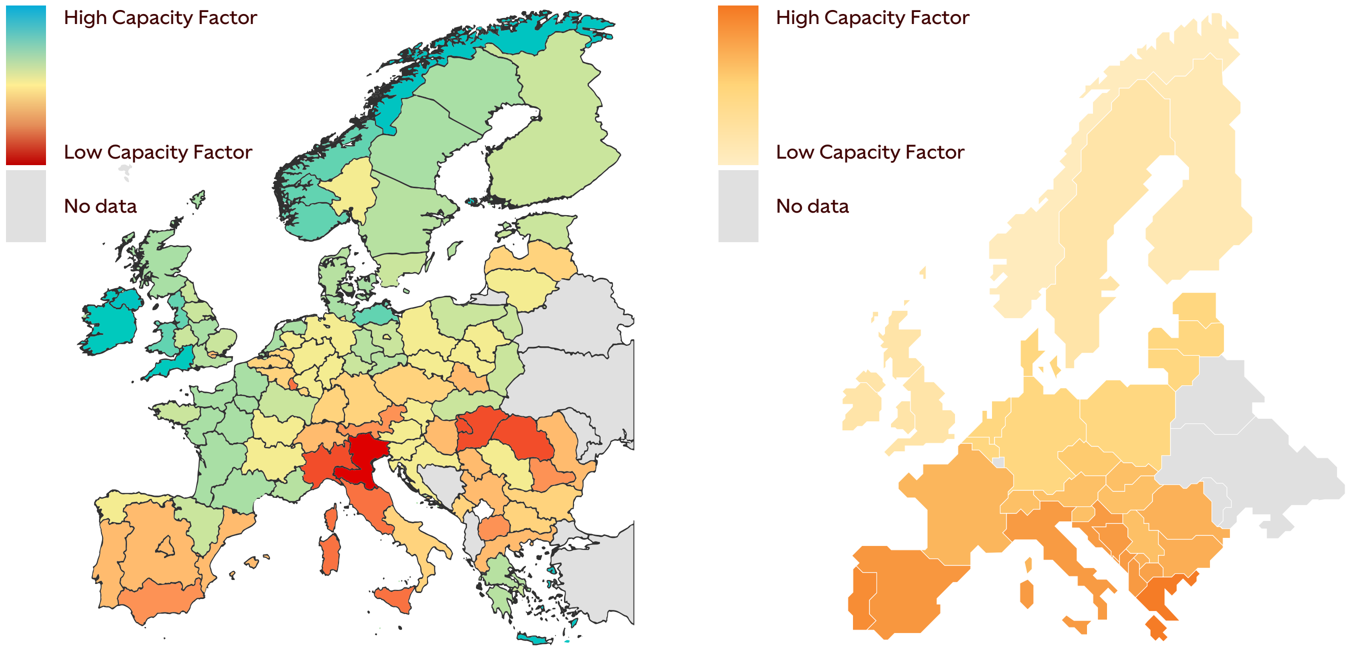
Upgrading hydropower is capital-intensive, and the marginal value of each additional project tends to decline. The new flexibility added to the power system should support the integration of intermittent renewables and support higher peak consumption, but from a societal and commercial viewpoint, it should not be so expensive that it undermines economic viability. Pumped storage introduces a new layer of complexity. Regulatory changes to electricity market pricing mechanisms or limitations to cross-border trade can significantly impact the viability of such projects and may discourage investment and thereby limit deployment. This challenge also applies to other flexible technologies, such as grid-scale batteries. In a system increasingly dominated by intermittent sources, barriers to investment in balancing technologies could be highly detrimental. To attract long-term investment and enable successful integration of flexibility solutions such as redesigned hydropower projects, price signals must reach producers and consumers, while taxation frameworks must be stable, transparent, and predictable.

Onshore wind has strong growth potential, but meets challenges beyond costs

Onshore wind is the most economically viable source of new electricity production in Norway and it is among the fastest to build (Figure 41). Existing Norwegian onshore wind farms have an average capacity factor of 38% which is among the best in Europe (Figure 39).[61] From north to south, Norway extends for 1,752 km, with wind conditions varying considerably in different parts of the country. Due to differences in wind resources, the costs per unit of wind power produced vary significantly across sites. Nevertheless, if the provision of affordable power for households and industry is a high priority, large volumes of onshore wind remains a main solution.

Onshore wind remains more economically viable than solar, offshore wind, and nuclear power throughout the analysis period (Figure 41), not only in terms of LCOE but also when adjusting for expected achieved prices.

39 Wind (left map) and solar (right map) resources across European regions, capacity factor (in %)



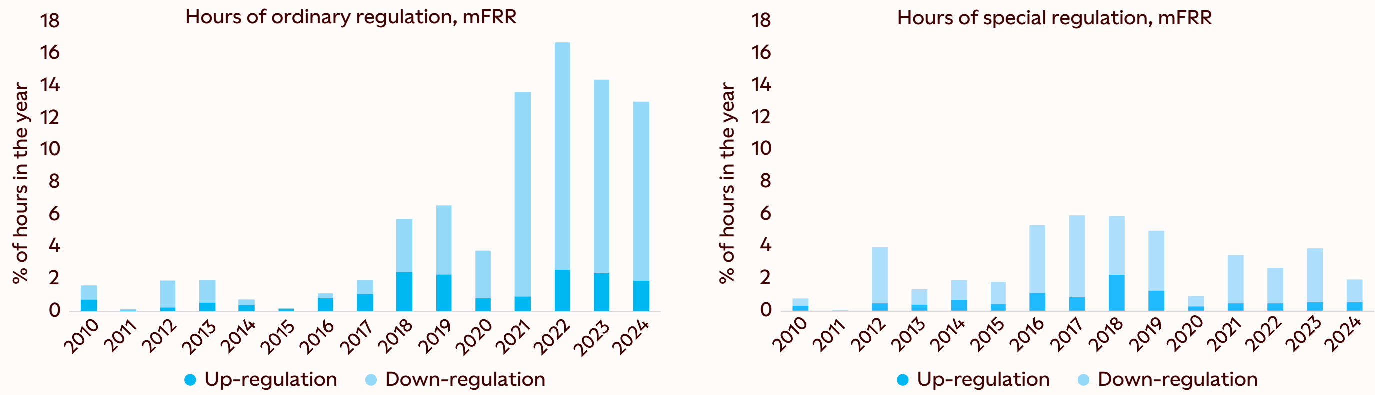
The future role of onshore wind in Norway's energy system depends largely on public acceptance. Several measures to improve processes for onshore wind power are being implemented, or are under way. Recent amendments to the Norwegian Planning and Building Act have granted municipalities greater authority over permitting decisions for onshore wind projects.[62] Municipalities will also receive higher revenues from developed sites. These changes are expected to help improve social acceptance, while also resulting in longer project timelines.

Hydropower plays a key and increasing role in delivering ancillary services

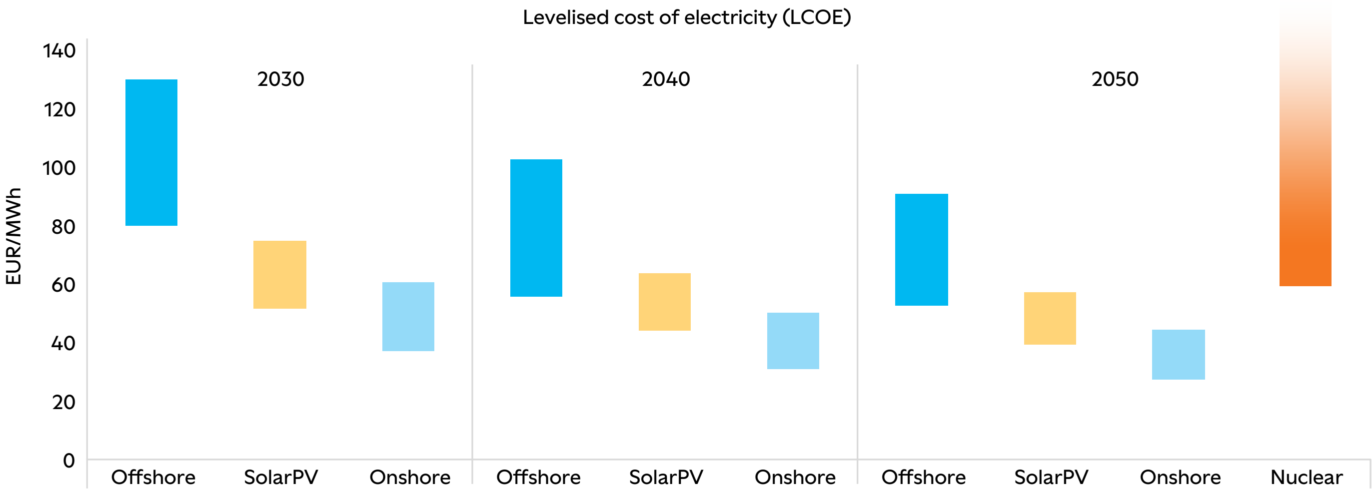
Hydropower can provide flexibility and system services within a range from seconds to days, as well as store energy for weeks, months or years. The rotating mass of hydropower turbines provides inertia, helping to stabilise the transmission grid. When grid frequency deviates from its required range, hydropower plants can make precise adjustments to turbines and gate openings, contributing to frequency regulation.

Figure 40 illustrates the number of hours the Svartisen power plant has provided both ordinary and special regulation for manual Frequency Restoration Reserve (mFRR) from 2010 to 2024. The data shows that the plant has actively contributed to grid stability during a significant portion of this period and the overall contribution has increased over time.

40 Delivery of ancillary services



41 Forecast of average LCOE per technology in Norway in 2030, 2040 and 2050 (€/MWh, real'24) [i]



In our scenarios, onshore wind generation increases by 10-42 TWh to 2050, from 16 TWh today (Figure 42). In *Unrest*, a combination of low local acceptance, less cost reductions, lower climate ambitions and less industrial activity causes slow build out, with new projects coming primarily after 2035. In *Green*, offshore wind production exceeds onshore wind production growth by a small margin by 2050. All scenarios have lower annual growth for onshore wind power than was seen in the period from 2015 to 2022.

Solar PV sees limited growth with unfavourable production profile over the day and year

Solar PV in Norway has an estimated average capacity factor of 8.5%.[63] This is lower than in the rest of Europe due to lower solar irradiance in northern Europe (Figure 39). While this makes solar PV less productive than in southern regions, utility scale solar PV remains one of the more affordable energy sources in Norway on a levelised cost of electricity (LCOE) basis, largely due to declining module cost. As reflected in Figure 41, onshore wind power is generally cheaper than solar in most places in Norway, and the achieved prices of onshore wind are higher due to a better correlation with seasonal demand patterns.

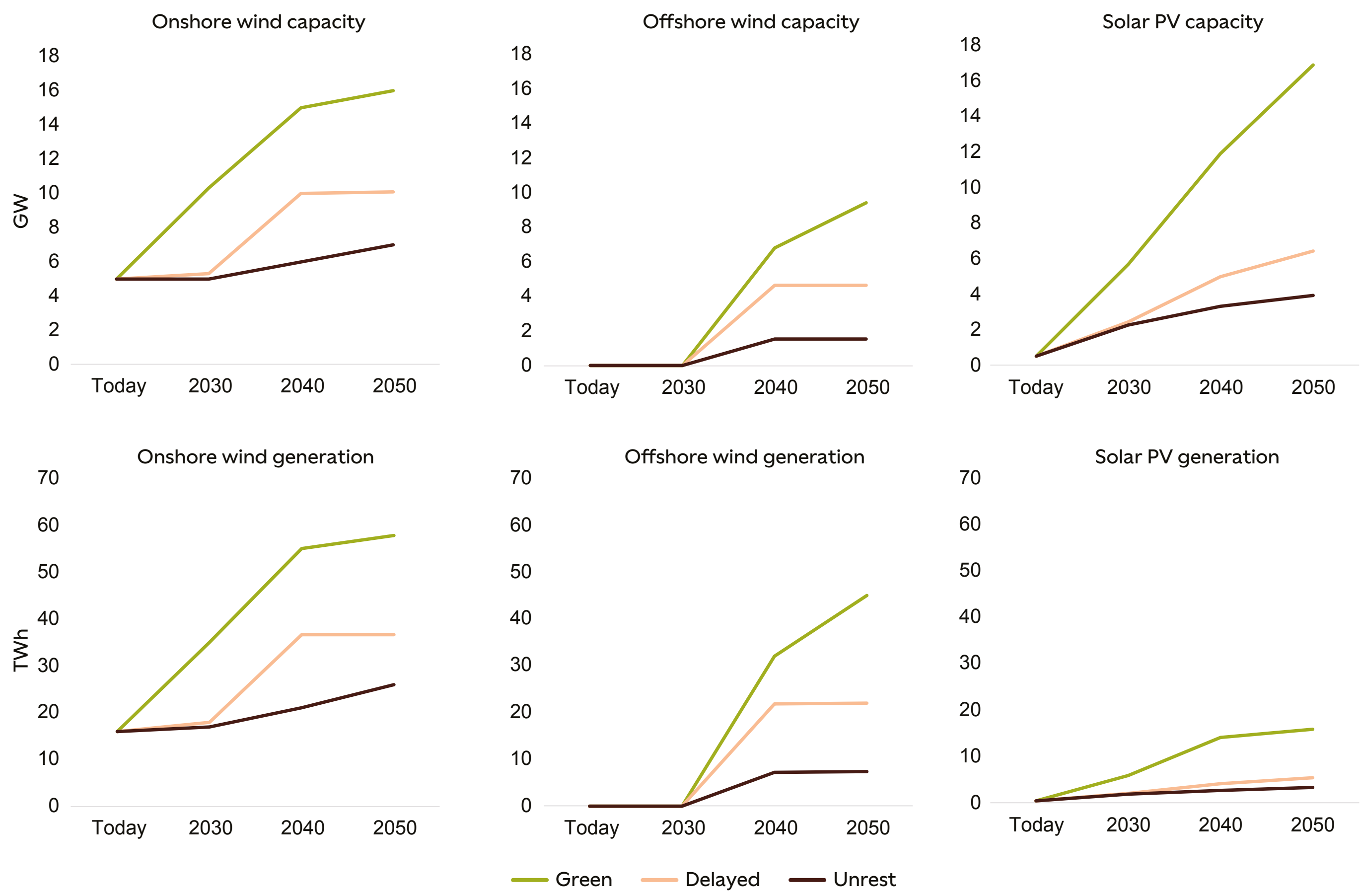
For Solar PV, the economic performance is challenged by an unfavourable seasonal profile and lower achieved market prices. The latter is largely due to increasing solar deployment across the Nordic region and continental Europe, which leads to electricity oversupply—and lower prices—during daylight hours, especially in summer. Most of the new capacity in our scenarios comes as rooftop installations rather than utility-scale farms. While utility-scale solar often is the cheapest per unit, it requires more land and may face greater local opposition. In contrast, rooftop solar often benefits from financial incentives and reduced grid tariffs. Solar PV deployment is highest in southern Norway, where conditions are more favourable.

Offshore wind and nuclear are capital intensive technologies with long lead times

Europe has a well-established wind industry, supported by strong public policies and private investments. Norway has vast ocean areas and thus significant long-term potential for expanding renewable energy production offshore. Offshore wind development in Norway already benefits from the experience and learning effects of earlier projects across Europe. In recent years however, offshore wind projects have experienced significant cost increases and delays, largely due to global supply chain disruptions that have driven up capital costs and extended delivery timelines. Going forward, we still expect cost reductions for bottom-fixed offshore wind power in Norway as we approach 2050, because of improved production efficiency and technological innovation globally (Figure 41).

Floating offshore wind technologies are less mature than bottom-fixed installations, resulting in greater uncertainty in future cost estimates. In Norway,

42 Onshore wind, offshore wind and solar PV production (TWh) and capacity (GW)



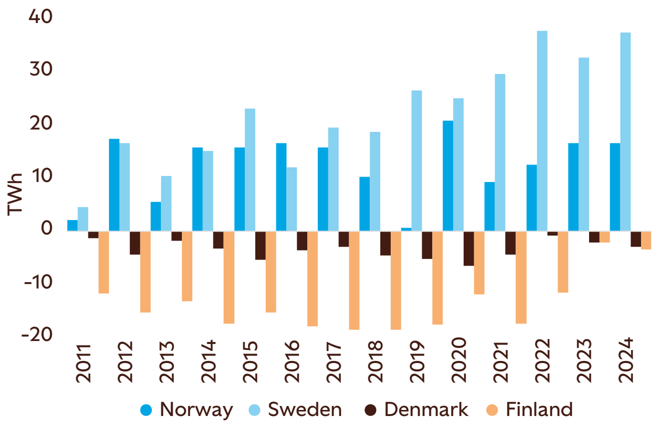
floating offshore wind turbines can be located relatively close to land in many places, thereby reducing grid costs while still having good wind conditions. In our *Green* and *Delayed* scenarios, we project that the costs of floating offshore will approach those of bottom-fixed installations by 2050. While onshore wind projects in Norway generally remain more cost-effective, offshore wind farms offer the potential for large-scale power generation with possibly less public opposition than onshore wind. The economic viability of offshore wind increases with hybrid connections to neighbouring energy systems in the North Sea compared with radial connections solely to Norway.

While nuclear power is, and will be, an important part of the European and Nordic power mix, it is less likely that nuclear power will be developed in Norway within the analysis period. The cost of nuclear is high and with our assumptions, nuclear is not competitive with the main renewable solutions in economic terms throughout the analysis period. The lead times for nuclear power production can vary, but in Europe the time from investment decision to start of operation have often been at least ten years.

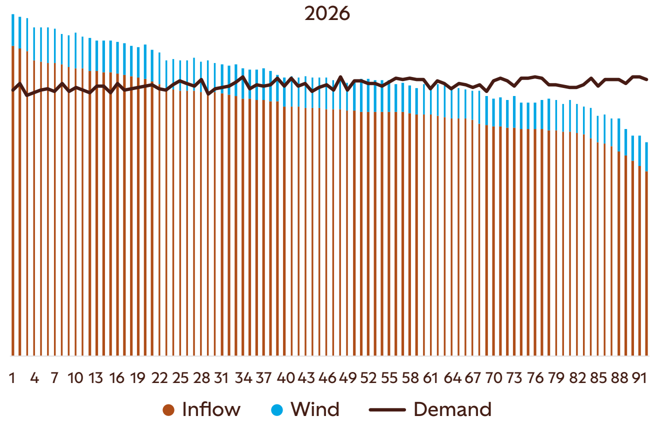
We also regard the risk of time and cost overruns as significant in future projects, as seen in Finland (Olkiluoto 3), the UK (Hinkley Point C) and France (Flamanville 3).[64] Small modular reactors might be a more promising solution in a Norwegian context. Still, our assessment is that too many uncertainties and unresolved issues remain to include nuclear in the three plausible scenarios for Norway analysed in this report. However, changed political priorities could potentially bring nuclear power into the mix towards the end of the analysis period.

[i] LCOE: Levelised cost of electricity in Norway. Outcome space reflecting different underlying resources but also differences in other cost inputs, for offshore wind, floating offshore is included from 2040, for nuclear, potential technology breakthrough gives larger outcome space. Additional costs or revenues, such as local resistance or achieved prices are not included.

43 Historic power balance in the Nordics per country (TWh)



44 Variation in inflow and wind production across weather years in example year 2026 (TWh)



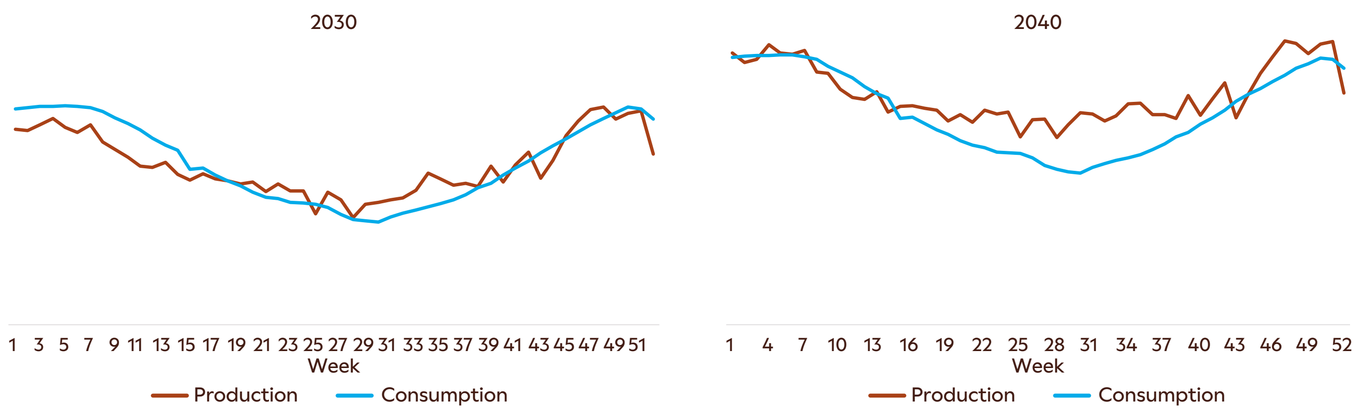
Interconnected power markets strengthen security of supply

The annual power balance (generation minus consumption and losses) has been positive in Norway and the Nordic region since 2012 as a result of high renewable investments and the commissioning of the Olkiloutto 3 nuclear plant in Finland (Figure 43). The Nordic power balance in a normal weather year remains positive in all three scenarios to 2050, while in Norway, the balance tightens towards 2030, as consumption grows faster than production capacities the coming years. In our scenarios, power generation investments and production pick up at varying speed during the 2030s and the Norwegian power surplus hence gradually increases (in normal weather years) again.

From 1990 to 2022, the Norwegian hydropower inflow varied by 65 TWh between the driest and wettest years. We will experience similar variability going forward, and with an expected tighter power balance towards 2030, import opportunities from neighbouring countries in dry and cold periods and years are crucial for the security of supply in Norway's hydro-dominated power system. When modelling the example year 2026 using 92 weather scenarios and current production capacity, the inflow varies close to 70 TWh across weather years (Figure 44). Without, or with little, cross-border interconnectors to neighbouring countries, we would need to invest in much more new back-up power capacity, with corresponding impact on land and nature, to ensure supply security in dry weather years (right side of the graph). At the same time, we would have had massive power surpluses with loss of production and loss of value in wet weather years (left side).

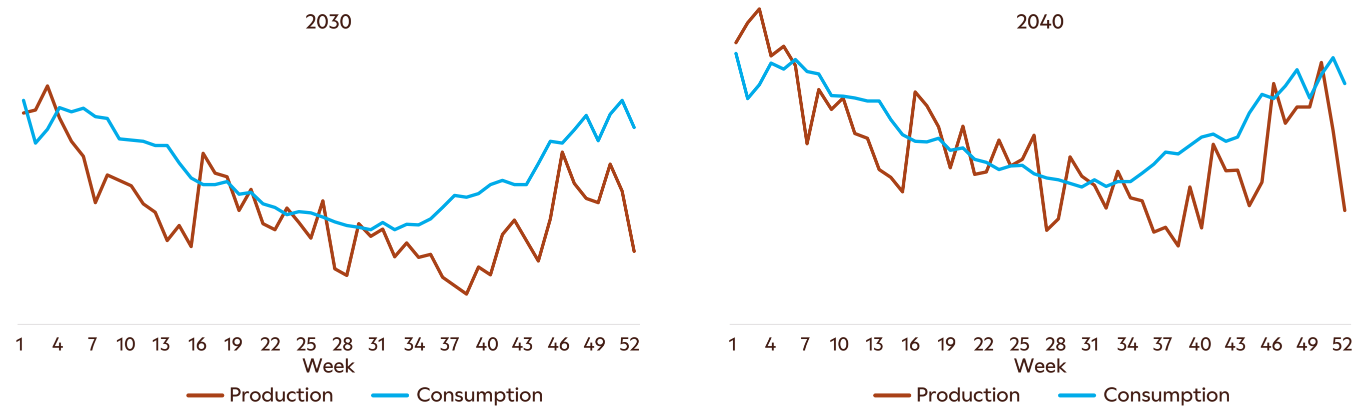
It should be stressed that although the annual power balance is net positive in a normal weather year, there are surpluses and deficits on a weekly, daily and hourly basis over the year and with large variations between regions. Figure 45 shows the average power balance on a weekly basis throughout the year

45 Weekly power production and consumption in Norway in 2030 and 2040, expected values (average over multiple weather years, GWh)



Location: Bondhusbreen, Norway

46 Weekly power production and consumption in Norway in 2030 and 2040 in a dry weather year (1996, a year with low annual inflow, GWh)

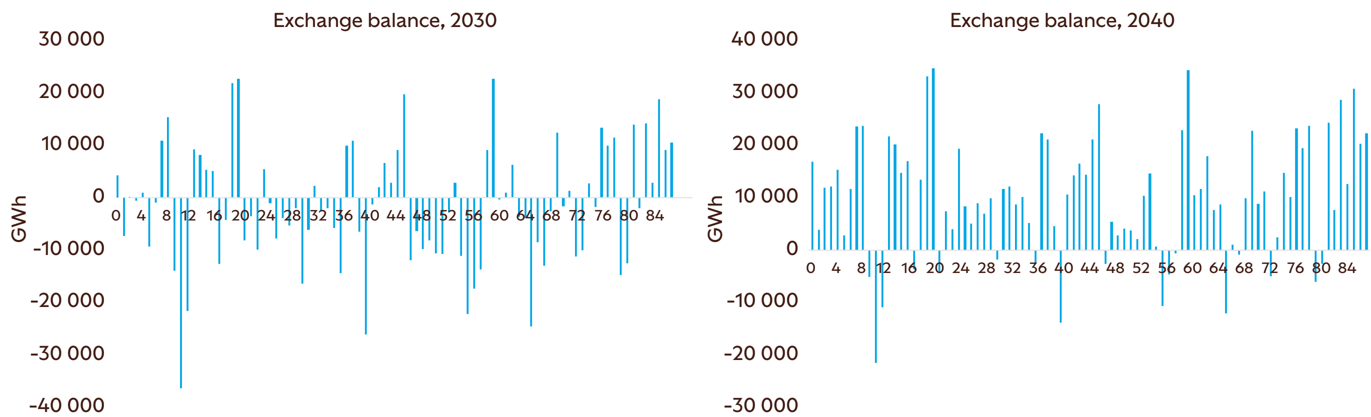


across 88 weather years in *Delayed* in 2030 and 2040. By 2040, the overall power balance is expected to improve compared to 2030. *Delayed* sees the tightest balance compared to the other two scenarios. Considering a close to normal weather year, we see that with our assumptions, there are many weeks of net import in 2030. Also in 2040, when the Norwegian power surplus is larger, we see periods of import, mainly during winter weeks, while during summer there is rather firm exports in the close to normal weather year (Figure 45).

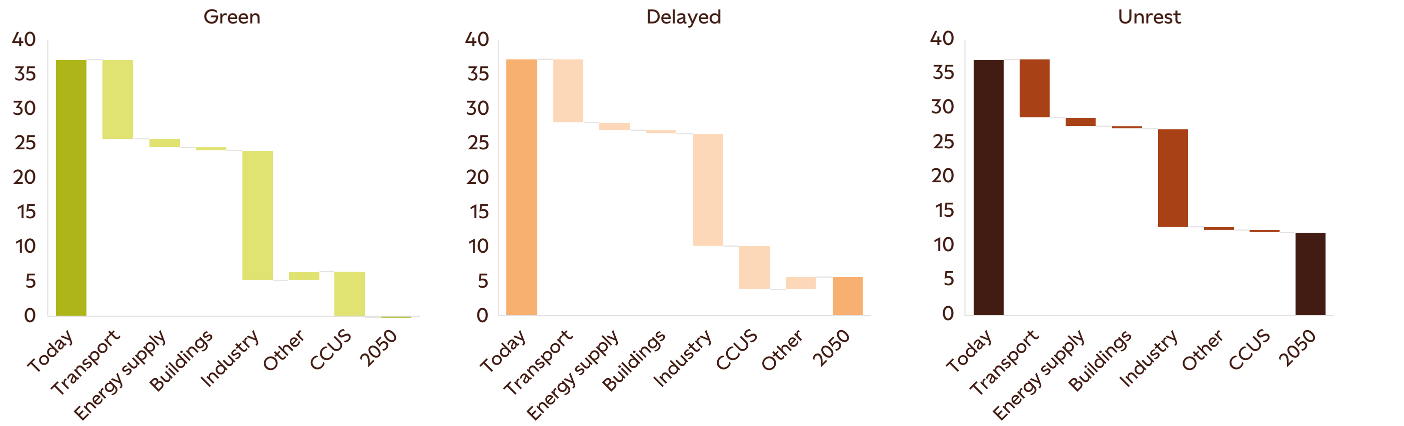
Figure 46 shows simulated weekly production and consumption in a particularly dry weather year in Norway in 2030 and 2040. It shows longer periods of net weekly electricity import lasting several weeks and even months. In 2030, the model simulations for a dry year indicates net weekly imports in more than 80% of the 52 weeks. In 2040, the corresponding share falls to 35%.

When considering the annual power balance across all 88 weather years that are included in our models, the changes from 2030 to 2040 across weather years become even more apparent. Figure 47 shows the net annual power balance for 88 weather years based on historical data. According to the analyses, in 2030 Norway may be a net importer of electricity for several consecutive weather year scenarios. While adjustments in the management of seasonal and annual reservoirs can partially mitigate import dependency, they cannot eliminate the need for imports over a year. Towards 2040, however, the power balance improves significantly in the Delayed Transition Scenario, partly as a result of growth in offshore wind and hybrid cables and Norway is then a net exporter of electricity for most weather years (Figure 47).

47 Net annual power balance for 2030 and 2040 (GWh) for 88 different weather year scenarios (x-axis)

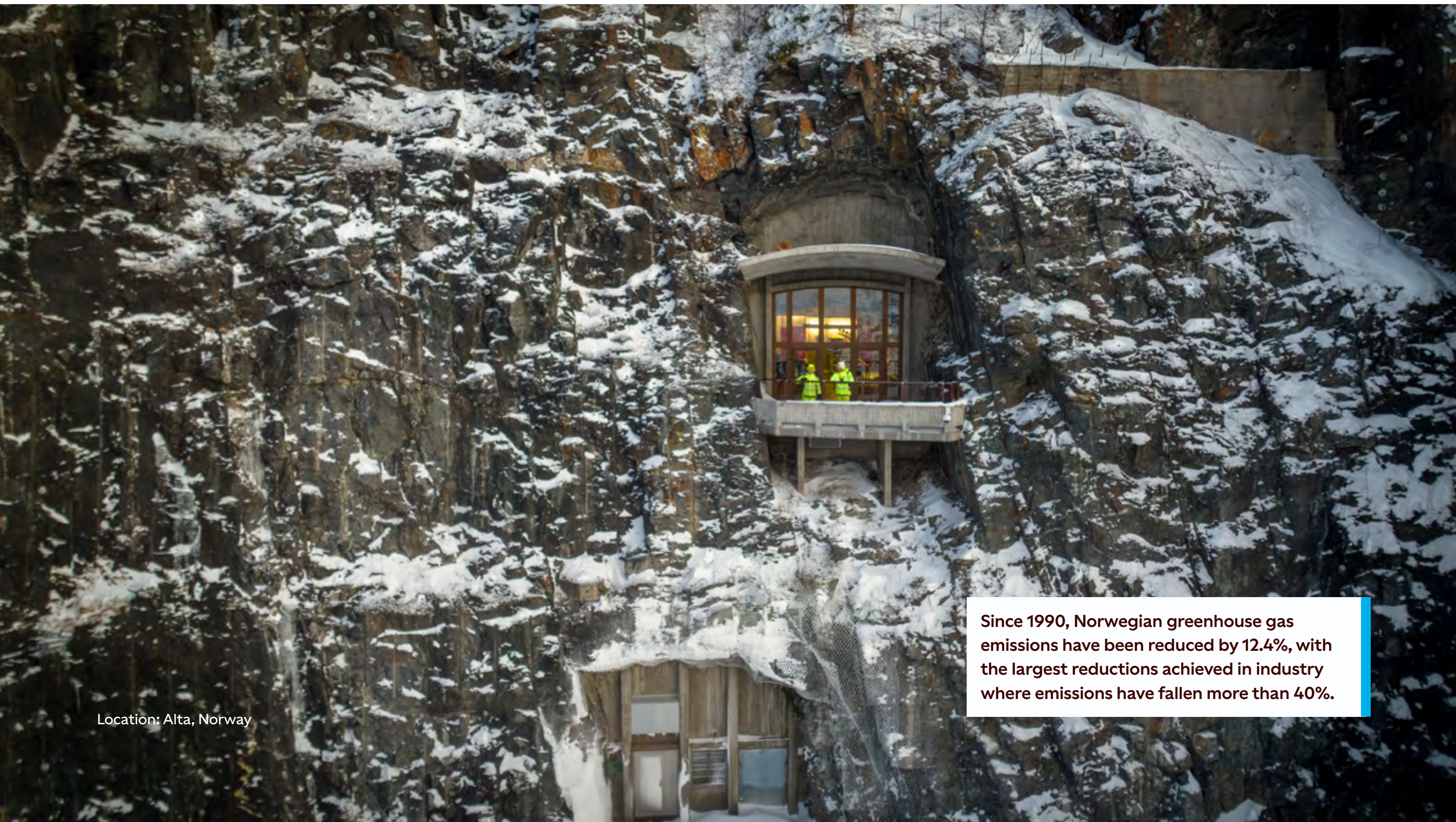


48 CO_2 emissions today and to 2050 in the Green, Delayed and Unrest scenario across sectors (Mt CO_2) in Norway



Norwegian CO_2 emissions in the three scenarios

Since 1990, Norwegian greenhouse gas emissions have been reduced by 12.4%, with the largest reductions achieved in industry where emissions have fallen by more than 40%.[65] CO_2 emissions decline at varying rates across sectors in our scenarios, but in all scenarios industry accounts for the largest cuts, followed by transport. In *Green*, reduced activity and electrification of offshore fields cut emissions in the petroleum sector by 96%, contributing 9Mt. Onshore industry emissions drop by 50-90%, contributing 5-10Mt when excluding CCS. Road transport is electrified across the three scenarios at different speed, and its share of total transport emissions declines to 25-36% by 2050, while aviation and shipping, which are harder to decarbonise, increase their shares to 64-75%. CCS is essential to meet climate targets, storing over 6 Mt CO_2 by 2035 in *Green* and reaching similar levels by 2045 in *Delayed*. More than half of this is in the form of carbon removals, followed by blue hydrogen and CCS in industry. In *Unrest*, CCS remains minimal due to lack of funding and policy support (Figure 48).



Location: Alta, Norway

Since 1990, Norwegian greenhouse gas emissions have been reduced by 12.4%, with the largest reductions achieved in industry where emissions have fallen more than 40%.

Navigating the complexity

Developing the future Norwegian energy system – take aways from our scenarios

Energy policies and decisions made today affect how well the energy system can serve society far into the future. Since the first Norwegian hydropower plant was commissioned more than 130 years ago, Norwegian electricity production and society have evolved in tandem. Societal needs have changed, and the electricity system has adapted accordingly to meet those needs. Going forward, the societal needs will continue to change, and likely at a higher pace than before.

Against this backdrop, the span of scenario outcomes for the Norwegian energy system to 2050 illustrates that we face high uncertainty in developing the future energy system, but at the same time there is a set of key findings that remain valid across the scenarios. Based on our scenario work, we highlight seven key take-aways which can inform decisions and policy making aimed at developing an affordable, resilient and sustainable Norwegian energy system towards 2050.

1. Electricity demand will grow faster

While electricity consumption in Norway has grown at a modest pace the last 25 years, we are now at a crossroad where demand for electricity will likely grow faster towards 2050. The Norwegian energy mix is around 50% fossil today. Clean electricity is needed to replace fossil fuels in transport, industry and the petroleum sector. In addition, we expect increasing demand from data centres as well as new industries using electricity as the main energy carrier. Energy efficiency measures are needed to limit the demand growth but would not be sufficient to hinder a growing need for more clean power.

2. Long term perspectives needed

The long lead time for new power projects and energy infrastructure means decisions made today determines the energy system we have in the 2030-ies. While energy debates often discuss the challenges of yesterday, they more rarely address what energy system society needs in ten years. Of particular importance in this regard is the fast transition from fossil to renewable power generation in the rest of Europe, which imply that we will face completely different power markets among our main trading partners the coming decades.

3. Hydro and onshore wind are the key solutions ensuring a cost competitive power system in Norway

Technology cost forecasts, power market modelling and energy system analysis confirm that onshore wind supported by flexible hydro power can provide large volumes of electricity at competitive costs in a European context. Until 2035 these are the only viable technologies that provide significant new production volumes to serve the increasing consumption.

4. Unavoidable trade-offs: affordability versus land-use

The combination of hydro power and onshore wind is the outstanding solution economically, but the desire for clean and affordable electricity must be balanced against land use impacts and social acceptance. These conflicting interests are main reasons why more expensive and/or immature technologies like floating offshore wind and nuclear gain support in the public debate. The additional costs for these technologies, however, need to be carried by society in the form of higher electricity prices or subsidies. Irrespective of preferences, policymakers must ensure that the regulatory framework align with the priority they set in areas like energy security, climate, competitive power prices and an affordable energy system, industrial growth and sustainable land-use.

5. There are no-regrets, too: energy efficiency and flexible end use solutions

Saving energy and ensuring efficient energy use are no regret options, but many of the main energy efficiency measures are unfortunately developing slowly as they rely on many decision makers and upfront costs are often high. Similarly, building flexible energy systems in heating of buildings and industrial processes that can use electricity as well as alternative energy carriers can provide highly valued flexibility to the future weather dependent power system.

6. Interconnectors make the energy system more secure and efficient

Our analysis of the future Norwegian power balance across different weather years shows how a well-developed collaboration with neighbouring countries serves the Norwegian power system well, both in wet and dry years. In assessing the benefits of inter-connectors, one must assess the future power systems in Norway and neighbouring countries, not the extreme market conditions after Russia's invasion of Ukraine. Well-connected energy systems limit the need for new power production and its land-use, strengthen energy security in dry years and revenues in wet years.

7. Price signals are vital

Electricity is a scarce and valuable resource, making price signals essential for guiding both short-term behavior and long-term investment decisions. The electricity system must deliver not only energy but also sufficient capacity to meet demand during peak load periods. Therefore, how energy is consumed—and what types of generation are added to the system—matters significantly.

Short-term price signals help balance the system by encouraging flexible consumers to shift their usage away from periods of tight supply. Long-term signals play a crucial role in directing investments toward solutions that optimize resource use. This includes measures like improving energy efficiency during high-demand periods (e.g., better insulation in buildings) and supporting generation technologies that can deliver power when it's most needed.
To attract long-term investments in flexibility solutions such as redesigned hydropower projects, price signals must reach producers and consumers, while taxation frameworks must be stable, transparent, and predictable.


Location: Erzhausen hydropower plant in Germany

ANNEX I:

Model and methodology

Statkraft's Green Transition Scenarios report extends current global energy trends and technology costs up to 2050 and is based on the expansion and development of known technologies. The scenarios are prepared by Statkraft's strategic analysis team in cooperation with experts in other fields, using Statkraft's own global and regional qualitative and quantitative analyses as well as in-depth studies of external sources.

Global scenarios

The starting point for the analyses is economic growth and population growth in line with a market consensus. The emissions analysed in the global scenarios are energy-related CO_2 emissions from fuel combustion (excluding the incineration of non-renewable waste) and non-energy CO_2 emissions from hydrogen feedstock in industry. Diffuse emissions (i.e. leaks and emissions from the transport and storage of fuels) and other industrial process emissions, such as from chemical reactions in the production of chemicals, cement and certain metals, are not included in the global scenarios. CO_2 emissions from land use, land use change and forestry (LULUCF) and non-CO_2 emissions, such as from methane, are excluded. The emissions are broken down into the power and heat sector, buildings sector (commercial and residential), transport sector (domestic and international), industry sector and a category for other sectors (agriculture, fuel supply and other non-energy use).

TABLE 9. Key parameters in Statkraft's scenarios, compared with the IEA and Bloomberg NEF scenarios.[66]

Sectors	Statkraft's Green Transition Scenario 2025	IEA STEPS (2024)	IEA Net zero (2024)	Statkraft's Delayed Transition Scenario 2025	Statkraft's Unrest Scenario 2025	BNEF NEO (2024) ETS Scenario
Annual growth in primary energy demand 2023-50	-0.38 %	0.43 %	-0.48 %	0.18 %	0.63 %	0.41 %
Power sector						
Demand	3.07 %	2.51 %	3.73 %	2.49 %	2.11 %	2.32 %
Wind power	8.27 %	6.36 %	9.00 %	7.30 %	6.32 %	7.20 %
Solar power	10.7 %	10.1 %	11.96 %	9.34 %	7.84 %	8.24 %
Hydropower	1.76 %	1.53 %	2.24 %	1.71 %	1.79 %	0.34 %
Unabated fossil share in power sector (TWh, 2050)	10.8 %	18.5 %	0.003 %	16.6 %	22.9 %	25.48 %
Primary Energy						
Oil consumption: annual growth 2023-50	-3.08 %	-0.34 %	-10.3 %	-1.17 %	-0.08 %	-0.49 %
Gas consumption: annual growth 2023-50	-0.72 %	-0.05 %	-5.63 %	-0.10 %	-0.04 %	0.99 %
Coal consumption: annual growth 2023-50	-5.30 %	-2.39 %	-15.3 %	-2.71 %	-1.55 %	-1.58 %
Global energy-related CO_2 emissions ($Gt\ CO_2$) in 2050	11.9	28.6	0	21.0	27.7	26.8

European and Norwegian scenarios

Modelling approach

The scenarios combine a TIMES energy system model with insights from detailed power market models in the countries in which we are active. The models include the entire energy flow from primary supply over transformation to demand services in end-use sectors like buildings, industry and transport. Statkraft's TIMES Energy Transition model for Europe and Norway is based on the TIMES model framework developed under patronage of the IEA. The model is a techno-economic optimisation model. It aims to supply demand for energy services at minimum total system cost by making investment decisions, as well as operating and trade decisions, under defined emission pathways. The power market models we use optimise and simulate power systems using stochastic dynamic programming up to 2050. The models take into consideration grid constraints between different areas. To account for variable weather, 88 (14) weather years have been used for the Nordics (Europe) in which water inflow for hydropower, wind and solar profiles are modelled consistently. The models provide forecasts for production, reservoir filling, water flow, consumption, rationing, power imports and exports and power prices. Gradual grid improvements aligned with TSO plans in Europe and between Norway's five price areas are expected across all scenarios. This includes some increase in cable capacity in the Nordic region in all scenarios, and some hybrid capacity for new offshore wind projects towards 2040 in *Green* and *Delayed*. Input data are based on both publicly available and proprietary sources as well as Statkraft-internal insights.

Greenhouse gas emissions

The EU: In the Green Transition Scenario, the EU's climate targets are met. CO_2 emissions are reduced by 56% by 2030 compared to 1990 levels, 92% by 2040 and net zero by 2050. In the Delayed Transition Scenario, the EU's targets are not met in time and greenhouse gas emissions are reduced by 40% in 2030 and 80% in 2050, compared to 1990. In the Unrest Scenario, the continued short-term priorities lead to greenhouse gas emissions only reduced by 60% in 2050. In the Unrest scenario, the energy system carbon cost is close to zero ('shadow cost'). The CO_2 price is endogenously modelled as a system shadow carbon cost. Energy related CO_2 emissions constitute a major part of CO_2 emissions, but there are also CO_2 emissions from other industrial processes. In the scenarios we analyse, energy-related CO_2 emissions and process emissions in the cement, steel and hydrogen sectors. CO_2 emissions are currently responsible for around 78% of the European greenhouse gas emissions excluding emissions and removals in land sectors. Non- CO_2 emissions in the scenarios are based on the EU 2040 Impact Assessment.[67] For the Green Transition Scenario data for LULUCF from the EU 2040 Impact Assessment Scenario S3 is used as input, while the Delayed Transition and Unrest Scenarios are based on Scenario S1.

Norway: The Norwegian emission pathways are influenced by the European pathways across the scenarios. In *Green*, Norwegian CO_2 emissions are reduced by 63% to 2035, in line with recommendations from the Norwegian Environmental Agency, and thereafter reaching net zero by 2050.[68] Non-CO_2 emissions and emissions from other sectors are based on the assessment of the 2050 Climate Change Committee (NOU: 2023: 25) for *Green*. In *Delayed* and *Unrest*, we assume CO_2 emissions in line with current policies to 2030.[69] From 2030, the two scenarios diverge. The *Delayed* scenario sees on average a 7.5 years' delay of mitigation actions from *Green*. The pathway is similar to the European *Delayed* scenario. In the Unrest Scenario, an extrapolation of current policies is assumed all the way to 2050.

TABLE 10. EU CO_2 emission reductions from 1990 to 2050 across scenarios (%)

	EU		
% CO_2 vs 1990	*Green*	*Delayed*	*Unrest*
2019	-25 %	-25 %	-25 %
2023	-36 %	-36 %	-36 %
2030	-56 %	-41 %	-41 %
2035	-74 %	-52 %	-45 %
2040	-92 %	-62 %	-49 %
2045	-96 %	-73 %	-54 %
2050	-100 %	-84 %	-59 %

TABLE 11. Norwegian CO_2 emission reductions from 1990 to 2050 across scenarios (%)

	Norway		
% CO_2 vs 1990	*Green*	*Delayed*	*Unrest*
2019	23%	23%	23%
2024	6%	6%	6%
2030	-29%	-12%	-12%
2035	-63%	-29%	-27%
2040	-75%	-46%	-39%
2045	-88%	-69%	-48%
2050	-99%	-82%	-61%

Energy service demand

End-use energy service demand is input to the TIMES model (e.g., car road travel, residential lighting, steam heat requirements in industry, etc.).

Scenario	Energy service demand input in TIMES model for the EU and Norway
Green	Buildings: Energy efficiency results in decreased energy service demand even as building stock increases. Fast heat pump build-out. Transport: High EV penetration and energy efficiency gains from car sharing and autonomous cars. High trade and economic growth increase demand for transport services compared to today despite more car sharing and automated vehicles. Industry: High economic growth partly counterbalanced by higher use of sustainable material, efficiency improvements and circularity. The demand for energy services in industry see modest growth from today. Energy efficiency measures result in a lower energy service demand in agriculture and industrial heat. New industrial activities, such as hydrogen production, battery manufacturing and data centres see significant increase from today to 2050.
Delayed	Buildings: Less focus on energy efficiency resulting in stable energy service demand as building stock increases. Slower heat pump build-out. Transport: Slower EV penetration and less energy efficiency gains from car sharing and autonomous cars. Industry: Self-sufficiency and security drive higher military and infrastructure spending and more homeshoring of European industry. This scenario has increased steel production and more heat processes. Energy service demand sees the highest growth compared to *Green* and *Unrest*.
Unrest	Buildings: Energy efficiency lose momentum, resulting in weak growth in energy service demand as building stock increases despite low economic growth. Slow heat pump installation rate. Transport: Limited EV penetration and less energy efficiency gains. Industry: Lower economic growth translates to lower industrial output. Industry energy service demand sees weak growth from today to 2050.
Bioenergy across scenarios	Access to sustainable bioenergy is limited. Import of biofuel remain at the current level European and Norwegian import and export of biomass at net zero
Petroleum sector production in Norway	The base case from the Norwegian Offshore Directorate Resource Report 2024 serves as input to the TIMES model. According to this projection, production decreases gradually from 243 million standard cubic meters of oil equivialent (scm oe) in 2025 to about 83 million scm oe in 2050 in line with a gradual production decline on the larger fields. This is a reduction of about two-thirds from 2025 to 2050.

Location: Talayuela, Spain

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