TRANSFORMING THE ENERGY MIX

European Parliamentary Technology Assessment Network

Report 2025

EPTA
European Parliamentary Technology Assessment

Transforming the energy mix

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PREFACE

Achieving European Union's 2050 carbon neutrality goal requires a profound and accelerated transformation of energy systems. This transition involves not only a reconfiguration of the energy mix, but also far-reaching technological consequences stemming from the choices made, as well as the crucial issue of social acceptability.

This report examines the deep structural shifts in national energy systems that are underway. It also looks into the new technological and industrial challenges related to this transition, and considers public acceptance and the capacity of societies to manage the social costs and benefits of the energy transition.

It results from the joint effort of members of the European Parliamentary Technology Assessment (EPTA) network. The network consists of 14 full member and 11 associate member organisations and assists parliaments in exploring interactions between science, technology and society for policy.

20 EPTA members have contributed to this year's report. Each member provides unique perspectives and experiences from their countries and regions regarding three main topics:

- Reconfiguring the energy mix for climate neutrality;

- Technological consequences of the political choices;

- Social acceptability and political sustainability of the energy transition.

The summary for policymakers synthesises recurring themes, differences, and similarities in member countries' policy approaches to reconfiguring the energy mix.

The French Parliamentary Office for Scientific and Technological Assessment (*Office parlementaire d'évaluation des choix scientifiques et technologiques* – OPECST) holds the EPTA presidency for 2025 and has initiated and coordinated this analysis.

The following report, however, is the result of a successful, distributed and unique effort from members in Europe, the US, and Japan, for which we are very grateful.

It will be presented and discussed at the EPTA Conference in Paris on 13 October 2025.

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TRANSFORMING THE ENERGY MIX: SUMMARY FOR POLICYMAKERS

The IPCC's reports on **climate change** have spurred global energy policies, driving countries to adopt renewable energy targets, carbon pricing mechanisms, and fossil fuel subsidies reforms to mitigate rising temperatures. The current and upcoming geopolitical upheavals are strengthening the need to ensure a form of energy sovereignty.

The European Union's 2050 **carbon neutrality** goal, enshrined in the European Climate Law (2021), aims to achieve net-zero greenhouse gas emissions by mid-century, balancing remaining emissions with removals. Intermediate targets include a 55% reduction in emissions by 2030 (compared to 1990 levels), supported by the "Fit for 55" package, which strengthens renewable energy, energy efficiency, and emissions trading policies and by different tools as the Recent "Clean Industrial Deal".

Achieving carbon neutrality by 2050 requires a **profound and accelerated transformation** of energy systems. This transition involves not only a reconfiguration of the energy mix, but also far-reaching technological consequences stemming from the choices made, as well as the crucial issue of social acceptability.

❖ RECONFIGURING THE ENERGY MIX FOR CLIMATE NEUTRALITY

Meeting the 2050 carbon neutrality target calls for deep structural shifts in national energy systems, many of which are already underway. These changes affect both the **demand** for energy and the **composition** of energy supply, with electricity systems at the forefront of the transition.

The evolution of energy demand reflects **major trends**: increased electrification of end-uses, the development of new applications (notably electric mobility and heat pumps), and the implementation of efficiency measures. Simultaneously, the energy mix itself is undergoing diversification. While fossil fuels (coal, oil, gas) still represent a significant share in many national mixes, their gradual replacement by low-carbon sources – nuclear energy and renewables (solar, wind, hydro, biomass) – is central to decarbonisation strategies.

The transition pathway **varies across countries** depending on political choices, resource availability, and industrial capabilities. Its evaluation involves the assessment of past and projected trends, the coherence of decarbonisation roadmaps with climate targets, and the robustness of strategies under different geopolitical and economic scenarios.

❖ TECHNOLOGICAL CONSEQUENCES OF THE TRANSITION

The transformation of the energy mix carries significant downstream implications, both **technical** and **industrial**.

The management of a more heterogeneous and decentralised energy system poses new challenges, particularly in terms of **grid** operation and **balancing** intermittent sources such as wind and solar. The shift to a low-carbon system necessitates greater flexibility on the demand side, through time-of-use tariffs and intelligent energy management systems.

These changes also impact **infrastructure**: transmission and distribution networks must be adapted to accommodate variable flows and bidirectional exchanges. On the industrial front, choices regarding technologies (e.g., small modular reactors, green hydrogen, carbon capture) determine the reorganisation of supply chains and the development of new manufacturing capacities.

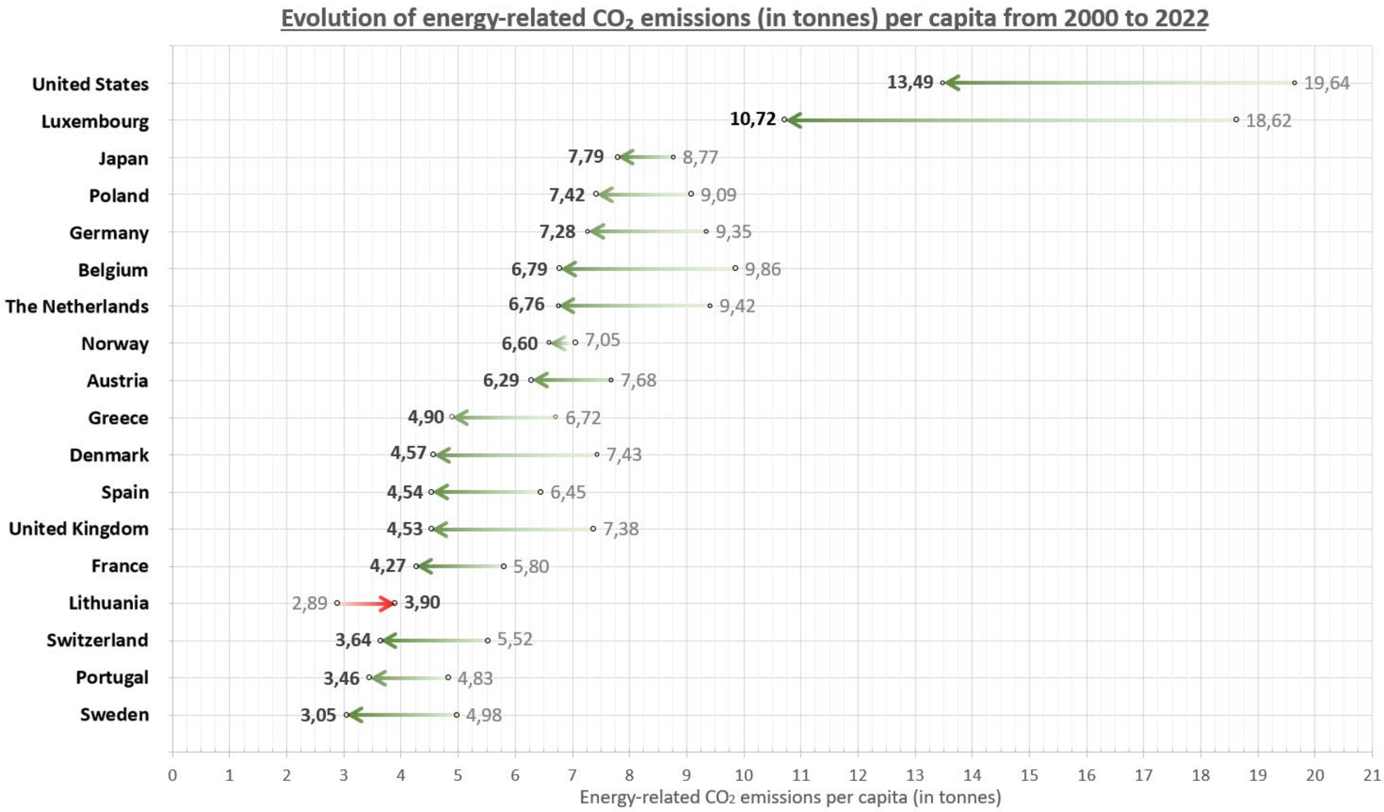
❖ SOCIAL ACCEPTABILITY AND POLITICAL SUSTAINABILITY

The success of the energy transition does not depend solely on technical feasibility or economic viability; it also hinges on public **acceptance** and the capacity of societies to manage the **social costs** and **benefits** of the transition.

While climate commitments have generally enjoyed broad support, events such as the **2022** gas crisis have heightened awareness of energy vulnerabilities, especially regarding price volatility and dependency on external suppliers. This has reopened debates on the pace and realism of **decarbonisation**, particularly the rapid shift toward a highly electrified system.

Questions of technology acceptability (notably nuclear and wind power) continue to **polarise** public opinion. At the same time, the distributional effects of energy policies, such as the cost of climate measures for households and SMEs, are gaining prominence in public discourse. Reconciling ambitious environmental objectives with economic equity and democratic legitimacy remains one of the central challenges of the transition.

The following is a synthesis of the responses provided by **20 members of the EPTA** to the questionnaire prepared by the French Parliamentary Office for Scientific and Technological Assessment (OPECST).



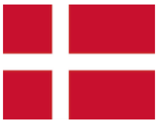
Source: *International Energy Agency*

I. ENERGY MIX AND THE CARBON NEUTRALITY OBJECTIVE (2050)

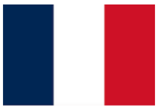
A. HOW HAS THE STRUCTURE OF ENERGY DEMAND EVOLVED IN YOUR COUNTRY IN RECENT YEARS?

EPTA members report a widespread **decline** in energy demand over the recent years. The electricity consumption of most advanced economies has also been steadily decreasing due to efficiency improvements and slow economic growth, in particular for the industry sector.

Most of the energy demand comes from the **transport** and **residential** sectors. The share of the industry consumption depends mostly on the importance of that sector in the national economy. Variations in the overall energy consumption also strongly depend on the **local climate**, with a significantly higher per capita demand in colder climates.



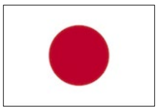
Denmark's total primary energy supply **decreased by 14.5%** between 2010 and 2023. The expansion of renewable energy has driven electrification, increasing electricity demand.



Between 2012 and 2024, final energy consumption in France fell by around 8.5%, from 1,613 TWh to approximately 1,498 TWh, continuing its **long-term downward trend**. The residential – tertiary sector is the largest final energy consumer, accounting for just over 40% of the total.

Over the past decade, Germany's total primary energy consumption has **declined** by more than **20%**, while electricity demand has fallen by 40%.

In Greece, oil and petroleum products remained the dominant energy source in 2023 (51%), with consumption levels **similar** to those of 2018.



Japan's final energy consumption **decreased** by **18.1%** from 2013 to 2023 and is projected to decline by another 10% by 2040 due to efficiency improvements.

Luxembourg's per capita electricity consumption has **decreased** by **27%** compared to 2000.

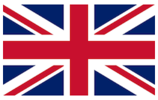
Over the last two decades, total energy use in the Netherlands has **decreased** by about **22%**.

Norway's final energy demand has remained broadly **stable** at around 215 TWh (Terawatt-hour) over the past decade. Per capita demand is well above the European average, reflecting cold winters. Electricity use has increased, while fossil fuel consumption has declined.

Between 2019 and 2023, primary energy consumption in Portugal **decreased** by **8%**, with natural gas use falling by 28% and oil by 10%, while renewable energy use increased by 20%.

From 2010 to 2023, Sweden's total energy consumption **declined** by **10%**, from 395 TWh to 353 TWh. Over the same period, the share of energy from all fossil fuels combined decreased from 34% to 25%.

Since 2010, Switzerland's energy consumption has **decreased** by about **10%** per decade, while its economy has grown by 30%. Improved electrification efficiency has offset the increase in electricity use.



In 2024, the UK's total final energy consumption was approximately 133 Mtoe (million tonnes of oil equivalent), **down** from 172 Mtoe in 2020. The transport sector is the largest energy consumer (41.3%), followed by the domestic sector (26%), commercial/public administration (15.8%) andindustry (14.9%).

U.S. energy consumption has remained relatively **stable**, from 97 quadrillion BTUs in 2000 to 94 quadrillion BTUs in 2024. However, average consumption per resident has **decreased** by 20%, from 344 million BTUs in 2000 to 277 million BTUs in 2024.

B. WHAT IS THE CURRENT COMPOSITION OF THE ENERGY MIX, AND WHAT ARE THE KEY POLICY OBJECTIVES OR PROJECTIONS BY 2050 (E.G. SHARE OF FOSSIL FUELS, NUCLEAR, RENEWABLES)?

Countries remain structurally reliant on **fossil fuel**, which dominates the energy mix, particularly in the form of oil, then gas. Solid fuels such as coal and lignite are less prevalent and a few countries concentrate most of their consumption.

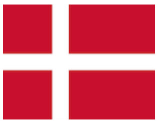
Electricity still represents a relatively **small share** of the final energy consumption. Nevertheless, **renewables** are gradually gaining ground within the overall energy mix. The share of **nuclear** energy varies significantly across countries, while the importance of hydropower largely depends on each country's natural endowments.

The overall EU energy mix reflects these results, being **dominated** by **crude oil and petroleum products** (37.7%), followed by natural gas (20.4%). Renewables now account for a comparable share (19.5%), while nuclear energy, though less prominent, remains significant (11.8%). Solid fuels complete the mix at 10.6%.

Renewable sources accounted for **41%** of Austria's total energy mix in 2023, well above the European average of around 25%. This is largely due to a well-developed **hydropower** sector, which produces 79% of the country's electricity from renewable sources.

In 2024, Belgium's gross energy production mix consisted of **nuclear energy** (41.3%), natural gas (17.7%), and renewables (34.2%), primarily wind, solar, and solid biomass.

Catalonia **imports 93%** of its energy. Nuclear power dominates electricity production, accounting for 59% in 2024. Renewables make up 21.6% of the energy mix, and the region aims to achieve a 100% renewable energy mix by 2050.



In 2023, Denmark's energy mix consisted of **46% renewables**, 38% oil, 10% natural gas, and 6% coal. In the electricity sector, 80% comes from renewables, including 40% from wind power, 30% from biomass, 7% from solar, and 3% from biogas.

Fossil fuels currently account for around **80%** of Germany's primary energy consumption. Renewables represent 42% of electricity production. The country closed its last three nuclear power plants in 2023.

Lithuania is now **fully independent** from **Russian** energy imports (gas, oil, and electricity). One of its key targets for 2030 is to generate electricity exclusively from renewable sources.

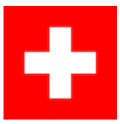
In 2024, Luxembourg's energy mix was composed of **56.3% oil products**, 17.6% electricity, 15.5% natural gas, 5.9% biofuels and waste, 3.9% heat, and 0.8% coal. Approximately **77.5%** of the country's total electricity demand is **imported**, primarily from Germany.

Norway's electricity mix is atypical in Europe: **hydropower** provides about **90%** of annual generation, while onshore wind accounts for around 10%. The country aims to reduce emissions by 90–95% by 2050, with an interim target of 55% by 2030.

In 2024, **hard coal** and **lignite** remained Poland's primary sources of electricity, generating 86.4 TWh (56.2% of gross electricity production – the **highest proportion** in the EU). However, the share of renewable energy sources in electricity generation reached a record high of 29.4% (45.2 TWh), driven mainly by wind energy and solar photovoltaics.

In 2023, Portugal's electricity generation was dominated by **hydropower** (30%) and wind power (27%). Renewable energy accounted for nearly 77% of electricity production. Portugal has set a goal to achieve carbon neutrality by 2045 and aims for a 93% renewable share in electricity by 2030.

About one-third of Sweden's total energy consumption comes from **electricity**, which is **98% fossil-free**. The country aims to achieve net-zero emissions by 2045 at the latest.



Sixty percent of Switzerland's energy consumption still comes from **fossil fuels**. In 2024, final energy consumption was divided as follows: 34.9% for fuels, 26.7% for electricity, and 12.3% for gas..

Three-quarters of the UK's energy comes from **fossil fuels**: 45% from petroleum and 29% from gas. Electricity accounts for 18% of final energy consumption.

In 2024, the U.S. energy consumption breakdown was as follows: **38% petroleum**, 36% natural gas, 9% renewable sources, 9% nuclear, and 8% coal. Electricity is a secondary energy source derived from these primary sources.

C. WHAT TRANSFORMATION PATHWAYS ARE CURRENTLY UNDER DISCUSSION OR IMPLEMENTATION TO ACHIEVE DECARBONISATION GOALS?

The overarching goal is to achieve **net-zero** CO_2 emissions by 2050. The EU has established this objective through the *European Climate Law*, which also sets the intermediate target for 2040 of 90 % reduction in net greenhouse gas emissions. Beyond the EU, most countries have adopted similar targets.

Support for renewable energy is central to **decarbonization** policies, particularly in countries where the electricity mix still relies on fossil fuels. Efforts are underway to phase out coal-fired power plants, while natural gas serves as a transitional fuel in this process. Several countries are expanding their use of nuclear energy.

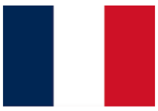
The **electrification** of industry is also part of the solution. The EU's *Clean Industrial Deal* plans to allocate €100 billion to the sector to accelerate its decarbonization and strengthen its competitiveness.

Austria's main challenges are **adapting infrastructure** and electrifying sectors previously reliant on fossil fuels, such as electric vehicles, heat pumps, and industrial processes—particularly in energy-intensive industries.

Belgium promotes renewable electricity generation primarily through market-based instruments, such as **Tradable Green Certificates** (TGC). Other tools include energy-saving incentives, regulatory sandboxes, and integrating end consumers into the energy transition.

Catalonia aims to increase the share of **electricity** in final energy consumption from 25% to over 75% by 2050, supported by 61.9 GW of renewable and storage capacity. Renewable thermal energy and fuels—such as green hydrogen and advanced biofuels—will play a strategic role in sectors where direct electrification is challenging.

Denmark's vision centers on **expanding offshore wind capacity**, with two projects to build energy hubs, each hosting 10 GW.



France has committed to achieving **carbon neutrality by 2050**, in line with the *Energy and Climate Law* (2019) and the French Energy and Climate Strategy, in which the expansion of low-carbon electricity supply to enable large-scale electrification of end-uses is a central pillar.

Germany aims to achieve climate neutrality by 2045. However, significant challenges remain: **90%** of energy in the **transport** sector and **80%** in **heating** still come from **fossil fuels**. As of now, only 1% of the 10 GW hydrogen capacity target for 2030 has been realized.

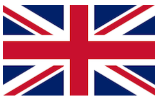
The Dutch *Climate Agreement* targets a 49% reduction in greenhouse gas emissions by 2030 (compared to 1990 levels) and carbon neutrality by 2050. In 2022, the government introduced a **national carbon tax** alongside the EU Emissions Trading Scheme, but the additional CO_2 tax was scrapped in 2024.

Norway's decarbonization strategy includes electrifying the transport sector and expanding renewable energy capacity to 30 GW by 2040. The country is also investing in **carbon capture and storage** (CCS) and improving energy efficiency in industry and households.

Poland's priority is expanding **renewable energy** sources, targeting 26.8 GW of solar photovoltaic capacity and 59 GW of wind energy by 2040. Additional measures include deploying nuclear energy, using natural gas as a transitional fuel, modernizing grid infrastructure, and decarbonizing the building and heating sectors.

Portugal closed its last **coal power plant** in 2021. The *National Hydrogen Strategy* (2020) identifies large-scale green hydrogen projects in Sines and Aveiro as key to decarbonizing heavy industry and boosting exports.

Spain plans to achieve climate neutrality by 2050 through electrification and a **100% renewable electricity mix**. By 2030, 35% of Spain's energy consumption should be electrified, and the country aims to install at least 40 GW of electrolyzers. All nuclear power plants are scheduled to close between 2027 and 2035.

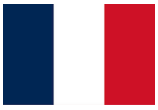


The UK's primary climate policy document is the 2021 ***Net Zero Strategy*** *(Build Back Greener)*. It outlines decarbonization strategies for all sectors to achieve net-zero emissions by 2050.

D. HAS YOUR ORGANISATION CONDUCTED ANY RECENT ASSESSMENT OF THESE EVOLUTIONS (E.G. SCENARIO MODELLING, SYSTEM-LEVEL IMPACT STUDIES)? IF SO, COULD YOU BRIEFLY DESCRIBE THE FINDINGS?

As a topic of major importance at the interface between policy and technology, the transformation of the energy mix has prompted **several reports by EPTA members**, covering issues from CO_2 taxation to next-generation nuclear technologies.

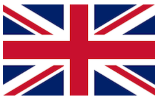
In Belgium, the Federal Public Service Economy updates its assessment of developments in the energy sector **every six months**. Additionally, the Spiral Research Center recently completed a literature review on Belgian energy policy.



In recent years, the **OPECST** has produced **several reports and briefing notes**, addressing the challenges of adapting the electricity grids, comparing different energy storage methods, and gathering expert testimony on next-generation nuclear technologies.

The research service of Luxembourg's Parliament has recently published a study on **CO_2 taxation** and its impact on behavioral and socio-economic changes.

While no recent comprehensive assessment exists, Switzerland has conducted a study on **negative emission technologies**. A report examining the challenges of nuclear power in the country is also scheduled for publication in 2026.



The UK's Parliamentary Office of Science and Technology (POST) has conducted research on **planning**, energy security, energy prices, storage, transport, renewable generation, clean power targets, and energy efficiency.

The United States has published numerous technology assessments, *Science & Tech Spotlights*, and **audits** related to evolving energy systems. These cover topics such as wind energy, carbon capture, hydrogen, ocean energy, nuclear microreactors, and fusion.

II. CONSEQUENCES OF TECHNOLOGICAL CHOICES

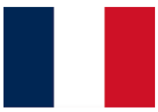
A. WHAT ARE THE MAIN TECHNICAL OR OPERATIONAL CHALLENGES ASSOCIATED WITH MANAGING A MORE DIVERSIFIED ENERGY MIX IN YOUR COUNTRY?

The growing share of **renewable energy** in most countries requires major changes. Electricity grids were often not originally designed to accommodate widely distributed energy sources, necessitating significant investments in both distribution and transmission infrastructure. The European Parliament's own-initiative report, "*Electricity grids: the backbone of the EU energy system*" (TA-10-2025-0136), emphasizes that the **energy workforce** will need to grow by 50% by 2030 to support renewable deployment and grid expansion.

Cross-border electricity capacity also needs to increase in many countries, particularly within the EU in order to respect the **15%** electricity interconnection target by 2030.

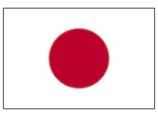
Energy storage is another major challenge, as the variability of energy production rises with the declining share of controllable energy sources worldwide.

Austria's current grid infrastructure was not originally designed to accommodate the high volume and geographic dispersion of renewable energy sources like wind and photovoltaics. To address this, the Ministry of Energy introduced the ***Integrated Austrian Network Infrastructure Plan*** in 2024, aiming to enhance flexibility and interoperability.



France's growing integration of renewable energy into its electricity mix requires enhanced flexibility, dynamic balancing, and better forecasting of intermittent output. The system must increasingly rely on the **nuclear** fleet's load-following capabilities, hydro storage, interconnections, and demand response to maintain balance in real time.

Greece's energy transition is particularly challenging due to its **insular** geography and **mountainous** terrain, which complicate infrastructure development compared to other countries.



Fluctuations in renewable energy output, particularly from photovoltaics, are increasing electricity surpluses in Japan. Relying solely on thermal or pumped-storage hydroelectric power is insufficient, and seasonal curtailment is required to manage supply.

Electrification in the Netherlands is causing **congestion** on both high- and medium-voltage networks.

Norway's main technical challenge is integrating new variable renewable energy sources, which reduce system inertia, while ensuring supply and demand are matched at all times. Grid transmission is **congested** in many areas, and constructing new lines typically takes about a decade.

Poland's primary challenge is the **obsolescence** of its electricity network, with over one-third of grid lines exceeding 40 years of age.

Portugal needs to reinforce its **cross-border** electricity capacity, particularly with Spain and France, to meet the EU's 15% electricity interconnection target by 2030.

The diversification of energy sources in Spain introduces intermittency and variability into the system. To manage these **fluctuations**, solutions such as storage, pumped hydro, and hydrogen are essential. Renewable energy also increases reliance on new technologies for effective grid management.

Nine out of ten Swedish network companies report an increased need for transmission capacity due to rising energy demands.

The shutdown of two **nuclear reactors** in 2032 and 2033 will disrupt Switzerland's energy mix. Since wind power is unpopular among the Swiss population, solar energy is being prioritized to balance the mix. However, solar energy also creates intermittency, making battery storage and pumped-hydro storage necessary to maintain grid stability.

One of the UK's key challenges is **energy storage**, as energy consumers and producers are often geographically separated. Other major issues include grid connections, the retirement of a significant portion of the industrial workforce, and the affordability of electricity.

B. WHAT MEASURES ARE BEING IMPLEMENTED OR CONSIDERED TO ENHANCE DEMAND-SIDE FLEXIBILITY (E.G. TIME-OF-USE TARIFFS, DEMAND RESPONSE)?

Variable pricing is considered a key instrument for enhancing demand-side flexibility. It is already in use in many countries and is being increasingly implemented as technical and regulatory requirements are addressed, particularly with the wider deployment of smart meters.

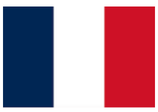
Smart grids are also promoted as a means to enhance demand-side flexibility.

The **industrial sector** can contribute as well. STOA notes that energy-intensive industries, especially aluminum and steel, possess substantial flexibility potential. However, these sectors face regulatory constraints and insufficient market incentives.

Since 2023, Austria has offered **financial incentives** to large electricity consumers who reduce or shift their consumption during peak hours (8 a.m.–12 p.m. and 5 p.m.–7 p.m.). The country is also enhancing demand-side flexibility by subsidizing home photovoltaic (PV) battery systems.

Dynamic electricity pricing has been operational in **Flanders** for three years and is being progressively rolled out in **Wallonia** since mid-June 2025.

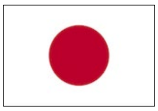
The Danish government has launched a feasibility study to explore lifting the **nuclear ban**, specifically assessing the potential of small modular reactors (SMRs) to support a high-renewables grid.



The French transmission system operator manages a **balancing mechanism** in which consumption sites can bid reductions or injections in response to its orders, with a specific remuneration of these demand-side offers. **Tariff instruments** are also being updated with a repositioning of off-peak hours at a lower price during the afternoon to take advantage of the abundant solar generation.

Germany lags behind other EU countries in **smart meter adoption**. Since 2025, all electricity providers have been required to offer time-of-use tariffs. The *Grid Charges Ordinance*, which proposes grid fee discounts for large consumers with steady baseload demand, is currently under debate.

Since January 2024, Greece has categorized electricity tariffs into **four color-coded pricing** tiers: blue, green, yellow, and orange.



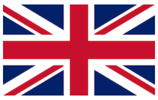
Japan's demand response strategy includes adjusting **industrial** operating hours, promoting on-site generation, and battery storage as key resources. Residents are encouraged to shift consumption in response to discounted tariffs.

Over **90% of Norwegian households** and **small businesses** have contracts tied to hourly spot prices. If effectively integrated, batteries could provide up to 100 GWh of grid flexibility by 2030.

Since August 2024, Polish electricity suppliers with over **200,000 customers** must offer variable pricing to encourage demand during off-peak periods.

Smart meters are installed in over 80% of Portuguese households.

Starting in October 2025, Sweden's Nordic spot market will introduce **quarter-hourly electricity pricing**. By 2027, all network companies must implement flexible tariffs.



The UK's 2021 *Electric Vehicle (Smart Charge Points) Regulations* mandate that **domestic EV chargers** include smart functionality. The government has also committed to extending this requirement to heat pumps.

Most U.S. utilities offer **time-variable pricing** programs, providing rate discounts to customers who voluntarily reduce consumption to support grid reliability.

C. HOW IS THE EVOLUTION OF THE ENERGY MIX AFFECTING ELECTRICITY AND GAS INFRASTRUCTURE (E.G. GRID CAPACITY, RELIABILITY, CROSS-BORDER FLOWS)?

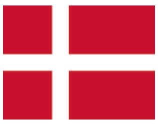
Large investments are required in transmission and distribution grids in order to accomodate the expected rise in electricity consumption and the diversification of energy sources. Cross-border interconnections also need to be strengthened. National infrastructure operators have developed plans to maintain and expand the grid capabilities.

Another key quantitative finding of the European Parliament's own-initiative report, "*Electricity grids: the backbone of the EU energy system*" (TA-10-2025-0136), is that the EU needs to invest **€584 billion in transmission and distribution electricity grids by 2030** to keep pace with the expected growth in electricity demand.

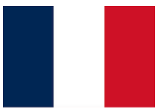
Austria's transition to pure hydrogen and methane-hydrogen blends requires repurposing **1,420 km** of existing gas pipelines and expanding the network by an additional **970 km** to accommodate the shift.

In 2023, the Belgian federal government approved the launch of the **second Modular Offshore Grid project** (MOG II), which includes constructing the world's first artificial energy island – Princess Elisabeth Island – to enhance offshore energy integration.

Developing renewable energy in Catalonia requires significant upgrades to **high-voltage transmission and distribution networks**, with an estimated investment of €13.3 billion. By 2050, the region aims to deploy 7.2 GW of storage capacity, including 3.7 GW of pumped hydro and 3.5 GW of battery storage.

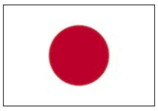


To support electrification, Denmark will develop new infrastructure to **convert excess renewable electricity** into hydrogen, synthetic methane, or e-fuels for use in transport, industry, and heating.



Cross-border electricity flows are becoming more structurally important. In 2024, France recorded record net exports of **89 TWh**, reflecting the recovery of nuclear output and high renewable availability. Reinforcing the **interconnections** with Spain, Italy, and Germany is a strategic priority to manage variability and enhance market integration.

Germany plans to install **4,800 km** of new transmission lines and reinforce **2,500 km** of existing connections to support its energy transition and accommodate growing renewable energy capacity.



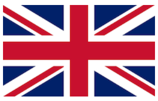
Japan's **cross-regional interconnection** lines remain underdeveloped, complicating supply-demand balancing as renewable energy adoption grows. Over the past decade, 1.2 GW of transmission capacity has been added, with plans to implement over 10 GW in the coming years.

Norway must transport electricity over **long distances** from remote hydropower plants to population centers in the southeast. While grid modernization is underway, permitting conflicts – particularly related to nature conservation – frequently delay construction timelines.

Poland's electricity transmission system operator plans to invest over **€64 billion** by 2034, including the construction of 4,850 km of 400 kV power lines. However, the country's interconnection capacity remains insufficient at 5%, far below the EU's 15% target for 2030.

In 2024, net electricity **imports** accounted for **20%** of Portugal's national demand, highlighting the need for enhanced domestic energy production or interconnection capacity.

Around **60%** of Swedish network companies report current or anticipated **limitations** in grid capacity, posing challenges for future energy demand and renewable integration.



The UK must expand its distribution network **fourfold** over the next seven years compared to the past three decades. Several food industry companies have already shifted refrigeration and sanitation processes to off-peak hours to optimize energy use.

The rise of variable renewable sources like wind and solar is increasing the complexity of supply-demand balancing in the U.S. electric grid—often described as the world's "***most complex machine ever made***". Energy storage is emerging as a critical solution to enhance grid flexibility.

D. WHAT ARE THE ANTICIPATED IMPACTS ON INDUSTRIAL VALUE CHAINS (E.G. MANUFACTURING CAPACITY, LOCALISATION, STRATEGIC DEPENDENCIES)?

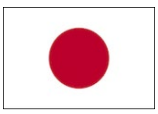
Industries are adapting to the evolving energy mix. In several countries, they are relocating closer to renewable electricity production. At the same time, decarbonization efforts continue but face challenges, with limited progress to date.

The use of **critical raw materials**, such as lithium and cobalt, essential for electric batteries and electronic chips, has become a major strategic challenge due to China's near monopoly on supply.

In Europe, **energy-intensive industries** are under **competitive pressure** due to energy costs. According to STOA, in 2024, industrial **electricity prices** in the EU reached €0.199 per kWh compared to €0.184 in Japan, €0.082 in China and €0.075 in the US. Prices in Europe are structurally higher due in large part to the marginal pricing model.

Bioenergy carbon capture is currently prohibited in Austria. However, the previous government proposed allowing geological sequestration of hard-to-abate emissions under strict safety and environmental regulations.

In September 2025, Germany's second-largest **steel company** announced it would **postpone or abandon** plans to produce "green" steel, citing economic and technical challenges.



Battery technology is recognized as essential for achieving carbon neutrality by 2050. However, shortages of critical raw materials pose a significant risk to deployment.

Since late 2023, **multiple incidents** have damaged Lithuanian infrastructure in the Baltic Sea, resulting in repair costs of approximately €40 million and increased energy costs for consumers estimated at €200–250 million.

In 2025, Luxembourg's parliament approved a €420 million **industrial decarbonization investment** plan for the period 2026–2038.

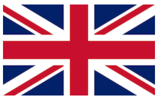
Since 2022, the Dutch government and industry have been discussing strategies to **decarbonize major emitting sectors** – such as steel, chemicals, and ammonia production – but progress has been limited so far.

Norway is a **leader** in Europe in sectors such as **carbon capture and storage** (CCS), offshore wind, and hydropower. Preserving expertise in these fields remains a priority to maintain its competitive edge.

Polish industrial firms are **relocating** from the coal-rich south to the north, closer to renewable energy infrastructure. The country is also bolstering its energy independence through projects like the Baltic Pipe.

Portugal possesses significant **lithium reserves**, which are crucial for the EU's battery value chains. However, mining projects in the Barroso region face **strong opposition** due to environmental and social concerns.

The expansion of renewable energy in Spain is increasing demand for **critical raw materials**. In response, several projects to develop recycling plants for these materials are emerging.



The upcoming UK Critical Minerals Strategy aims to reduce dependence on **overseas critical minerals** and maximize domestic resources. Key initiatives include lithium mining in Cornwall, nickel extraction in Wales, and recycling rare earth magnets in Birmingham and Belfast.

The growing adoption of technologies like wind turbines and electric vehicle motors is expected to drive up demand for **critical minerals** in the coming decades. The U.S. relies heavily on imports, particularly from China, which supplies **70%** of these minerals.

III. SOCIAL ACCEPTABILITY OF THE ENERGY TRANSITION

A. HOW WOULD YOU CHARACTERISE THE LEVEL OF PUBLIC ACCEPTANCE OF THE ENERGY TRANSITION IN YOUR COUNTRY?

Public support for the EU's energy transition is in general **strong** : polls show consistent concern about climate change (85% of Europeans consider it a serious problem), even higher support (88%) for renewable energy action.

But the **decline** in support for the energy transition stems from rising energy costs, economic hardship, and perceived unfairness, as households face higher bills and unequal burdens, while energy security fears – exacerbated by the Ukraine war – undermine confidence in rapid fossil fuel phase-outs.

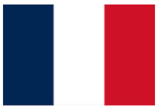
QC1. What does a European Union energy policy mean to you? (MAX. 3 ANSWERS) (%)

	EU27	AT	BE	BG	CY	CZ	DE	DK	EE	EL	ES	FI	FR	HR	HU	IE	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK
Ensuring more affordable energy prices for consumers	40	38	42	43	47	35	41	31	41	51	38	38	46	38	45	40	44	50	45	42	48	32	27	45	36	22	43	43
Investing in innovative energy technologies	33	28	28	30	34	23	36	34	27	35	39	31	32	34	21	25	38	29	35	19	32	38	25	33	23	38	36	30
Decreasing energy consumption across Europe - i.e. insulating homes or making products more energy-efficient	30	29	27	27	38	28	24	33	25	36	28	24	29	39	43	31	36	24	35	34	29	32	32	31	29	28	31	37
Coordinating European countries on energy matters	27	36	24	17	25	21	36	19	22	33	23	20	25	20	26	26	27	19	26	17	31	25	18	26	18	49	20	17
Improving energy infrastructure between and across European countries	27	30	27	24	23	22	30	37	28	29	28	31	23	27	25	27	27	22	28	26	33	38	20	23	23	40	26	20
Driving European climate neutrality	25	32	24	16	17	15	32	37	19	26	19	39	25	27	25	25	22	19	26	16	19	33	25	23	14	34	18	21
Preventing electricity black-outs and energy shortages	22	34	24	29	15	20	25	24	32	25	23	32	19	30	21	18	17	26	13	22	14	27	20	17	23	22	20	24
Ensuring nuclear energy is safe and secure	21	20	27	22	19	28	16	23	22	18	13	29	33	13	16	21	19	22	28	17	13	29	19	16	20	27	19	30
Supporting countries outside the European Union in moving to clean energy systems	16	17	14	13	13	11	13	23	8	21	15	16	15	20	19	13	17	13	20	12	21	15	20	17	16	19	15	13

1st Most Frequently Mentioned Item
2nd Most Frequently Mentioned Item
3rd Most Frequently Mentioned Item

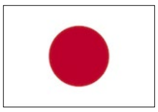
Source: *Special Eurobarometer 555, Europeans'attitudes towards EU energy policy, Summary report, April-May 2024*

Over **75%** of Austrians support the expansion of **renewable energy** and related infrastructure.



While public support for the energy transition is relatively high, acceptance in principle has lately been met with resistance in practice. Some political actors have called for **moratoria** on **renewable deployment** or stepped back from Low Emission Zone regulation, highlighting the tensions between environmental goals and perceived constraints on mobility.

In Germany, **80%** of respondents currently support the continued expansion of **renewable** energy sources.



A public opinion survey reveals strong support for prioritizing renewable energy sources such as **photovoltaics** (69.3%) and **wind power** (59.5%). Fewer respondents support the continued use of **coal**-fired power (8.7%), natural **gas**-fired power (16.9%), or **nuclear power** (22.4%), which Japan plans to phase out gradually.

In Lithuania, **76%** of respondents support the expansion of **renewable energy** as a means of strengthening national independence.

There is strong public support in the Netherlands for increasing reliance on **solar** (78%) and **wind** energy (69%), with less enthusiasm for nuclear energy (36%).

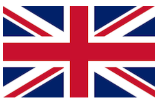
Although 70% of Norwegians acknowledge that human activity affects climate change, their priority remains **economic development** and energy prices rather than environmental concerns.

In 2024, 45.9% of Poles view the energy transition favorably, 29.9% negatively, and 24.2% remain undecided. Public acceptance – especially in coal-dependent regions – remains a significant challenge. Only **25%** of the population supports achieving climate neutrality by **2050**.

Public opinion in Spain **opposes nuclear energy** development. While some wind and solar projects have faced local opposition, Spaniards generally support the energy transition.

60% of Swedes favor increased investment in **wind** power, while **solar** power enjoys steady approval ratings of **75–80**%.

In Switzerland, rooftop solar and large-scale hydropower are the most widely supported methods of electricity production. More than **two-thirds** of the population believe all **eco-friendly technologies** should be used if additional electricity is needed.



While the UK's Net Zero policy enjoys majority public support, it is not considered a priority. Only **19%** of the UK public believes the **2050** *Net Zero goals* will be achieved.

CO_2 capture and storage, like many energy technologies, has faced **public opposition** and is likely to encounter more in the future. The U.S. emphasizes the importance of effective communication and community engagement as new energy projects are developed.

B. TO WHAT EXTENT HAS THE ENERGY PRICE CRISIS OF 2022 INFLUENCED PERCEPTIONS OF ENERGY POLICIES AND CLIMATE COMMITMENTS?

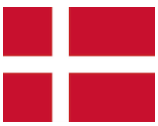
The 2022 energy price crisis sharply exposed **vulnerabilities** in the EU's energy policies, intensifying public and political debates over the balance between climate commitments and affordability.

Over 60% of Europeans have **reduced** energy consumption due to the 2022 crisis.

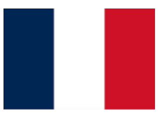
While the crisis reinforced the urgency of energy **independence** and renewables, it also fueled **skepticism** about over-reliance on intermittent sources and accelerated calls for pragmatic adjustments—such as extending gas infrastructure or nuclear power—to ensure stability during the transition.

In 2023, almost **two-thirds** of Austrians believed politicians should prioritize addressing rising prices and securing energy supply. The *Get Out of Oil and Gas* campaign (2022–2024) supported households and businesses in replacing oil and gas heating systems with renewable alternatives.

In 2022, **63%** of Belgians thought the war in Ukraine and rising fossil fuel prices should speed up the green transition. Yet, concerns about **purchasing power** are increasingly challenging this perception.



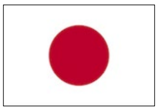
Residents not connected to **central heating** faced periodic energy price spikes in 2022, driving the expansion of Denmark's central heating systems and private electric heat pumps. However, this growth has recently slowed as gas and wood pellet prices have fallen.



The energy price shock of 2022 has acted as a stress test for French public attitudes toward energy policy and climate ambition. France introduced a **tariff shield to cap electricity and gas price** increases for regulated consumers. However, the link between energy and economic issues remain salient, fueling skepticism about the pace and costs of the transition.

Since 2022, public opinion in Germany has increasingly recognized the challenges of the energy transition for industry, reflecting concerns about economic **competitiveness** and feasibility.

During the 2022 energy crisis, Greece also faced severe climate impacts, including **heatwaves** and intense **wildfires**. These events underscored the urgent need for a green transition and reinforced the importance of building resilience in Greek society and the economy.



Compared to Europe and the U.S., Japan experienced a **smaller rise** in energy prices in 2022, reflecting its different energy market dynamics.

As the first EU member state to completely **terminate** gas, oil, and electricity **imports from Russia**, Lithuania has demonstrated that energy independence is achievable without significant supply disruptions or adverse effects on consumers.

Since 2025, **state subsidies** in Luxembourg only cover 50% of the excess electricity costs, reducing financial support for consumers.

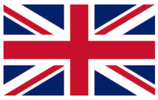
Since 2022, public debates on energy policy in Norway have shifted toward price **protection, sovereignty, and energy security**. The government introduced a support scheme covering most electricity costs for households when prices exceeded 0.70 NOK/kWh (approximately 6 euro cents).

In 2022, 65% of Poles believed that the war in Ukraine and rising energy prices should accelerate the **green transition**. However, data from 2023–2024 suggests that this initial wave of public mobilization is weakening.

Portugal has one of the highest rates of **energy poverty** in the EU, with 20.8% of the population unable to adequately heat their homes in 2023.

According to surveys, **64%** of Spaniards support accelerating the deployment of **renewables**, yet the public has not significantly changed its lifestyle since 2022.

In 2024, **85%** of Swedish respondents reported **reducing** their energy consumption, compared to 74% in 2021, reflecting increased awareness and behavioral changes.



The average annual gas and electricity bill in the UK rose from £1,216 in winter 2021/22 to £2,380 in winter 2022/23, before stabilizing at £1,849 in summer 2025. As a result, **83%** of people now support the idea of **national energy autonomy**.

C. ARE THERE SPECIFIC TECHNOLOGIES (E.G. WIND POWER, NUCLEAR ENERGY) THAT RAISE SIGNIFICANT CONTROVERSY OR PUBLIC RESISTANCE?

Overall, national public opinion is broadly **supportive** of the development of renewable energy. Nevertheless, the '***Not in my backyard***' phenomenon is evident across many countries: once a project is proposed in a specific locality, local opposition tends to rise significantly.

While **wind** energy plays a crucial role in the energy transition, it is often met with public concerns. These include its perceived impact on landscapes and local environments, potential noise disturbance, and possible effects on biodiversity.

Photovoltaics tend to be more popular than wind power, largely due to the potential for direct financial benefits for households and businesses.

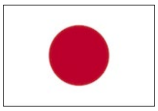
Public opinion in Europe on **nuclear** energy remains deeply **divided**: while some countries view it as a crucial low-carbon solution for energy security, others reflect strong skepticism due to safety concerns and waste management issues.

Austria has consistently **opposed nuclear energy** since the 1978 referendum. Attitudes toward wind power vary regionally, with stronger support in the east and greater resistance in the west and south.

In May 2025, Belgian authorities **repealed** the 2003 law that mandated a gradual **nuclear phase-out**. This decision allows the continued operation of reactors in Doel and Tihange, which were originally scheduled to close in 2025.

While **two-thirds** of households in Catalonia support accelerating renewable energy deployment, many proposed solar and wind projects face judicial challenges led by local organizations.

Germany shut down its **last three nuclear power** plants in April 2023, marking the end of its nuclear energy era.



Nuclear energy remains a contentious issue in Japan. When asked whether nuclear energy poses a safety risk, 58% of residents answered "yes". On the renewable side, opposition to new installations, such as photovoltaic (PV) projects, is increasingly observed.

Luxembourg's population, neighboring municipalities, government, and parliament regularly contest the long-term reliability and safety of France's Cattenom **nuclear power plant**, located near the border. Calls for its closure persist.

The last two Dutch governments have announced plans to build new nuclear facilities, which could be sited in the Zeeland region.

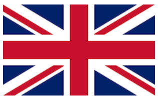
Public opposition has largely stalled onshore wind development in Norway, with **opposition tripling** from 2015 to 2020. In contrast, support for nuclear power has tripled since 2016.

Two-thirds of the population supported nuclear power plants in 2022, and 55% backed new wind farms in 2024. Opposition is stronger in smaller towns and rural areas, where these projects are often located.

Nuclear energy is politically **excluded** in Portugal.

In 2024, only **one-third** of respondents in a Swedish survey expressed support for establishing **wind farms** in their local area. To encourage local councils to approve new **wind farms**, the Swedish government has proposed a mechanism where property taxes paid by power companies are returned to **municipalities**.

56% of the Swiss population supports reopening the **debate on nuclear energy**. For the Swiss, security of supply, low energy prices, and carbon neutrality are the three primary considerations.



In spring 2025, **73%** of the UK public supported **onshore wind farms**. However, support dropped to **37%** when projects were proposed in **local areas**, due to concerns about visual and ecological impacts. Similar contradictions are observed with solar farms.

The recovery of **critical minerals** from non-traditional sources is still in its early stages, and the potential effects on nearby populations are not yet fully understood. The U.S. is actively working to promote public acceptance of these emerging technologies.

D. IS THERE AN ONGOING PUBLIC OR PARLIAMENTARY DEBATE REGARDING THE REALISM, COST, OR SOCIAL EQUITY OF THE ENERGY TRANSITION?

A vigorous public and parliamentary **debate** is underway about the **realism** of the energy transition, with critics arguing that ambitious timelines clash with infrastructure limitations, industrial competitiveness and geopolitical uncertainties.

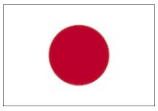
Cost concerns dominate discussions, as **households** and **industries** grapple with rising energy prices, carbon taxes, and green subsidies, sparking calls for more equitable burden-sharing—especially for low-income groups and energy-intensive sectors facing disproportionate financial strain.

The **successful achievement** of the energy transition requires a long-term strategic vision, active public participation, transparent communication and a fair distribution of both benefits and burdens.

In 2025, Austria introduced an amended ***Electricity Market Act*** following extensive consultations. Ministerial responsibilities were restructured, though climate-damaging subsidies remain a contentious issue.

Belgium has yet to submit its updated **National Energy-Climate Plan** (NECP) to the European Commission, due to ongoing **disagreements** among its four energy ministers.

Germany is debating whether to postpone the 2035 ban on **combustion engines**, with discussions centered on feasibility and economic impacts.



In Japan, the **National Diet** is actively debating the cost, technical feasibility, and social equity of energy policies. Critics question the realism of nuclear and decarbonized thermal power targets, while raising concerns about energy poverty and transition measures.

Luxembourg has enshrined the climate emergency in its **Constitution**, emphasizing the need for energy efficiency and renewable energy.

87% of energy-intensive firms in the Netherlands report that slow energy infrastructure development and network congestion pose **significant challenges** to meeting 2030 and 2050 sustainability targets.

In Norway, all political parties support **household** energy relief, but they differ on the level of support and the extent to which market signals should be moderated.

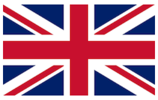
Poland's **coal regions** remain at the center of political debates on the energy transition. Local governments and energy companies are advocating for increased public funding to support the transition.

Portugal is currently debating the creation of an Interministerial Commission for Climate Action to **coordinate** national efforts.

A recent survey in Spain identified **modernizing the electricity grid** as a top priority to prevent blackouts. The government has launched a €13.56 billion plan to upgrade the grid by 2030.

In Sweden, **energy efficiency** is a higher priority for the opposition than for the government, which focuses primarily on **electricity production and infrastructure**.

Switzerland is engaged in a public and parliamentary **debate on nuclear energy**, including discussions on extending the lifespan of existing plants, constructing new ones, and ensuring long-term energy security.



In a recent announcement, the **Conservative Party** in UK declared it would no longer support the 2050 *Net Zero target*, citing excessive costs for consumers.

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I. ENERGY MIX AND THE CARBON NEUTRALITY OBJECTIVE (2050)

A. EVOLVEMENT OF THE STRUCTURE OF ENERGY DEMAND IN RECENT YEARS

Heating and cooling accounted for 40% of energy consumption in 2023, of which 61% came from fossil sources[1]. Of the total energetic final energy consumption, the transport sector accounted for 33%, private households for 26%, services for 10% and agriculture for 2% (preliminary numbers)[2] The industry sector accounts for 29%, of which energy-intensive industry sectors consume two-thirds.[3] The highest total energy demand comes from iron and steel, overwhelmingly steel, followed by the chemical and petrochemical industry, paper and pulp and cement.[4] These shares have remained fairly stable over recent years: In total, from 2020 to 2024, the share that transport accounted for increased by 1.7 percentage points, households' share by 1.5 percentage points; the shares for industry decreased by 1.2 percentage points, and the shares for services and agriculture remained almost the same, with a slightly more remarkable increase in the share consumed by private households during the height of the pandemic.[5] During the same period, the population grew by more than 10%.[6] While gross consumption of fossil sources declined by 1% per annum (oil) to 3% per annum (coal) from 2005 to 2023, renewable energy consumption has increased considerably to fill this gap. Growth in renewable energies was primarily observed in the electricity sector – the most important energy carrier after oil products with a share of 21% of energetic end use by 2023 – the contribution of wind power to electricity production increased almost six-fold and contributed 11.4% in 2023 and that of photovoltaics increased to 8.7% over the same period, starting from a negligible share in 2005, and with installed capacity increasing at the remarkable rate of 36.4% p.a.

[1] *https://energie.gv.at/energiewende/wie-schreitet-der-ausbau-von-erneuerbaren-energien-in-oesterreich-voran.*
[2] *https://www.statistik.at/statistiken/energie-und-umwelt/energie/energiebilanzen.*
[3] *https://www.bmwet.gv.at/Services/Publikationen/publikationen-energie/zahlen.html.*
[4] *https://www.nefi.at/files/media/Pdfs/NEFI_Szenarienbericht_v15_WHY_Design.pdf.*
[5] *https://oesterreichsenergie.at/fakten/energiegrafiken/detailseite/struktur-des-energetischen-endverbrauchs-nach-sektoren.*
[6] *https://www.wko.at/statistik/Extranet/Langzeit/Lang-Einwohner.pdf.*

B. CURRENT COMPOSITION OF THE ENERGY MIX AND KEY POLICY OBJECTIVES OR PROJECTIONS BY 2050

As of 2023, renewable sources accounted for 41% of Austria's total energy mix. This puts Austria sixth in Europe, well above the average of around 25%. The policy objective is to increase this share to 57% by 2030 and to almost 100% by 2040.[1] The share of renewables in energy for transport is 13%, and 39% for heating and cooling; however, key policy objectives focus on industry and the heating and cooling sector. The Conservative Party is engaging in watering down the phase-out of fossil fuel vehicles[2] and the EU climate law amendment by supporting the deferral of the decision from the EU Environmental Council to the European Council, to the consternation from the two other government parties[3]. Primary energy consumption is composed as follows: natural gas, 18.5%; oil, 35.7%; coal, 7.7%; PVE, 1.6%; wind, 2.2%; hydropower, 11%; ambient heat, 2.4%; biogenic, 18.8%; combustible waste, 2.1%; nuclear, 0%. Gross energy consumption declined by 0.4% p.a. during the period 2005-2023. Imports, consisting mostly of oil and gas, decreased by 14% in volume in 2023, yet still accounted for 76% of primary energy consumption. In contrast, exports, primarily from renewable sources, increased by 19%, but their size was still only one-fifth of imports.[4] The share of renewable energy in electricity generation has traditionally been high due to the well-developed hydropower sector. In 2023, 79% of the electricity produced came from renewable sources. The Federal Government's goal is for the electricity sector to be 100% renewable by 2030, on a national balance basis.[5]

C. TRANSFORMATION PATHWAYS UNDER DISCUSSION OR IMPLEMENTATION

The most significant transformation currently being implemented involves the substantial expansion of renewable energy in the electricity sector, including the necessary infrastructure, as well as the electrification of areas previously powered by fossil fuels, such as electric vehicles and heat pumps for heating and industrial processes.[6] As Austria's industry is relatively energy-intensive, a shift to net zero requires natural gas as a

[1] *https://energie.gv.at/energiewende/wie-schreitet-der-ausbau-von-erneuerbaren-energien-in-oesterreich-voran.*
[2] *https://www.kleinezeitung.at/wirtschaft/20093269/lockerung-in-sicht-eu-ueberprueft-co2-grenzwerte-fuer-autos-noch-heuer.*
[3] *https://www.puls24.at/news/chronik/eu-umweltminister-beraten-eu-klimaziel-keine-entscheidung/438579*
[4] *https://www.bmwet.gv.at/Services/Publikationen/publikationen-energie/zahlen.html – Energie in Österreich 2024.*
[5] *https://www.parlament.gv.at/gegenstand/XXVII/I/733.*
[6] *https://www.bmwet.gv.at/Services/Publikationen/publikationen-energie/netzinfrastrukturplan.html.*

bridging fuel and hydrogen as feedstocks and energy carriers in the long run for the transition to direct reduction of basic metals.[1] The Gas Diversification Act (Gasdiversifizierungsgesetz) stipulates the retrofitting of plants for the use of alternative fuels. Austria's RePowerEU chapter from 2023 pledges to expand hydrogen infrastructure and production, to streamline application procedures for wind power and other renewables – which hitherto require approval on several jurisdictional levels – to electrify regional railroads, and to expand the charging infrastructure for electric vehicles.[2] The current government has committed to improving efficiency in all sectors, expanding the electricity network and preparing the gas distribution network for hydrogen. It also plans to promote circular economic practices, as well as CCS and CCU, and to play a leading role in bioenergy carbon capture[3], which is currently forbidden in Austria. However, the previous government conducted an evaluation and recommended that the parliament permit the geological sequestration of hard-to-abate emissions under strict safety and environmental regulations.[4] Hydrogen and power-to-gas will play a crucial role in sector coupling and flexibility needs, given the dominance of hard-to-abate sectors during the transition to a renewable energy system.[5]

D. TECHNOLOGY ASSESSMENT STUDIES

Although the ITA has not recently published on the topic itself, it contributed significantly to the Austrian Panel on Climate Change (APCC) Special Report "Structures for climate-friendly living".[6] The report concludes that a successful transformation of Austria's energy system toward carbon neutrality fundamentally depends on deep structural changes across all areas of society. Current societal, economic, and infrastructural conditions often make climate-friendly lifestyles difficult, as existing systems still favour carbon-intensive behaviours. The report emphasises that mere technological advances are insufficient; comprehensive shifts are necessary in consumption, production, mobility, housing, and institutional frameworks. Halving Austria's final energy consumption by 2050, combined with scaling up renewable energy, is considered achievable, but will require coordinated economic, social, and cultural transformations alongside technological

[1] *https://aar2.ccca.ac.at/chapters/4.*
[2] *https://commission.europa.eu/business-economy-euro/economic-recovery/recovery-and-resilience-facility/country-pages/austrias-recovery-and-resilience-plan_en#repowereu-measures-in-austrias-plan, https://www.bundeskanzleramt.gv.at/eu-aufbauplan/aktuelles/rat-der-eu-billigt-oesterreichs-neues-repowereu-kapitel.html.*
[3] *https://www.bundeskanzleramt.gv.at/bundeskanzleramt/die-bundesregierung/regierungsdokumente.html.*
[4] *https://ccca.ac.at/fileadmin/00_DokumenteHauptmenue/02_Klimawissen/Policy_briefs/CCCA_Policy_Brief__2_CaCTUS_2025.pdf.*
[5] *https://www.bmwet.gv.at/dam/jcr:b39eaea4-9c1e-493e-80f8-17d67b91b8d2/studie_perspektiven-sektorkopplung.pdf.*
[6] *https://klimafreundlichesleben.apcc-sr.ccca.ac.at/.*

innovation. Structural barriers – such as economic growth dependencies, spatial organisation (including urban-rural divides), and entrenched institutional practices – must be addressed. Social inclusion, participatory governance, regular cooperation between stakeholders, and democratic public engagement are highlighted as vital for anchoring climate-friendly structures in the long term.

II. CONSEQUENCES OF TECHNOLOGICAL CHOICES

A. MAIN CHALLENGES ASSOCIATED WITH MANAGING A MORE DIVERSIFIED ENERGY MIX

Austria faces several key technical and operational challenges in managing a more diversified energy mix as it increases the share of renewables while maintaining grid stability and supply security. One major challenge is that the current grid infrastructure was not originally designed to handle the high volume and geographic dispersion of renewable energy sources such as wind and photovoltaics. Managing variable energy input, especially from decentralised sources, requires significant expansion and modernisation of transmission and distribution networks. Investments in grid flexibility, digitalisation (smart grids), and advanced control systems are essential for balancing fluctuating generation and demand, preventing bottlenecks, and ensuring real-time operability. To meet these requirements, the Ministry of Energy presented the Integrated Austrian Network Infrastructure Plan (ÖNIP) in 2024. This overarching strategic planning instrument is designed to facilitate the rapid and targeted expansion and conversion of a smartly interconnected energy infrastructure. The unified approach to the simultaneous transmission of higher-level energy for electricity, gas, and hydrogen for the first time should enable the necessary expansion of renewable energy generation to be coordinated as effectively as possible with grid development, storage, and flexibility options.[1] A point of contention that has recently emerged is the planned increase in network fees to finance grid expansion. The government has only just retracted its announcement regarding feed-in tariffs for small prosumers.[2] Nevertheless, the financing issue needs to be resolved. Studies show that the Austrian electricity grid has a very high level of supply security; however, reducing the installed capacity of gas-fired power plants would lead to supply shortages in Austria. Therefore, to further expand renewable energy generation, additional low-emission flexibility options must be developed, such as additional storage

[1] *https://www.bmwet.gv.at/Services/Publikationen/publikationen-energie/netzinfrastrukturplan.html.*
[2] *https://www.derstandard.at/story/3000000285303/strommarktgesetz-keine-netztarife-f252r-kleine-pv-anlagen.*

facilities, demand response and hydrogen-compatible power plants.[1] Expanding the storage facilities will certainly be important. According to a recently published study.[2] Austria will require a substantial increase in electricity storage capacity to achieve a fully renewable energy system. The estimated storage requirements would far exceed the volumes of current pumped hydro storage. Furthermore, seasonal storage using hydrogen as an energy carrier is considered essential for balancing supply and demand, especially during periods of low renewable energy production.

B. MEASURES IMPLEMENTED OR CONSIDERED TO ENHANCE DEMAND-SIDE FLEXIBILITY

Austria is actively implementing and considering several measures to enhance demand-side flexibility in its electricity system. In 2022, Austrian Power Grid (APG), the national transmission system operator, was appointed as the technical implementation agency for demand-side response products under the Electricity Consumption Reduction Act (SVRG). The scheme, which started in 2023, allows large consumers (e.g., industrial and commercial entities) to reduce or shift their consumption during peak periods (8–12 am and 5–7 pm) in exchange for financial incentives. A key objective is to achieve and maintain a 5% reduction in consumption during peak hours.[3] Current legislation requiring electricity suppliers to offer dynamic tariffs (the Electricity Market Act, EIWG) is under review. Some suppliers have already started offering such tariffs, but interest has been limited so far. Smart meters are a prerequisite for dynamic tariffs, and their distribution in Austria is already well advanced. Dynamic tariffs aim to enable households to adjust their electricity consumption to take advantage of favourable price periods, thereby improving the integration of renewable energy generators. These tariffs are primarily aimed at households with flexible electricity consumption, such as those with electric cars, photovoltaic systems, and stationary batteries.[4] However, due to their low adoption rate and the limited research available, it is not yet possible to comment on their impact. Another approach to increasing demand-side flexibility in the Austrian electricity system is to subsidise home PV batteries.[5] This development began in 2021/22 with national and regional grants under the Renewable Expansion Act (EAG). These incentives are designed to increase self-consumption, enhance grid stability, and promote energy independence. PV battery storage capacity has

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[1] *https://positionen.wienenergie.at/wp-content/uploads/2023/09/Flexibilitaetsoptionen-betrieb-oesterreichisches-stromsystem.pdf.*
[2] *https://doi.org/10.1016/j.segy.2024.100148.*
[3] *https://www.apg.at/en/news-press/apg-becomes-implementation-agency-for-demand-side-response-electricity-saving-product/ and https://pb1-medien.apg.at/im/dl/pboxx-pixelboxx-18765/221219_Obernosterer_DSR-Produkt.pdf.*
[4] *https://www.verbund.com/de/privat/strom/dynamischer-stromtarif.*
[5] *https://ebz-photovoltaik.at/foerderung-fuer-pv-speicher/.*

been increasing sharply in recent years.[1] However, this development is also viewed critically due to the high system costs involved and because there are other options with a smaller ecological footprint.[2]

C. IMPACTS ON ELECTRICITY AND GAS INFRASTRUCTURE

Transforming Austria's energy mix from fossil fuels to renewables will have a significant impact on the country's electricity and gas infrastructure. In response to these changes, the Austrian Network Infrastructure Plan (ÖNIP) considers higher-level energy transmission for electricity, gas and hydrogen together. It indicates significant additional transport requirements within the Austrian electricity transmission grid infrastructure, as well as the necessity for upgrading the gas transmission network. However, the challenges facing the electricity and gas networks are different. The gas network must adapt to a decline in methane demand and the requirements of a growing hydrogen economy,[3] as well as harnessing Austria's biomethane potential. Austria's main gas grid manager estimates that the increased use of pure hydrogen and methane-hydrogen blends requires the repurposing of 1420 km and expansion by 970 km of the existing gas distribution network of dedicated pipelines for pure hydrogen[4], including Austria's section of the South H_2 Corridor to be launched in 2030[5] By contrast, the electricity network's focus is on integrating a significant increase in renewable electricity generation, managing the growing demand for electricity and increasing long-distance power flows across Europe. Austria remains a central hub for electricity and gas in Central Europe.[6] It helps to balance surplus renewable energy generation from neighbouring countries (e.g., wind energy from Germany and solar energy from Italy) and exports hydro power to the west and north. In addition, it hosts large underground gas storage facilities. By maintaining and developing the required infrastructure, Austria is contributing to its own and its neighbours' energy transition. A study by the Austrian Energy Agency concludes that the significant growth of photovoltaic (PV) systems in Austria will require a substantial expansion and modernisation of grids and low-voltage transformers. The study also discusses several other measures, including accelerated approval procedures and the use of centralised battery systems in local grids.[7]

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[1] *https://www.bmwet.gv.at/dam/jcr:35a533b7-5724-464b-8737-ad014c18cd03/PV-Speichersysteme%20-%20Marktentwicklung%202024.pdf.*
[2] *https://epub.oeaw.ac.at/ita/ita-projektberichte/ITA-AIT-9.pdf.*
[3] *https://doi.org/10.1016/j.segy.2024.100151.*
[4] *https://www.aggm.at/energiewende/h2-roadmap/.*
[5] *https://www.e-control.at/documents/1785851/1811582/20250218-01_Alfons-Haber.pdf/39ceb107-c829-a063-90e5-1b133c3d66cf?t=1739889183589.*
[6] *https://energy.ec.europa.eu/system/files/2020-03/at_final_necp_main_en_0.pdf.*
[7] *https://oesterreichsenergie.at/publikationen/ueberblick/detailseite/netzdienliche-pv-der-zukunft.*

D. ANTICIPATED IMPACTS ON INDUSTRIAL VALUE CHAINS

The goal of reducing dependency on Russian gas is closely tied to decarbonisation efforts. Demand-side decarbonisation pathways include efficiency improvements, electrification, fuel switching, carbon capture technologies, and circular economic aspects.[1] While high energy prices motivate measures to reduce demand, as well as increases in energy efficiency and process innovation, the impact of the transition away from fossil fuel sources is already noticeable. Austria's steel industry produced 5.5% of the EU's raw steel in 2024, a share that has decreased only marginally since 2020.[2] Around 90% is produced in plants with blast furnaces and basic oxygen furnaces, and the rest in plants with electric arc furnaces.[3] The industry responds by replacing blast furnaces with electric arc furnaces[4], exploring technology for low temperature hydrogen combustion,[5] and using hydrogen as feedstock for direct reduced iron.[6] The Austrian government prioritises the strategic use of hydrogen in the steel industry, as a feedstock in the chemical industry, and for high-temperature heat in industrial sectors.[7] Scrap metal is expected to play a crucial role in reducing energy needs; however, the availability of sufficiently pure materials for the predominantly high-quality steel produced in Austria may become an issue.[8] In order to maintain and even expand manufacturing capacity - as declared in the government programme from 2025[9] – and reach emission targets and the goal of near 100% renewables, Austria depends on CCRS, particularly for cement[10] and hydrogen as an integral future feedstock also for synthesis of ammonia in the chemical industry, and on electrification of boilers and increased use of biofuels for pulp and paper.[11] This has to be accompanied by a corresponding increase in electricity production and imports.[12] There is a shortage of low-skilled labour for the installation and maintenance of renewable energy infrastructure. However, in the long run, the energy transition is expected to increase

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[1] *https://www.nefi.at/files/media/Pdfs/NEFI_Szenarienbericht_v15_WHY_Design.pdf.*
[2] *https://www.eurofer.eu/assets/publications/brochures-booklets-and-factsheets/european-steel-in-figures-2025/European-Steel-in-Figures-2025_23062025.pdf.*
[3] *https://www.eurofer.eu/assets/Uploads/Map-20191113_Eurofer_SteelIndustry_Rev3-has-stainless.pdf.*
[4] *https://reports.voestalpine.com/2425/qr/2/management-report/investments.html.*
[5] *https://www.eenews.ch/de/article/49938/energiefakten-austria-gruner-stahl-von-lichtbogenofen-und-ccs-technologien&page.*
[6] *https://www.voestalpine.com/greentecsteel/en/Net-zero-CO2-emissions-by-2050/.*
[7] *https://www.bmwet.gv.at/dam/jcr:ef159cbe-5950-4ee0-b19a-01448251add4/Hydrogen%20Strategy%20for%20Austria_Executive-Summary.pdf.*
[8] *https://www.wifo.ac.at/wp-content/uploads/upload-6926/s_2024_oesterreichs_stahlindustrie_49227924.pdf.*
[9] *https://www.bundeskanzleramt.gv.at/bundeskanzleramt/die-bundesregierung/regierungsdokumente.html.*
[10] *https://aar2.ccca.ac.at/chapters/4.*
[11] *https://nachhaltigwirtschaften.at/resources/nw_pdf/umsetzungsplan-energiewende-2024-bf.pdf.*
[12] *https://www.bmwet.gv.at/dam/jcr:dec84832-ac4d-4af9-a557-51b72abe3e9f/Studie_Energiewendereport_%C3%96sterreich.pdf.*

employment in medium- and high-skilled sectors primarily.[113] Information and training campaigns are part of a strategy to foster innovation and shift value chains back to Europe in a bid to reduce dependence on imported technology.[2] It remains to be seen how the new government's planned and already implemented policies will affect this trajectory.

III. SOCIAL ACCEPTABILITY OF THE ENERGY TRANSITION

A. PUBLIC ACCEPTANCE OF THE ENERGY TRANSITION

Based on existing studies, public acceptance of the energy transition in Austria is generally high, though nuanced.[3] A recently conducted survey indicates widespread concern about climate change and broad support for the necessary measures to protect the climate, with over 75% of Austrians supporting the expansion of renewable energies and energy infrastructure.[4] Support for policies, however, varies depending on the type of measure, with those perceived as fair and beneficial, such as public transport subsidies, receiving greater backing. Meanwhile, while acceptance of renewable energy projects is strong nationally, it is often weaker locally due to the 'Not In My Back Yard' effect, particularly concerning wind power.[5] Concerns about visual impact, noise and cost drive local resistance. Wind power is more widely accepted in Austria's eastern regions, which are windier and already have a large number of operating turbines, than in the western Alpine regions, where almost no turbines have been installed so far.[6] Photovoltaics, particularly on rooftops and facades, as well as in large open spaces, are more popular than wind power due to the prospect of personal financial gain and because they face less local opposition. Overall, acceptance hinges on perceived fairness, costs, and trust in political institutions. The literature suggests that effective public participation, transparent communication, and equitable distribution of benefits and burdens are crucial to foster stronger societal support for Austria's energy transition and climate goals[7].

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[1] *https://aar2.ccca.ac.at/chapters/4.*
[2] *https://www.bmwet.gv.at/dam/jcr:dec84832-ac4d-4af9-a557-51b72abe3e9f/Studie_Energiewendereport_%C3%96sterreich.pdf.*
[3] *https://pure.iiasa.ac.at/id/eprint/19533/1/NEKP_Wissenschaftliche_Bewertung_der_Massnahmen_der_Stellungnahmen_Februar2024.pdf.*
[4] *https://doi.org/10.1016/j.ecolecon.2025.108708.*
[5] Ibid.
[6] *https://link.springer.com/article/10.1007/s10098-019-01734-9.*
[7] *https://pure.iiasa.ac.at/id/eprint/19533/1/NEKP_Wissenschaftliche_Bewertung_der_Massnahmen_der_Stellungnahmen_Februar2024.pdf.*

B. ENERGY PRICE CRISIS OF 2022 AND PERCEPTIONS OF ENERGY POLICIES AND CLIMATE COMMITMENTS

A representative survey conducted in 2023 found that rising prices and securing energy supplies were among the population's greatest concerns since the war in Ukraine began.[1] Almost two-thirds of Austrians believed that politicians should pay more attention to this issue, while only a quarter were satisfied with the federal government's climate and energy policy. However, Austrians did see progress in securing energy supplies. Shortly after the outbreak of the war, only 15% believed that the federal government was doing enough in this regard; a year later, this figure had doubled. In response, the federal government increased its support for climate protection measures aimed at reducing dependence on fossil fuels.[2] A notable example of this was the nationwide 'Raus aus Öl und Gas' (Get out of oil and gas) campaign (2022-24), which offered substantial financial incentives to businesses and individuals transitioning from fossil fuel-based heating systems to more sustainable alternatives and undertaking thermal building renovations. During the 2022 energy price crisis, the market for climate-friendly technologies experienced a sharp decline in the short term, but this trend reversed to strong growth the following year. In the photovoltaic (PV) sector, following a decade of continuous growth in newly installed capacity, a record increase of 2,603 MW peak was achieved in 2023. A year earlier, demand for heat pumps had already reached a historic high, growing by 60% compared to the previous year[3]. While the majority of the population remained sceptical about government energy policies, many citizens took matters into their own hands and invested more in low-carbon and energy-saving technologies. Notably, recent years have seen a sharp increase in energy communities in Austria,[4] most of which are led by citizens. A popular narrative is that participation provides an opportunity to actively contribute to the energy transition, while fostering independence from energy companies[5] which have made considerable profits during the energy crises, something that was met by popular indignation.[6]

[1] *https://www.gallup.at/fileadmin/images_and_pdfs/marktstudien/2023/Gallup_PA_Charts_Der_Blick_auf_die_Rechnung_motiviert_zum_Energiesparen_26012023.pdf.*
[2] *https://www.bundeskanzleramt.gv.at/eu-aufbauplan/projekte/raus-aus-oel-und-gas-foerderung-des-austauschs-von-oel-und-gasheizungen.html.*
[3] *https://nachhaltigwirtschaften.at/resources/nw_pdf/schriftenreihe-2025-23a-marktstatistik-2024.pdf.*
[4] *https://www.e-control.at/documents/1785851/1811582/2024+EAG_Monitoringbericht_Barrierefrei_Final.pdf.*
[5] *https://doi.org/10.1016/j.eist.2024.100901.*
[6] *https://www.derstandard.at/story/3000000229947/breite-kritik-an-220bergewinnen-der-landes-energieversorger.*

C. SPECIFIC TECHNOLOGIES RAISING SIGNIFICANT CONTROVERSY OR PUBLIC RESISTANCE

There has been strong, long-standing opposition to nuclear energy in Austria. Since the 1978 referendum that banned the operation of nuclear power plants, public resistance has remained high.[1] The country opposes the use of nuclear power both domestically and at the European level, as demonstrated by the government's legal action against the EU's classification of nuclear and gas as "green" technologies.[2] This resistance is driven by concerns about radioactive waste and safety issues, and anti-nuclear activism is prevalent among both the general population and policymakers. Wind power is a frequent topic of debate at both regional and local levels. For example, a 2025 public referendum in Carinthia resulted in a narrow non-binding majority in favour of banning new wind turbines, reflecting concerns about landscape protection and local impact. The vote was driven by two far-right parties that ran a strong campaign in favour of the ban.[3] Support for wind projects varies widely by region, with eastern Austria generally being more supportive. In contrast, western and southern regions tend to be more resistant, often citing visual and environmental concerns.[4] The results of the recent referendum also revealed significant differences within Carinthia, with the strongest support for the ban being found in areas where no turbines had been previously installed.

D. PUBLIC OR PARLIAMENTARY DEBATE ON THE ENERGY TRANSITION

With the Greens participating in the Austrian government for the first time (2020–2024), there has been a significant change in national energy policy. The Greens headed a ministry that combined all key areas of responsibility for comprehensive climate protection (at that time, the Federal Ministry for Climate Protection, Environment, Energy, Mobility, Innovation, and Technology, BMK). Consequently, energy policy has shifted toward accelerating the energy transition, expanding renewable energy sources, setting ambitious climate targets, and implementing energy efficiency measures.[5] This pronounced energy policy was the subject of much public debate. However, due to substantial price hikes in electricity and gas from 2022 onwards, the debate temporarily shifted towards affordability and security of supply. Nevertheless, even during this period, attempts were made to present climate-friendly technologies as part of the solution.[6] A key legislative proposal to reform the national energy market (the Electricity

[1] *https://homepage.univie.ac.at/peter.weish/schriften/austrias_no_to_nuclear_power.pdf.*
[2] *https://time.com/6196779/austria-challenging-eu-over-green-gas-label/.*
[3] *https://www.theinternational.at/carinthians-vote-to-ban-wind-turbines/.*
[4] *https://link.springer.com/article/10.1007/s10098-019-01734-9.*
[5] *https://www.parlament.gv.at/gegenstand/XXVII/I/733.*
[6] *https://kontext-institut.at/inhalte/krieg-ukraine-russland-gasabhaengigkeit/.*

Market Act, ElWG) was drafted by the Green-led ministry but failed to gain majority support within the previous government.[1] An amended version of the proposal was introduced by the new government in 2025. A total of 570 comments were submitted during the four-week review period, demonstrating significant interest from various societal groups. Key discussion points included modernising the electricity market, improving consumer rights, promoting renewable energy sources, ensuring the security of supply, increasing transparency in wholesale energy trading, and introducing flexible grid fees and dynamic electricity contracts. The issue of energy poverty was also a key concern. Ministries and the government were involved, as were energy companies, consumer representatives, environmental organisations, and trade associations.[2] Removing climate-damaging subsidies is an ongoing point of contention. In the energy sector, these subsidies mainly pertain to natural gas and diesel. In 2022, they corresponded to around 0.8–0.9% of GDP.[3] The new government disbanded the BMK and split responsibility for climate matters and environmental protection, as well as energy, into two newly formed ministries, alongside agriculture and economic affairs, respectively.[4]

[1] *https://www.parlament.gv.at/aktuelles/pk/jahr_2025/pk0394.*
[2] *https://www.parlament.gv.at/gegenstand/XXVIII/ME/32?selectedStage=101.*
[3] *https://www.fiskalrat.at/dam/jcr:6fccb9a1-de30-4342-a387-206986cdacd4/Session_1_1_Kletzan_Slamanig.pdf.*
[4] *https://www.energie-und-management.de/nachrichten/politik/detail/aus-fuer-klimaministerium-254700 and https://www.profil.at/oesterreich/umwelt-und-klima-ministerium-abgeschafft-co2-preis-und-klimaneutralitaet-bis-2040-bleiben/403015993.*

BELGIUM

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As a preamble, we would like to endorse Fressoz's stark observation (2024): there is no such thing as an energy transition. On the one hand, energy sources tend to accumulate rather than replace one another, as is confirmed in the last Belgian energy data overview (FPS Economy, 2025a). Hence, the increase in the share of renewables in both energy production and consumption has not led to any reduction in the use of fossil fuels. On the other hand, at the European and Belgian level alike, energy policies aimed at reducing GHG emissions display both implementation and ambition gaps (EU JRC, 2025). Further, the shift towards the (far-)right in global politics is demonstrating, day after day, detrimental effects on the prominence of environmental policies. This translates into clear setbacks, or concessions, regarding commitments needed to limit global warming to 1.5 °C above pre-industrial levels, including but not limited to: the recurring and increasingly persistent calls to 'pause' environmental regulations, the heavy reliance on 'flexibilities' – such as carbon credits – in setting objectives, the preservation of commercial interests rather than ecological ones (e.g., as evidenced by the European Commission's recent commitment to purchase €700 billion worth of fossil and nuclear fuels from the US over the next three years), or else the promotion and support of techno-solutionist options (e.g., Small Modular Reactors and transmutation, Carbon Removals and Carbon Capture Use and Storage, etc.).

Belgium is no exception to this trend. Further, energy policy responsibilities and controls in the country are shared between the Federal Government and the three Regions. As a result, the country has four energy ministers, each supported by their own administration, and four regulators. This fragmentation of competences leads to substantial coordination challenges and exacerbates political inertia on these issues. For instance, despite already being a year behind schedule, Belgium has still not submitted its updated National Energy-Climate Plan (NECP) to the EU Commission due to a lack of agreement between the four concerned entities. Belgium is currently the last country without such plan, alongside Poland, and the Commission threatens to initiate infringement proceedings.

Nonetheless, a number of Belgian energy policies are still aimed towards achieving carbon neutrality and will be the focus of this report. A significant part of the analysis that follows is derived from a recent literature review on energy policy in Belgium conducted by three members of the Spiral research centre (see Sabbe et al., *forthcoming*).

I. BELGIAN ENERGY MIX AND THE CARBON NEUTRALITY OBJECTIVE (2050)

A. ENERGY DEMAND

Net energy imports remained high, mainly from oil products (63.5%) and natural gas (27.4%). Besides, in 2024, energy dependence – i.e., the ratio of net imports to the sum of gross domestic consumption and energy supplied for international maritime transport – stood at 75.9%, well above the EU average (FPS Economy 2025a). While the Coronavirus pandemic then the Russian invasion of Ukraine had led to a decline in energy consumption the previous years, in 2024, both primary and final energy consumption increased compared to 2023. Petroleum products continue to account for the largest share of total final consumption, at 48.2% (the vast majority of which is used in the transport sector); followed by natural gas at 25,2%. Electricity (including from renewables) stands at 17,2%, renewables (excluding electricity) at 6,2%, while a negligible proportion of solid fossil fuels and heat top it off (FPS Economy 2025a).

B. CURRENT COMPOSITION OF THE ENERGY MIX

The Belgian energy sector is characterised by a corporatist structure, with electricity and gas production largely in the hands of private companies (Van de Graaf et al. 2022). In 2024, the Belgian gross energy production mix was composed of nuclear energy (41.3%), natural gas (17.7%), renewables (mainly wind, solar, solid biomass: 34.2%) and, to a lesser extent, solid fossil fuels and steelmaking gases (2.9%), petroleum products (0.3%) and other sources (including pumped hydropower, recovered heat, non-renewable waste and others: 3.6%) (FPS Economy 2025a). The Federal Public Service (FPS) Economy emphasises that the most notable increase over the last decade has been in renewable energy, where production has increased by 79.3% (+11.5 TWh) compared to 2015 (FPS Economy 2025a, 31). Yet, contrary to the historical trend of a 225% increase between 2015 and 2023, renewable electricity production decreased by 5.7% (-1.6 TWh) between 2023 and 2024. Further, the share of renewable energy in final energy consumption was 14.0%. in 2024: if that meets the baseline (13%) imposed by European regulation, it remains well below both the EU average and Belgium’s target of 21.7% renewable energy by 2030 (FPS Economy 2025a).

C. CURRENT PATHWAYS TO ACHIEVE DECARBONISATION

Overall, Belgium's transition to climate neutrality relies on energy efficiency and reduced consumption, as well as electrification - supported by the development of renewable energy sources - wherever possible. For sectors that are difficult to fully decarbonise (e.g., industry or waste) compensating measures are envisioned, such as carbon removals and sequestration (FPS Health, 2020). Legal, technical, financial, participatory instruments are regularly adopted to sustain the Belgian energy transition. Below are some of the measures – in 2023 alone, Belgium reported a total of 241 single policies addressing climate change (European Commission 2024) – that have been attended to in academic literature regarding Belgium.

Support instruments: In Belgium, renewable electricity generation is primarily promoted through market-based instruments under the form of Tradable Green Certificates (TGCs) (Carton 2016). Belgium has four distinct TGC programs, emitted by relevant energy regulators: one for each regional government and one managed by the federal government to reward offshore wind generation. Although TGCs were intended to create a market favouring green energy solutions, they have sparked controversies (see section 3.3). Besides, measures have also been taken to reduce energy consumption in the transport sector, which remains one of Belgium's most energy-intensive sectors (IEA 2022). Significant improvements were achieved, notably through the implementation of support policies for electric passenger cars (Dolge et al. 2023). Although e-mobility remains marginal amid increased road traffic, electric vehicle registrations grew to reach 3.1% of the passenger car fleet (IEA 2022).

Energy-saving incentives: Despite recent progress, Belgium's energy intensity remains significantly higher than the EU average. This low energy efficiency performance (Lu and Lu 2019) is often attributed to an aging, inefficient building stock (e.g., Singh et al. 2013; Coppens et al. 2022). The federal and regional governments have taken measures to improve the energy efficiency of residential buildings, such as minimal requirements for roof insulation in Flanders, or financial incentives to promote residential building stock efficiency.

Experimental regulatory sandboxes: At regional and federal levels and besides public subsidies and taxes, Belgium innovates with the introduction of regulatory sandboxes to boost experimental energy transition innovations (e.g., local energy, flexible participation in electricity markets, distribution network tariffs) and regulatory learning through derogations (Beckstedde et al. 2023).

Integrating the final consumers: Many energy transition instruments focus on integrating the final energy consumer, or prosumer, into the process. Key issues include understanding consumers' behaviour and their degree of consciousness (Van de Velde 2009) as well as their capacity to change their behaviour accordingly, moving from passive to active citizens (Campos et al. 2020). One of the most studied participatory instruments in Belgium are the *(renewable) energy communities* (REC) (Bauwens 2019; Bonfert 2024; Conradie et al. 2021), also known as *community-driven energy* (Van Summeren et al. 2020), or *collective action initiatives* (Gregg et al. 2023). These initiatives are seen as key energy transition drivers (Van Summeren et al. 2020; Bauwens and Devine-Wright 2018) which introduce "logics of proximity, spatial selectivity and collectivity" (Juwet 2019, 1902) essential for the creation of *transition cities* and to build resilient local communities (Kenis and Mathijs 2014).

D. ASSESSMENT OF THESE EVOLUTIONS

They are updated every six months by the Federal Public Service Economy The Spiral Research Center recently conducted a literature review on Energy Policy in Belgium that identifies the main consequences of technological choices and social challenges regarding energy issues (Sabbe, Frenay & Parotte *forthcoming*) – mobilized in the next sections. The Center is currently working on four energy research projects: (1) the vanguard visions of small modular reactors (NUVanguard Project 2024-2026), (2) the mundane decay of nuclear infrastructures (2022-2025 MUNDEC project), (3) low carbon and labour transitions (2020-2025 Belspo LAMARTRA project), (4) Carbon Capture Utilisation and Storage for highly emitting infrastructures (FNRS project 2024-2028). We identify three potential avenues for future interdisciplinary research programs on energy policy in Belgium:

(1) Investigate the development of, and expectations associated with, advanced energy technologies such as small modular reactors (SMRs), nuclear transmutation for high-level radioactive waste management, green hydrogen, cross-border offshore hybrid hubs, and their socio-technical consequences for energy systems.

(2) Investigate the purposive phase-out of existing technologies and to focus on aging infrastructures that need to be repaired, replaced or transformed.

(3) Fostering inclusive and coordinated energy governance. In Belgium, there is still a need to comprehensively map and compare public engagement with energy and net zero. This ranges from "dominant practices" (e.g., public surveys viewing the public as consumers) to the formation of *diverse participation collectives* (such as energy communities), and *emergent and overflow* forms of participation (e.g., digital and mundane publics) (Chilvers and Longhurst, 2016).

II. CONSEQUENCES OF TECHNOLOGICAL CHOICES

A. THE MAIN TECHNICAL OR OPERATIONAL CHALLENGES FOR A MORE DIVERSIFIED ENERGY MIX

As already mentioned, Belgium is characterized by a long-standing dependence on primary energy imports (Dallenes et al. 2023) due to limited indigenous primary energy resources and a high degree of energy intensity (Faraji Abdolmaleki et al. 2023). Over the years, this historic dependence on imported energy sources have led to technical and operational choices to ensure the security of energy supply – which has long been, and remains, a dominant frame of reference in Belgian energy governance (Sabbe et al. *forthcoming*) - that now have strong implications for achieving and managing a diversified energy mix.

Ever since the 1973 oil crisis, Belgian policymakers have sought to diversify the sources and geographical origin of primary energy sources to guarantee the security of supply. While the diversification strategy for crude oil imports originally focused on "switching from the Middle East to the North Sea (Norway and the UK) and the former Soviet Union" (Brown et al. 2014, 73), it now focuses on compensating "the loss of the Russian share (about 30%)" (FPS Economy 2025b, 39) ever since its subjection to European embargo. Similarly, by the early 2000s, most natural gas imports originated from the Netherlands, Norway, Algeria, and the UK (Shenk 2008). In 2019, the gradual phase-out of the Groningen gas field in the Netherlands led to an increase in Liquified Natural Gas (LNG) imports from Russia. Since 2022, Belgium has further diversified its natural gas imports "by increasing the share of gas in liquefied form" (FPS Economy 2025b, 43). Over the years, his long-lasting reliance on diversified gas and oil imports required the development of extensive energy infrastructure which includes pipelines, refineries, and an LNG terminal at Zeebrugge. As a result, Belgium became a major international hub for the redistribution of fossil fuels in North-western Europe. In particular, following the decrease of Russian gas imports, "the proportion of gas transiting through Belgium towards the east of Europe has increased since 2022, reaching 70% in 2023" (FPS Economy 2025b, 43). <u>This prominent role as a transit hub has deepened Belgium's infrastructural and economic entanglement with fossil energy</u>, creating a significant lock-in in favour of fossil energy sources.

Another key challenge for maintaining a diversified energy mix in Belgium lies in the (poorly coordinated) decommissioning of major energy infrastructures. This is not a new phenomenon: the once-prominent coal industry disappeared with the closure of the last exploitation in Flanders in 1992 (Van de Graaf et al. 2022). More recently, electricity generation from solid biomass declined sharply (–18.6%) following the closure of Belgium's largest biomass power plant in 2023 (FSP Economy 2025, 33). Nuclear energy provides a further illustration. Adopted as a central pillar of Belgium's electricity system in 1968 (Söderholm, 1998), nuclear power has remained a key contributor to the country's electricity mix. In 2003, following the entry of the Green Party into government in 1999, the federal government opted for a gradual nuclear phase-out policy by 2025 (see subsection 3.3). However, the shutdown of Doel 1 and Doel 2 was postponed by ten years in 2015 due fears of electricity shortages. In 2022 the federal government decided to extend the operation of Doel 4 and Tihange 3 until 2035 in response to the energy crisis. Ultimately, the 2003 phase-out law was repealed in May 2025, marking a decisive reversal of the country's nuclear exit strategy after the decommissioning of two reactors: Doel 3 in September 2022 and Tihange 2 in January 2023. This policy shift introduces pressing challenges, particularly the maintenance and repair of nuclear reactors that are, and will continue to be, subject to mundane decay, especially when kept in operation beyond their originally planned lifespan (See: MUNDEC, subsection 1.4). The nuclear example illustrates how <u>poorly coordinated decommissioning efforts can undermine both diversification and long-term stability</u> in Belgium's energy system.

Similarly, without any clear preferences on end-of-life strategies for energy infrastructures, the decommissioning of windfarms (Goethals and Maes 2023) or PV panels (Van Opstal and Smeets 2023) and the associated waste management remains a blind spot in Belgian energy transition. Indeed, over the past decades, the country's renewable electricity generation capacity has increased considerably, reaching 13.8 GW or 50.6% of the total installed electricity generation capacity in 2023 (FPS Economy 2025b). Although beneficial for the environment, this strong investment in solar and wind energy sources also entails challenges for grid management, as production remains intermittent. For instance, while between 2022 and 2023 "wind-based production increased by 25.0% thanks to high wind speeds in 2023" (FPS Economy 2025b, 33), it then fell by 9.5% in 2024 due to unusually low wind speeds (FPS Economy 2025a, 33). Seasonal vulnerabilities also remain acute, as shortages are most likely to occur during winter periods of high demand and limited (solar) output. To mitigate such shortage risks, the federal government has introduced a Strategic Reserve (SR) in 2014, mobilized only as a force majeure. In 2021, a Capacity Remuneration Mechanism (CRM) was established to ensure adequate resources from the winter of 2025–2026 onwards and stimulate long-term investment in new capacity (Mastropietro et al., 2024). Unlike the SR, which targets urgent shortfalls, the CRM is a market-based instrument providing support to a broad range of solutions – including generation, storage, and demand management – thus aiming to secure supply while incentivizing structural investment (Vandorpe, 2022). <u>Beyond intermittency, Belgium's energy infrastructure is also exposed to broader climate risks</u> which should be integrated in long-term energy policy planning (e.g. Brajkovic et al., 2025). Such risks notably include floods, such as those experienced in Wallonia in 2021, and recurrent droughts that increasingly test the resilience of energy production, transport, and distribution systems as well as bear economic impacts that may not only persist but intensify over time (Usman et al., 2025).

B. MEASURES BEING IMPLEMENTED OR CONSIDERED TO ENHANCE DEMAND-SIDE FLEXIBILITY (E.G. TIME-OF-USE TARIFFS, DEMAND RESPONSE)?

We have not specifically covered this topic in our analysis. Please, see relevant information in other subsections. Time-of-use tariffs, however, can serve as an insightful illustration of the different rhythms of energy policy in Belgium: while 'dynamic' electricity pricing has already been in place in Flanders for three years, it is being progressively implemented in Wallonia since mid-June. Brussels-Capital is still lagging behind but could have this option by the end of this year.

C. EVOLUTION OF ELECTRICITY AND GAS INFRASTRUCTURE (E.G. GRID CAPACITY, RELIABILITY, CROSS-BORDER FLOWS)

In the past decades, Belgium has also increased the share of renewables as part of the EU 2020 (2009/28/EC) and 2030 (EU/2023/2413) targets to reduce EU-Wide greenhouse gas (GHG) emissions. This mainly resulted from increased solar and wind capacity supported by federal and regional public subsidies (e.g., Boccard and Gauthier 2021; Delbeke et al. 2023). Offshore wind-based production, in particular, is set to gain in prominence. Since 2020, Belgium has an operational offshore wind capacity of 2.26 GW as part of the Modular Offshore Grid (MOG) I. In 2021, federal authorities have agreed to the development of an additional 281 km² wind zone in the North Sea in view of expanding total offshore wind capacity to 5.4-5.8 GW by 2030 (Penneman et al. 2023). In 2023, the federal government also approved the launch of the MOG II project, including the construction of the world's first artificial energy island – the Princess Elisabeth Island - which will host the offshore electricity transmission infrastructure. MOG II seeks to form "the cornerstone of the future integrated European offshore grid" (Elia, 2025) by improving interconnection with other offshore wind projects in the North Sea. However, MOG II is facing soaring costs: in just a few years, the budget has increased from €2,2 billion in 2021 to an estimated €7-8 billion today (CREG, 2025). While these overruns can be partly explained by design choices and initial underestimations of investment costs, supply chain pressures, rising raw material prices and inflation due to the geopolitical tensions are proving to be the main reasons for the increase (Creg, 2025).

Following the 2022 energy crisis – exacerbated by the Russian invasion of Ukraine and the end of Russian gas imports – the Belgian Government announced its inclination to mitigate the risk of power outages by extending the operating life of the Doel 4 and Tihange 3 nuclear reactors. In December 2023, an agreement with Engie was reached to keep Doel 4 and Tihange 3 operational for ten years beyond their planned closure in 2025, requiring an investment of 1.6 to 2 billion euros (ENGIE 2023).

Over the years, Belgium achieved greater cross-border interconnections with neighbouring countries' high voltage grids (COM/2015/080). Furthermore, as a result from a gradual integration to the EU energy market and its well-developed gas infrastructure (see subsection 2.1), Belgium is favourably positioned to attract and redistribute natural gas flows to north-western European markets (CREG 2023).

III. SOCIAL ACCEPTABILITY OF THE ENERGY TRANSITION

A. STATE COORDINATION, PUBLIC ACCEPTANCE AND SOCIAL DRIVERS

Social research on the drivers and constraints of energy transition in Belgium focuses on two main trends. As outlined in section 3.4, the first concerns the coordination challenges arising from the multiplicity of private and public actors involved, and the legal, technical, financial, and participatory instruments adopted for the energy transition (Sabbe et al. *forthcoming*). Researchers also explore how inadequate bureaucratic and stigmatizing state social assistance practices (Bartiaux et al. 2018), and a complex institutional structure (Bartiaux et al. 2021) can hinder changes in individual energy consumption behaviour. As such, energy-saving practices and renewable energy consumption remain strongly related to individual cultural and socio-economic status (Bartiaux et al. 2016; Albrecht and Hamels 2021; Dallenes et al. 2023). Vulnerable groups, facing limited access to economic and cultural resources (Dallenes et al. 2023), also suffer energy policy inequalities and structural barriers to embracing green energy practices. In other words, it is harder for these groups to adopt energy saving practices (Bartiaux et al. 2016); to make renovation investments (Albrecht and Hamels 2021); or to oppose fossil fuels and nuclear energy (Dallenes et al. 2023). As presented in the following subsection, the 2022 energy crisis also had a considerable impact on energy (transition) policy perceptions

B. TO WHAT EXTENT HAS THE ENERGY PRICE CRISIS OF 2022 INFLUENCED PERCEPTIONS OF ENERGY POLICIES AND CLIMATE COMMITMENTS?

Due to Belgium's structural dependency on energy imports, households were deeply affected by the 2022 energy price crisis (CREG, 2023), further exacerbating pre-existing socio-economic fragilities in the country. Household electricity prices reached about €0.38/kWh in the second semester of 2022, compared to €0.20/kWh a year earlier, while natural gas prices more than doubled in the same period (Eurostat, 2025).

Specifically, this rise in energy prices accentuated long-standing energy poverty issues. In previous decades, energy market liberalization efforts had not produced the expected price reductions and exposed households to higher price volatility (Tõnurist et al. 2015; Meyer et al., 2018; Huybrechs et al. 2011). This issue is further compounded by an aging housing stock which drives high heating expenditures due to poor insulation and low energy performance – particularly in Brussels and in Wallonia where a majority of dwellings predate 1981 (Bartiaux et al., 2021). Although there are no official figures on energy poverty in Belgium, it is estimated that about 10% of Belgian households spent over 10% of their income on maintaining comfortable indoor temperatures in 2021 (Antunes et al. 2023). By 2022, the King Baudouin Foundation (KBF) reported that the share of households affected by energy precarity had increased to 21.8%, nearly seven percentage points higher than the year before. This rise especially affected Wallonia (29.2%) and Brussels (28.2%), compared to Flanders (16.4%). This also coincided with a sharp rise in self-reported energy poverty (KBF 2024).

Consequently, the 2022 crisis affected both public perceptions of energy policy and national climate commitments. On the one hand, it highlighted the risks of external dependency and the social costs of delayed investment, thus reinforcing public support for structural measures. The European Investment Bank (EIB) yearly climate survey indicates that in 2022 nearly two-thirds of Belgians (63%) believed that the war in Ukraine and increasing fossil fuel prices should accelerate the green transition (EIB, 2022). Likewise, according to the 6th edition of the International Observatory on Climate and Public Opinion, public support for nuclear energy rose from 43% in 2021 to 56% in 2024 (Obs'COP 2024), ultimately culminating with the 2025 repeal of the 2003 Belgian nuclear phase-out law. On the other hand, immediate concerns due to rising prices may have temporarily overshadowed decarbonation and energy efficiency objectives, as evidenced by the government's decision to permanently reduce the VAT – from 21% to 6% – on electricity and gas for household consumption. Short-term relief measures, such as expanded social tariffs and tax cuts, also gained strong political and public support to mitigate hardship.

C. CONTROVERSY AND PUBLIC RESISTANCES ON SPECIFIC TECHNOLOGIES

Nuclear energy in Belgium has long been the object of controversies and frictions. The 1970s and 1980s were marked by several accidents (Three Mile Island in 1979 and Chernobyl in 1989) and local scandals (i.e., the 1987 Transnuklear affair) that fuelled the antinuclear sentiment in Belgium: first among Green parties, trade unions, then followed by other parties (Eggermont et al. 2007). With the participation of Green parties in the Verhofstadt I government in 1999, the coalition agreement included a plan for a gradual nuclear phase-out, justified by a commitment to environmental sustainability and energy diversification (Dumont and De Winter 1999). In January 2003, a law was enacted to gradually phase-out nuclear energy for electricity generation by 2025. However, Belgium's phase-out policy saw various revisions in the following decades. In 2015, amid fears of an electricity supply shortage, the federal government postponed the shutdown of Doel 1 and 2 reactors by ten years (de Frutos Cachorro et al. 2019). In March 2022, it was decided to keep Doel 4 and Tihange 3 in service until 2035 to bolster security of supply. Most recently, in May 2025, Belgian authorities repealed the gradual nuclear phase-out law, enabling the continued operation of these reactors beyond the initial planned closure in 2025. Although no formal commitments were made, this also reopens the possibility of developing new nuclear capacity in the future, including with Small Modular Reactors (SMRs). As outlined in subsection 3.2, this intervenes in a context of increasing public support for nuclear energy in Belgium.

Studies have also highlighted local controversies over the siting of wind energy projects. In particular, the LACSAWEP project (Van Rompaey et al. 2011) found that among residents near proposed onshore wind projects, visual landscape degradation, noise, shadow flicker, and proximity are recurring reasons for opposition, with symbolic values attached to land often weighing more than economic benefits. Similarly, the Superior Health Council's advisory report acknowledged that, although not proven to cause serious health damage, wind turbines may affect the quality of life in residential areas, thus leading to local resistance (SHC 2013). Furthermore, the legal procedure structuring the implantation of windfarms was also found to be a possible catalyser of frustrations, fuelling distrust of developers and authorities (Rossignol et al. 2017; Van Rompaey et al. 2011).

Some controversies have also erupted over the support schemes for household solar photovoltaic (PV) installation. While the introduction of Tradable Green Certificates (TGCs) did not result in widespread PV adoption, this changed in 2006 with the introduction of a generous premium support (Tõnurist et al. 2015; Collard 2012). However, overgenerous subsidies led to a significant financial burden on regions – necessitating reductions in PV premiums until 2015 (De Groote et al. 2016) – as well as a perverse *rebound effect* in energy consumption among PV owners (Boccard and Gauthier 2021). Additionally, Bartiaux et al. (2016) noted that such a support scheme, financed by direct and indirect taxes on all citizens, had increased social inequalities because only those with greater financial resources can afford PV panels.

D. ONGOING PUBLIC, PARLIAMENTARY DEBATE AND STATE COORDINATION REGARDING THE REALISM, COST, OR SOCIAL EQUITY OF THE ENERGY TRANSITION

Since the third reform of the Belgian State in 1988, the elaboration of energy transition policies has been complicated by fragmented competences between federal and regional governments (Jay 2010). This complex articulation has produced a patchwork of policies and recurrent coordination challenges (Happaerts 2015; Van Opstal and Smeets 2023) as illustrated by the six-year required to reach a burden-sharing agreement to comply with the 2020 EU renewables target agreement in 2015. Over the years, the need for improved coordination gave rise to various intergovernmental initiatives, such as the ENOVER/CONCERE concertation platform and the National Climate Commission. In 2017, the Inter-federal Energy Pact further reflects regional and federal ministers' willingness to articulate a concerted vision for EU 2030 and 2050 targets. Yet, despite these efforts, the NECP revision reveals persistent difficulties in aligning federal and regional energy transition policies.

Lately, Belgian authorities have also shown interest in innovative technologies for supporting the energy transition. In 2022, the federal government granted SCK-CEN – the national nuclear research centre – €100 million for research on SMRs over the 2023-2028 period. These advanced reactors are presented as a cheap, flexible, reliable, and decarbonized option to replace ageing nuclear capacity. However, early (over)optimism may gradually fade as international experts point possible profitability issues and uncertain feasibility regarding large-scale factory production and deployment (Böse et al. 2024). Federal and regional authorities have likewise advocated the development of green hydrogen (Sapnken et al., 2023), which, though still at an early stage, is featured among policy priorities. Cross-border hybrid hubs – transforming the North Sea in the "green power plant of Europe" (De Croo 2023) by integrating renewables, hydrogen and carbon capture, utilisation and storage (CCUS) – are also promoted as cornerstones of the future energy system, with potential to advance energy transition, security, diversification, and accessibility.

Some scholars question this stance, arguing that "disruptive or 'breakthrough' technologies" (Coppens et al. 2022, 11) are not necessarily needed to achieve mitigation objectives. They suggest *doing without, doing with less* as new innovation horizons (Goulet and Vinck 2022), introducing exnovation policies – the purposive termination of existing energy infrastructures and practices – as the flipside of innovation (David and Gross 2019). For example, Fossati et al.'s (2022) study of Brussels' Low Emission Zone highlights exnovation as a relevant policy instrument for redefining networks and rationales through the purposive phase-out of internal combustion engines.

In the same vein, there is also a necessity of <u>ensuring public and stakeholder involvement in the process.</u> For instance, nuclear energy research indicates that decommissioning was often overlooked in the design and financial planning of current nuclear reactors. Likewise, anticipating high-level waste management and the associated hosting sites generate a host of social, economic, and technical challenges. Lessons from these experiences may therefore help to *systematically* anticipate and assess discontinuation policies for current and future energy infrastructures, including former coal burning plants but also renewables.

Current research (e.g., Delvenne et al. *forthcoming*; Sabbe et al. *forthcoming*) also stresses that the <u>maintenance, repair, and decommissioning of energy infrastructures</u> require sound policy choices and an adaptation of socio-technical practices. Suh issues merit careful consideration in Belgium, a country that has experienced several phases of de-industrialization and inherits ageing energy infrastructures. Just like roads and railways, nuclear reactors, high voltage lines, and hydraulic turbines are ready-made infrastructures that usually escape attention and recognition, yet require considerable investment and daily care. In Belgium, special attention should be given to the extension of nuclear reactor operation, as material and human constraints (e.g., micro-fissure management, recruitment and retention of maintenance staff) are vital to maintain safe operation. Organizing the phase-out and decommissioning of such infrastructures is and will remain a challenging issue.

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CATALONIA

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I. ENERGY MIX AND THE CARBON NEUTRALITY OBJECTIVE (2050)

A. EVOLUTION OF THE ENERGY DEMAND AND ENERGY MIX IN CATALONIA[1]

Over the past two decades, the evolution of Catalonia's energy demand has been closely related to changes in its energy mix (see the latest official temporal series in **Fig. 1**). After years of steady growth, final energy consumption peaked in 2007 at 16.6 million tonnes of oil equivalent (Mtoe), reflecting a mix dominated by fossil fuels (primarily petroleum products and natural gas). The global financial crisis marked a turning point, leading to a significant contraction in demand and a gradual shift in the composition of the energy mix. A modest recovery followed, but the COVID-19 pandemic in 2020 brought another abrupt drop, from which demand had not fully recovered.

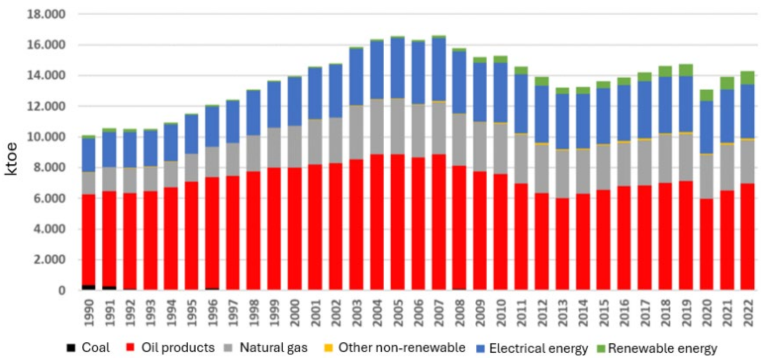

***Figure 1**. Evolution of final energy consumption by type in Catalonia (1990-2022)*

By 2022, Catalonia's final energy consumption was 14.3 Mtoe, about 14% below its historical peak and similar to early-2000s levels. The energy mix remains dominated by fossil fuels. Petroleum products, mainly for transport, accounted for nearly half (48.7%) of all final energy consumed, while natural gas contributed 19.7%. Electricity, which is generated from a combination of nuclear, fossil and renewable sources, made up 24.7% of final demand. Renewables, encompassing biomass, biogas, biofuels and ambient heat, represented just under 6% of the mix, while coal has become almost irrelevant, at just 0.1%.

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[1] *All the data in this section correspond to the following reference: "Resum de les principals dades del balanç energètic de Catalunya fins el 2022", Institut Català de l'Energia (ICAEN), March 2024.*

Despite the slow pace of change, **there are signs that the energy mix is evolving.** The share of fossil fuels in final energy consumption has declined from nearly 72% in 2010 to 68.6% in 2022, thanks to both reduced use of oil and gas and the gradual rise of renewables. Electricity's share has plateaued, reflecting reduced industrial and service sector demand. The electrification rate, i.e. the proportion of final energy met by electricity, stood at 24.7% in 2022.

Finally, **the contribution of renewables is gradually increasing, but remains modest.** Renewables covered 10.1% of gross final energy consumption in 2022, slightly below the 2020 peak of 10.7%, boosted by biomass for heating, biofuels in transport, and nearly 500 MW of solar PV self-consumption.

The sectoral breakdown of energy demand further illustrates the persistence of this traditional mix (**Fig. 2**). Transport dominates with 37.9% of final demand. Industry, which draws on both natural gas and electricity, accounted for 32.2% in 2022, a decline from previous decades due to efficiency gains and structural changes. The more electrified domestic and services sectors together make up about 28.5% of demand. The primary sector remains marginal.

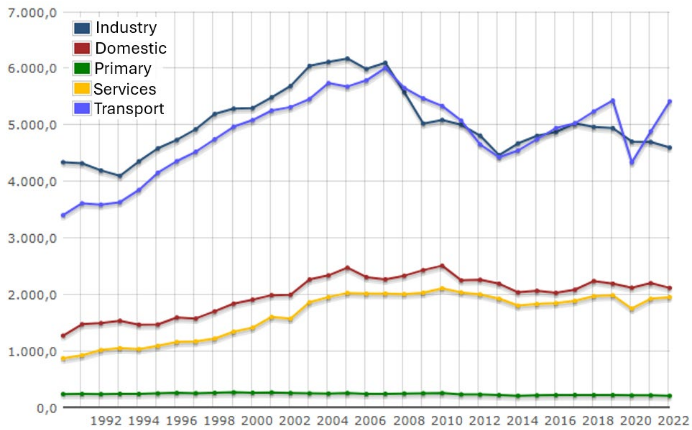

Figure 2. *Energy consumption sectoral breakdown (in ktoe), Catalonia 2022*

B. CURRENT ENERGY MIX AND KEY POLICY OBJECTIVES BY 2050

Catalonia's primary energy mix in 2025 remains heavily dependent on imported fossil fuels, although renewable energy is gaining ground. **Catalonia still imports ~93% of its energy**[1,2] (~65% excluding nuclear), with oil and petroleum products dominating the mix, followed by natural gas and a smaller share of nuclear energy from local plants. Renewables, while growing, still represent a modest portion of the total with hydro, wind, solar and biomass together accounting for just over 10% of gross final energy consumption.

[1] *All the data in this section correspond to the following reference: "Resum de les principals dades del balanç energètic de Catalunya fins el 2022", Institut Català de l'Energia (ICAEN), March 2024.*
[2] *In 2022, imports accounted for 93.3% of the total energy supply (65.9% considering nuclear energy a local source).*

Catalonia's electricity generation mix in 2024[1] **remains dominated by nuclear power**, which supplied around 59% of gross generation (22.2 TWh), mainly from the Ascó I-II and Vandellós II plants (see **Fig. 3a-3b**). Fossil-based technologies such as combined-cycle gas turbines (~13%) and cogeneration (~8%) still play a significant role, while **renewables contributed about 21.6%, which although still low is the highest share so far this century**. Within renewables, wind energy accounted for 7.6%, hydro rebounded to 9.6% thanks to improved rainfall and solar PV reached about 3%. Installed capacity at the end of 2024 was approximately 11.6 GW, with renewables representing roughly 33%. Solar PV continues to grow, driven by self-consumption with 126,752 installations registered, totaling 1,381 MW in 2023. Wind capacity remains at about 1.4 GW, while pumped hydro storage stands at 440 MW.

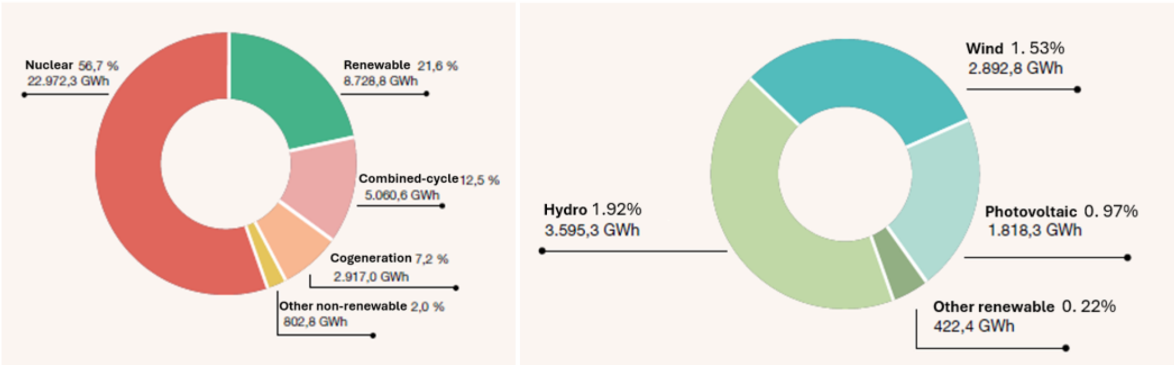

Figure 3. *Electricity production by technology, Catalonia 2024 [ref 68]*

Looking ahead, **Catalonia's energy policy is defined by the ambitious objectives set out in the PROENCAT 2050 roadmap**[2], framed by Law 16/2017 on *Climate Change* and the *Pacte Nacional per a la Transició Energètica*. The strategy prioritizes efficiency, decentralized renewables with strong focus on self-consumption and increased citizen and business participation. The central goal is to achieve a climate-neutral energy system by 2050, eliminating greenhouse gas emissions (GHG) from the energy sector (currently accounting for 73% of total) and phasing out fossil fuels and nuclear, with energy imports below 8%. By mid-century, the energy mix is projected to be almost entirely renewable with wind and solar photovoltaic forming the backbone of electricity generation.

The roadmap outlines a two-phase strategy. By 2030, the plan aims to reduce consumption by 30% relative to 2017, achieve 50% renewable electricity and 70% installed capacity, and deploy 2.2 GW of storage. By 2050, the plan is to achieve 100% renewable electricity, electrify 76–78% of final energy demand and cut energy-related GHG by 99%.

[1] *"Balanç elèctric de Catalunya 2024", Institut Català de l'Energia (ICAEN), June 2025.*
[2] *"Prospectiva Energètica de Catalunya 2050" (PROENCAT 2050), Institut Català de l'Energia (ICAEN), April 2023.*

C. TRANSFORMATIVE PATHWAYS TOWARDS DECARBONIZATION

According to PROENCAT 2050[1], **electrification will drive the transition,** rising the share of electricity in final energy consumption from 25% today to over 76% by 2050, thanks to the widespread adoption of electric vehicles, heat pumps and the electrification of industry. To support this transition, Catalonia will install a total capacity of 61.9 GW, composed of 33.2 GW of solar photovoltaic, 26.6 GW of wind and 7.2 GW of storage[2]. These efforts are designed to make electricity the core of the energy system, replacing fossil fuels in transport, heating and industry. **Renewable thermal energy and renewable fuels, such as green hydrogen and advanced biofuels, will play a strategic role in sectors where direct electrification is difficult**, including heavy industry and long-distance transport.

This transition will also require a major boost in **energy efficiency and a reduction in overall demand**, achieved through building retrofits, the deployment of electric mobility and the electrification of thermal industrial processes. Despite projected growth in GDP and population, total final energy consumption is expected to fall by more than 30% compared to 2017. Storage and grid modernization will be essential to manage the variability of renewables, with over 7 GW of storage capacity planned by 2050[3].

II. CONSEQUENCES OF TECHNOLOGICAL CHOICES

A. TECHNICAL AND OPERATIONAL CHALLENGES OF A DIVERSIFIED ENERGY MIX

Catalonia's pathway to a climate-neutral energy system by 2050 requires a **fundamental transformation of its electricity sector**. The current model, based on centralized and dispatchable generation, will be replaced by a highly electrified system dominated by variable renewable energy sources, with solar PV and wind representating more than 90% of installed capacity. At the same time, electricity demand is projected to more than double, reaching around 100 TWh by 2050 driven by the electrification of transport, heating and industry. This shift introduces multiple and interrelated technical and operational challenges.

The integration of intermittent resources is the main challenge. Daily and seasonal mismatches between generation and demand will require advanced forecasting, real-time balancing and flexible system operation. Flexibility solutions will be critical playing a central role. **Storage capacity** must grow from negligible levels today to about 7.2 GW by 2050.

[1] *"Prospectiva Energètica de Catalunya 2050" (PROENCAT 2050), Institut Català de l'Energia (ICAEN), April 2023.*
[2] Ibid.
[3] Ibid.

These technologies will address short-term imbalances, but seasonal storage remains unsolved, requiring optimized reservoir management and, eventually, green hydrogen (3-4 TWh) as a long-term solution. **Cross-border interconnections** with neighboring regions must also expand substantially, reaching around ~13GW by 2050[1] (a 53% increase) to enable energy exchanges reducing curtailment risks and ensuring security of supply. Without this reinforcement, seasonal balancing would require uneconomical overcapacity.

Rising electricity demand and network complexity will require a **major grid transformation** shifting from a unidirectional transmission network to a decentralized, bidirectional architecture integrating hundreds of thousands of distributed installations across Catalonia. PROENCAT estimates €13.3 billion in grid investment by 2050, including new circuits, transformers and substations. Smart grids, digitalization and automated controls will be essential to maintain stability in a low-inertia environment where conventional synchronous generation is phased out.

The transition also raises **market and regulatory challenges**. The current marginal pricing model, with often a single zone per country, is ill-suited to a system dominated by renewables with high fixed and near-zero marginal costs. Prices increasingly depend on ancillary services and congestion charges, set in fragmented and often opaque markets. As a result, long-term contracts and power purchase agreements (PPAs) are gaining importance, with limited transparency. At the same time, scaling distributed generation and demand response requires regulatory frameworks that empower consumers and energy communities.

B. INNOVATION AND CHANGES IN THE INTEGRATION OF NEW ENERGY SOURCES

Catalonia's energy transition must be viewed within the broader Iberian context. While Catalonia lags behind, Spain and Portugal have seen major growth in wind, solar, and hydro, gaining extensive experience in integrating variable renewables. As **Fig. 4** shows, Spain's share of wind and solar is comparable to Germany and above the EU average, whereas Catalonia has made only limited progress.

[1] *"Prospectiva Energètica de Catalunya 2050" (PROENCAT 2050), Institut Català de l'Energia (ICAEN), April 2023.*

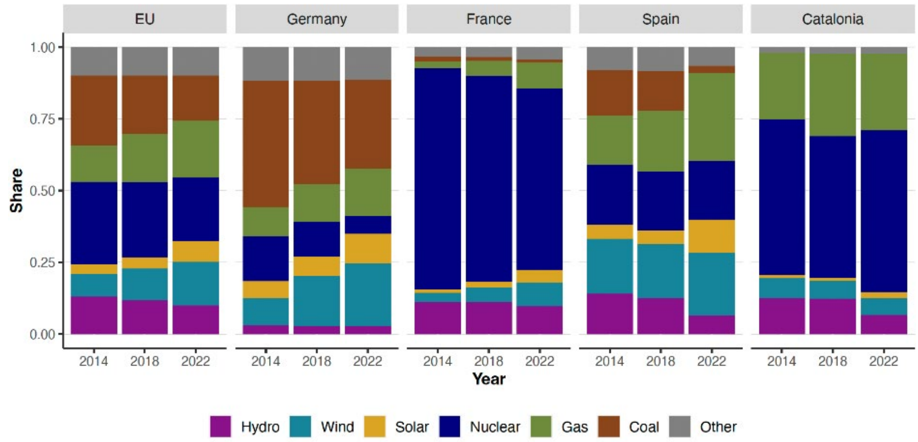

***Figure 4.** Evolution in Catalonia Energy Mix compared to nearby territories, 2014-2022*

Given the large increase in renewable intermittent sources, the Iberian market has made substantial adjustments to its operations in the last decade, such as increasing the frequency in trade in line with European market changes, better synchronizing the grid with the rest of the European network and gradually incorporating renewable resources into the provision of ancillary services. The blackout in April 2025 highlights **the need for further improvements in the regulatory framework**. There will also be an immense need for innovation at low voltage levels to deal with the integration of growing solar rooftop PV generation in homes and businesses.

On the demand side, Spain has been a leader in mandatory flexible pricing plans (e.g., with its pioneering implementation of default real-time pricing in 2016). However, its benefits in demand response have been limited[1]. When it comes to time-of-use pricing, both mandatory access charges and commercially available tariffs provide differentiated hourly prices that encourage time substitution. The evidence so far is that **these tariffs have been more successful at making households shift their consumption**[2], but there is a substantial mismatch between time-of-use prices and the cost of energy in the market, with often high residential prices during solar surplus. Therefore, demand programs have been unable to engage households at the appropriate level of granularity.

The next wave of regulation innovations that are currently being developed will bring a **second transformation to rules and regulations by facilitating the participation of batteries and flexible demand resources,** which, at the moment, has fallen behind compared to other Union members or other markets with a large presence of solar power (e.g., California and Australia). The absence of a clear regulatory framework for demand flexibility

[1] *"Estimating the Elasticity to Real-Time Pricing: Evidence from the Spanish Electricity Market," Natalia Fabra, David Rapson, Mar Reguant, and Jingyuan Wang, AEA Papers and Proceedings, May 2021.*

[2] *"Measuring the impact of time-of-use pricing on electricity consumption: Evidence from Spain," Jacint Enrich, Ruoyi Li, Alejandro Mizrahi, and Mar Reguant, Journal of Environmental Economics and Management, Jan 2024.*

has prevented local companies from developing commercial products, as the incentives are lacking. However, there should be substantial potential given the solar generation profiles (e.g., focused on industrial applications able to modulate their energy needs or domestic applications with EVs that utilize V2G capabilities).

C. NEW INFRASTRUCTURE NEEDS

The shift to a fully renewable electricity system by 2050 will profoundly **reshape Catalonia's energy infrastructure.** Installed capacity is expected to grow 5.5 times, from ~11 GW in 2017 to nearly 62 GW in 2050, dominated by wind and solar PV. This expansion will require **high-voltage transmission and distribution networks upgrades, with an estimated investment of €13.3 billion,** and the deployment of smart grids capable of managing bidirectional flows and integrating hundreds of thousands of distributed installations. **Interconnection capacity** with neighboring systems must also increase to 13.4 GW to manage seasonal variability and enhance security of supply.

Storage will be critical for system flexibility. By 2050, Catalonia plans to deploy **7.2 GW of storage capacity, split between 3.7 GW of pumped hydro and 3.5 GW of batteries**, to balance short-term variability and maintain reliability. In contrast, the role of natural gas will decline progressively. Conventional gas infrastructure will be gradually decommissioned, with potential alternative use in renewable gases such as biomethane and green hydrogen in industrial clusters and heavy transport. Alongside local hydrogen production for on-site consumption/storage, **a large-scale hydrogen pipeline such as the projected H2med**[1], could enable large-scale hydrogen trade, connecting the Iberian Peninsula's renewable potential to the rest of Europe through Catalonia.

D. INDUSTRIAL IMPACTS FROM THE ENERGY TRANSITION

The energy transition will **transform Catalonia's industrial landscape over the next 25 years** as the system shifts towards renewables, reducing import dependency and prioritizing local generation. Catalonia's strong solar resource and hybrid PV-plus-storage systems will provide competitive renewable power for domestic and industrial uses. Deep electrification will dominate, with electricity's share of industrial energy demand rising from 30% in 2017 to 78% by 2050. This requires redesigning processes, including use of high-efficiency heat pumps, electrified furnaces and green hydrogen for hard-to-abate sectors such as cement, steel and chemicals.

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[1] *On April 8 2024, H2med project was listed as a Project of Common Interest (PCI/PMI) in the Official Journal of the European Union (EU) 2024/1041.*

The transition will accelerate new industrial ecosystems in renewables, energy storage, hydrogen technologies and digital energy services, alongside an emerging sector for grid modernization and flexibility platforms. The automotive industry will undergo a profound transformation, driven by the shift to electric mobility, creating opportunities in battery manufacturing, power electronics and charging infrastructure, as well as in second-life applications for EV batteries, which will support storage markets and circular business models.

Circular economy and bioeconomy principles will reshape production, with petrochemical hubs (e.g., Tarragona) pivoting to biorefineries, while rural synergies will expand biogas and biomethane production from agricultural and organic waste. To mitigate critical material dependencies (copper, lithium, cobalt, rare earths), innovation in recycling, material efficiency and substitution will be essential.

Employment impacts will be net positive but uneven. Renewables and efficiency will create twice as many jobs per unit of investment as fossil and nuclear, many of them local, especially in building renovation and zero-emission construction. However, energy-intensive industries and the automotive sector will face major restructuring, requiring reskilling and digitalization. SMEs will need targeted support for financing and technology adoption.

A dedicated industrial strategy must ensure regulatory stability, infrastructure access and innovation support, while promoting electric mobility, decarbonization of heavy industry, storage technologies and digital energy markets.

III. SOCIAL ACCEPTABILITY OF THE ENERGY TRANSITION

A. CATALONIA: DIFFICULTIES IN ACCEPTABILITY

Compared to other jurisdictions, **Catalonia has faced substantial resistance to the energy transition**. Public debate has largely centered on the perceived impacts of renewable energy deployment, particularly the visual footprint of wind and solar installations and their competition with agricultural land use. Achieving 62 GW of renewable capacity by 2050 will require allocating an additional 2.5% of Catalonia's territory (around 80,000 ha) for ground-mounted solar and wind farms, raising complex challenges in land-use planning, biodiversity protection, and social acceptance. While priority will be given to rooftop PV and anthropized spaces, these options will only cover 16–25% of electricity demand, making large-scale installations unavoidable.

When examining survey data, the general responses from households are not too discouraging. According to recent 2025 Omnibus Barometer[1], two-thirds of households (66.6%) agree that accelerating renewable deployment is necessary to combat climate change, even if it alters the current landscape, while only 26% favor slowing down deployment to preserve the landscape. Furthermore, support for reserving land in each region for renewable projects is relatively high, with an average score of 6.7/10 for wind and 7.2/10 for solar on a 0–10 scale. This suggests a general predisposition toward renewables, especially solar, despite concerns about local impacts. However, in practice, many proposed **solar and wind projects face judicial challenges led by local organizations**. One potential interpretation is that, while general population is not vehemently opposed to renewable energy, a lack of strong public support leaves space for organized opposition groups to dominate the discourse. This gap between general approval and local resistance underscores the **need for participatory planning, transparent benefit-sharing mechanisms, and clear communication strategies to build trust** and ensure that the energy transition is perceived as both necessary and fair.

B. THE IMPACT OF THE 2022 ENERGY PRICE CRISIS

The energy crisis did not negatively impact the perception of the energy transition, although it made inequities regarding energy access much more salient. **In fact, given Catalonia's great solar potential, the energy crisis coincided with the rapid increase in rooftop solar PV installations in the territory**. Rooftop solar can be economically attractive in Catalonia, and the crisis provided another reason to invest in self-generation, due to the higher energy prices and the existing Next Generation subsidies at the time[2].

The adoption of rooftop solar by the most able households can be of concern, and local initiatives are trying to increase the access of vulnerable households to solar energy communities, even if these are being developed slowly and with excessive regulatory burden. These efforts are not faced with opposition, as they tend to be local rooftop installations, which have wide support in Catalonia.

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[1] *"Òmnibus de la Generalitat de Catalunya 2025-1", Centre d'Estudis d'Opinió (CEO), June 2025.*

[2] *"Situació de les energies renovables a Catalunya i propostes per descarbonitzar la forma de viure i producir a Catalunya", Departament de Territori, Habitatge i Transició Ecològica, Generalitat de Catalunya, September 2025.*

C. PUBLIC AND PARLIAMENTARY DEBATE: THE PERFECT AS THE ENEMY OF THE GOOD

In Catalonia, there is broad consensus that action against climate change is needed. Catalonia as one of the first in southern Europe to pass a comprehensive **Climate Change Law in 2017**, aligning with efforts in countries such as France, Sweden and the UK. The **Declaració d'Emergència Climàtica in 2019**[1] and other official statements have set ambitious targets and deadlines, and most citizens agree that decarbonization must advance. The Catalan government has also advanced in creating a **public energy company to supply renewable energy** to all its branches, which has grown steadily since its establishment in 2022. To lead by example, the Parliament of Catalonia has launched a temporary program aimed at decarbonizing its operations as much as possible by 2030 and incorporating a climate perspective into legislative activity and all institutional processes.

However, this consensus in legislation has been less strong when it comes to the private development of renewable energy. At the local level, **opposition to renewable energy projects, even to solar power, has been significant.** These reactions often reflect in NIMBY (*Not in My Back Yard*) dynamics driven by concerns about the impact on the landscape, competition with agricultural land, the perception of lack of local benefits or ultimately the way projects are managed. Issues of equity and environmental justice are central in the public debate, particularly regarding the rural land use for energy generation or concerns about the return of the investments to the local community versus large corporations.

To circumvent these bottlenecks in deployment, Catalonia is proposing legislation to define clear territorial priorities for renewables. Previous attempts, however, failed to gain parliamentary approval. These initiatives are now being revised**, with signs of improved coordination between regional authorities, rural stakeholders, and developers**. Encouragingly, rural leaders, farming groups, and renewable energy developers seem to be finding more common ground, which could help reconcile climate objectives with territorial concerns. While tensions remain high, there is cautious optimism that new agreements could make the transition faster and fairer thanks to participatory planning, benefit-sharing schemes, and transparent project management.

[1] *"Acord del Govern de declaració d'emergència climàtica", Secretaria del Govern, Departament de la Presidència, Generalitat de Catalunya, May 2019.*

DENMARK

Democracy X

I. ENERGY MIX AND THE CARBON NEUTRALITY OBJECTIVE (2050) – DENMARK

A. EVOLUTION OF ENERGY DEMAND IN RECENT YEARS

Denmark has experienced a notable transformation in its energy consumption and energy over the past decades, with the pace of change accelerating between 2010 and 2025. The country's total primary energy supply (TPES) decreased from approximately 814 petajoules (PJ) in 2010 to roughly 696 PJ in 2023. (1)

***Table 1**: Danish gross energy consumption by fuel with ten year intervals 1980 to 2023*

Gross energy consumption by fuel

Climate adjusted [PJ]	1980	1990	2000	2010	2023
Total gross energy consumption	**814**	**819**	**839**	**814**	**696**
Oil	546	355	376	312	255
Natural gas	0	82	192	176	62
Coal and coke	241	327	175	147	41
Waste, non-renewable	5	8	14	16	18
Renewable energy	22	48	81	163	319

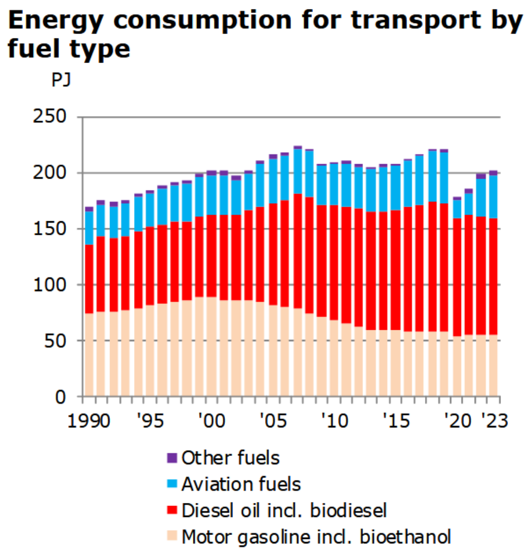
Denmark has no domestic coal resources and has therefore always been dependent on imported coal for electricity and heat production. For decades coal was an important energy source, especially after the oil crisis of the 1970s, when many power plants were converted from oil to coal to secure supply. With rising climate demands and green ambitions, however, phasing out coal became a central political goal. In 2017 the government announced that coal would be retired no later than 2030, and since then a number of major combined heat and power plants have gradually been converted to other fuels such as biomass and waste. Energy and supply crises have occasionally postponed planned closures, but coal consumption has nevertheless plummeted in recent years, and in 2025 Denmark was able to produce electricity and heat for several months without coal for the first time. Today only one large coal-fired plant remains in operation and Denmark is close to completely phasing out coal from its electricity and heat production. (1,2)

Natural gas consumption has also seen a sharp decline. From a peak of 5 billion cubic meters (bcm) in 2010, consumption fell steadily to 2.3 bcm in 2023 and is projected to dip below 2.0 bcm in 2025. The drop has been driven by the transition away from natural gas in heating systems, especially in households and industry, where electrification and biogas alternatives are increasingly prevalent. (2)

In electricity demand, the picture is more nuanced. While total consumption has risen slightly due to the electrification of heating (via heat pumps) and transport (notably electric vehicles), this growth has been offset by higher efficiency in household appliances and industry. Denmark's electricity grid is increasingly reliant on renewable energy, and demand-side management technologies are helping to optimise consumption and reduce peak loads. Industry demand has remained relatively stable, but with a clear trend toward decarbonisation through electrified processes and the use of waste heat recovery systems. (1)

In the transport sector, which remains the most oil-dependent, there has been some progress with the rollout of EVs and investments in public transport electrification. However, conventional fuels still dominate, and a significant structural shift is expected only in the latter part of the 2020s.

This decline occurred despite a modest rise in GDP, illustrating a growing decoupling of economic growth from energy consumption. Key drivers of this reduction include advances in energy efficiency for both industry and households. (1)



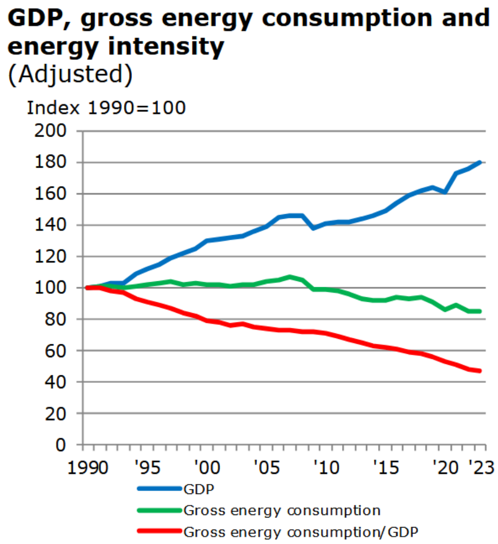


Figure 1: Illustration of the energy consumption by fuel type for transport in Denmark (1)

Figure 2: Illustration of the gradual decoupling of the Danish GDP growth and energy consumption (1)

B. CURRENT ENERGY MIX AND POLICY OBJECTIVES TOWARD 2050

As of 2023, Denmark's energy mix reflects both legacy dependencies and transitions. Fossil fuels still make up a significant share of the total energy supply (see table 2) oil accounts for approximately 35 to 37 percent, used primarily in transport; natural gas makes up about 8 percent, and coal is nearly eliminated, contributing with approx. 5 percent of energy due to the closure of major coal-fired power plants. (1) In contrast, renewables now constitute about 45 percent of Denmark's final energy consumption (2).

Within electricity generation, renewables dominate with an 80 percent share (2). Wind power leads the mix, contributing roughly 40 percent, while biomass (used mainly in combined heat and power plants) accounts for 30 percent. Solar energy has also expanded significantly, comprising 7 percent of electricity generation in 2024. Biogas contributes a smaller but growing share of approximately 3 percent (2).

Electricity production by fuel

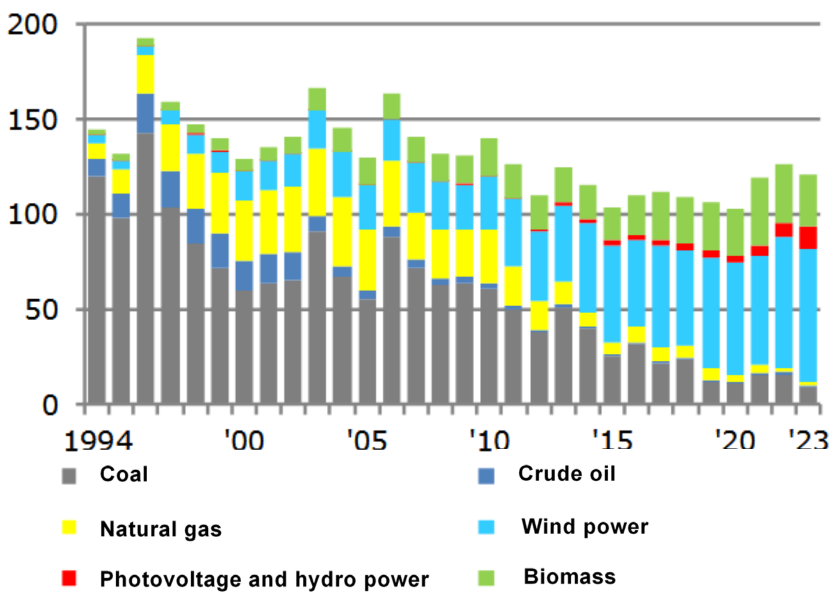


Figure 3*: Electricity production by fuel type (1)*

Although Denmark has no domestic nuclear energy production due to a national ban in place since 1985, about 3 to 4 percent of its electricity consumption is met through imports from nuclear-powered grids in Sweden and Germany.

Looking forward, Denmark's policy framework is anchored in the 2020 Climate Act, which mandates a 70 percent reduction in greenhouse gas emissions by 2030 relative to 1990 levels and full carbon neutrality by 2050 (3). The government's Energy Strategy 2050 outlines a complete transition to renewable energy across all sectors. By 2030, Denmark aims to achieve 100 percent renewable electricity, complemented by a 50 percent renewable share in heating, largely via heat pumps, electric boilers, and biomass-based district heating (4).

The strategy also includes the total replacement of fossil natural gas with green gases like biomethane by 2030 and the expansion of offshore wind capacity to between 9 and 14 gigawatts (GW). Additionally, the nation targets 9 GW of installed solar PV capacity by 2030, up from approximately 3.5 GW in 2023 (1)(2).

While nuclear energy remains officially excluded from the Danish energy system, in May 2025, the government initiated a 12-month feasibility study on lifting the nuclear ban, specifically exploring the potential of small modular reactors (SMRs) as a carbon-free baseload option to support a high-renewables grid.

C. TRANSFORMATION PATHWAYS UNDER DISCUSSION AND IMPLEMENTATION

Denmark's transformation toward a carbon-neutral energy system by 2050 is underpinned by a variety of pathways and integrated strategies. Central to this vision is the expansion of offshore wind capacity and the development of energy islands. The most ambitious of these projects involves the construction of two energy hubs, one in the North Sea and another on the island of Bornholm. These hubs will initially host 3 GW of offshore wind each, with the North Sea facility scalable to 10 GW. These islands are designed to serve as major power export stations and conversion centers for hydrogen and other green fuels, significantly contributing to the EU's broader decarbonisation objectives. (5)

Another transformative element is the electrification of heat. Denmark is rapidly shifting away from individual fossil-fuel-based heating systems toward electrified district heating networks. Technologies such as electric heat pumps and large-scale electric boilers are being deployed to decarbonise residential and industrial heat. This strategy not only reduces emissions but also provides grid flexibility by enabling the absorption of surplus wind and solar power during periods of low demand (6)(2).

Power-to-X technologies are under development to support sector coupling and long-term storage. These involve converting excess renewable electricity into hydrogen, synthetic methane, or e-fuels for use in transport, industry, and heating. Several large-scale Power-to-X facilities are under development, particularly in western Denmark near Esbjerg, which will serve as both production and export centers. However, the future of Power-to-X remains uncertain, as recently several large investments and projects have been paused or cancelled. (7)

Finally, Denmark is strengthening its electricity grid and expanding interconnections with neighbouring countries to ensure reliability in a highly renewable system. This includes investments in battery storage, demand-side response systems, and cross-border interconnectors with Germany, Norway, and the UK. (5)

II. SOCIAL ACCEPTABILITY OF THE ENERGY TRANSITION

A. PUBLIC ACCEPTANCE OF THE ENERGY TRANSITION

The public understanding of the need for the energy transition is generally high as is the acceptance of- and support for it. However, the closer renewable energy installations come to people's homes, the smaller the acceptance. Landscape visuals, noise, and lack of local compensations are typical causes of local resistance. The most dominant, however, is the lack of public engagement. Locals are often upset about being steamrolled by planners and developers and only being consulted after decisions have been made. Residents in scarcely populated areas, where wind and solar installations are often placed, criticize the fact that they must bear the burden of energy need in bigger cities (Copenhagen in particular) and live with installations that others are profiting from. And they find it unfair and unreasonable that raising such issues is discarded as NIMBYism. A new law in passing will allow for bigger compensations for residents affected by the installation of renewables but fails to acknowledge the need for early engagement, even reducing the opportunities for complaining and time allocate to the obligatory hearing process. Attempts by town halls to include early public engagement in public tenders have been challenged in court.

B. THE INFLUENCE OF THE ENERGY PRICE CRISIS OF 2022 ON PERCEPTIONS OF ENERGY POLICIES AND CLIMATE COMMITMENTS

Especially homes unconnected to central heating suffered periodic spikes in energy prices, having relied on gas and wood pellets for heating their houses. This, kickstarted the expansion of the Danish central heating system and private installations of electrical heat pumps, but recently this expansion rate has slowed as prices for gas and wood pellets have decreased.

C. SPECIFIC TECHNOLOGIES THAT RAISE SIGNIFICANT CONTROVERSY OR PUBLIC RESISTANCE

Especially wind and solar causes local resistance. So much so that that their implementation on land has almost completely stopped. Denmark does not have nuclear power but in recent years it has been debated whether it could be introduced to the Danish energy mix. In parallel, attempts to find permanent storage for nuclear waste from a no longer active test reactor have failed several times due to public resistance at locations identified as potential storage sites. Also, the exploration of sites for carbon storage have met considerable local resistance.

D. PUBLIC AND PARLIAMENTARY DEBATE REGARDING THE REALISM, COST, OR SOCIAL EQUITY OF THE ENERGY TRANSITION

The two most heated, public debates are around installation of solar panels and the price of meat. Local elections are due on November 18, 2025, and some politicians have thundered against “iron fields”, making this a prominent election topic in some municipalities. The question of meat prices has been triggered by public debate about the need for the agricultural sector to deliver greenhouse gas reductions. Reduction of meat production has been identified as one of best ways of achieving that, but many politicians have referring to social equity as an argument for keeping meat prices low enough for all citizens to be able to eat pasta with meat sauce. Another, often debated issue, is a statement from 2023 from the current Minister for Climate, Energy and Utilities that Danish climate policies should have support from 80% of the population. It has been debated since, whether such a level of support is necessary and/or realistic.

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EUROPEAN UNION

Panel for the Future of Science and Technology (STOA) for the European Parliament

PRELIMINARY NOTE ON STOA CONTRIBUTION

While the EPTA template is designed for national contributions describing country-specific developments, STOA contribution provides an overview of EU-wide energy policies, stats, trends, and recent positions. It is important to note that the EU sets the overarching energy policy goals, such as promoting clean energy and security but it is up to the Member States to decide the specific sources in their energy mix, as enshrined in Article 194 of the Treaty on the Functioning of the European Union (TFEU).

INTRODUCTION

The European Union is progressing towards its 2050 carbon neutrality objectives, with current projections indicating a 54% reduction in net greenhouse gas emissions by 2030, approaching the 55% target. This assessment, based on the European Commission's May 2025 evaluation of updated National Energy and Climate Plans (NECPs), demonstrates that EU energy policy framework established since 2020 is delivering measurable transformation of the energy system.

The last few years have been characterised by unprecedented acceleration in renewable energy deployment, shifts in energy demand patterns and strategic responses to geopolitical energy security challenges following Russia's invasion of Ukraine. However, significant technical, operational and financing challenges remain as the EU approaches the energy and climate 2030 milestone and 2050 net-zero goal.

I. ENERGY MIX AND THE CARBON NEUTRALITY OBJECTIVE (2050)

A. HOW HAS THE STRUCTURE OF ENERGY DEMAND EVOLVED IN THE EU IN RECENT YEARS?

According to Eurostat, between 2020 and 2023, the EU's primary energy consumption fell to 1,211 Mtoe in 2023, representing a 3.9% decrease compared to 2022 and the lowest level since 2005. Similarly, final energy consumption decreased to 894 Mtoe in 2023 (−3.0% compared with 2022), reaching also the lowest level since 2005, except for 2020 which was impacted by the COVID-19 pandemic.

The sectoral breakdown of final energy consumption in 2023 was the following:

• Transport: 32% of final energy consumption (rail, road, domestic aviation, and inland shipping)

• Households: 26% consumed by private households in citizens' dwellings

• Industry: 25% of total final energy consumption

• Commercial and public services: 14%

• Agriculture, forestry and fishing: 3%

The final energy consumption by source in 2023 was the following:

• Petroleum products: 37% (heating oil, petrol, diesel fuel)

• Electricity: 23%

• Natural and manufactured gas: 20%

• Direct use of renewables: 13% (wood, solar thermal, geothermal, biogas)

• Derived heat: 5% (district heating)

• Solid fuels: 2% (mostly coal)

Note that within the EU countries, the final energy consumption pattern varies considerably.

B. WHAT IS THE CURRENT COMPOSITION OF THE EU ENERGY MIX, AND WHAT ARE THE KEY POLICY OBJECTIVES OR PROJECTIONS BY 2050 (E.G. SHARE OF FOSSIL FUELS, NUCLEAR, RENEWABLES)?

The EU's overall energy mix (the supply of energy for all activities - gross available energy) consisted of five main sources:

• Crude oil and petroleum products: 37.7%

• Natural gas: 20.4%

• Renewables: 19.5%

• Nuclear: 11.8%

• Solid fuels: 10.6%

Regarding energy independence, in 2023, the EU produced 42% of its own energy and imported 58%. In terms of domestic EU energy production, renewables accounted for 46% of total EU energy production, making it the largest contributing source in 2023. Nuclear energy represented 29%, solid fuels 17%, natural gas 5%, and crude oil 3%.

Due to EU sanctions following the Russian invasion of Ukraine, Russian energy imports fell dramatically from 2022 to 2023: oil and petroleum products from 21% to 4%, natural gas from 23% to 11%, and solid fossil fuels from 23% to 1%.

The 2050 projections considering the current policy frameworks and targets are the following:

• Decarbonisation: 55% emission reduction by 2030 and net-zero emissions by 2050 (In 2022 emission levels were 31% lower than in the reference year 1990).

• Renewable energy: 42.5% of gross final energy consumption by 2030 (The share of renewables in gross final energy consumption in the EU was 24.6% in 2023).

• Primary energy consumption: Maximum 1,128 Mtoe by 2030 (In 2023 was 7.3% away from target).

• Final energy consumption: Maximum 846 Mtoe by 2030 (In 2023 was 5.7% away from target).

• Electrification of final energy consumption: 35% by 2030 and 61% by 2050 (was 23% in 2023).

C. WHAT TRANSFORMATION PATHWAYS ARE CURRENTLY UNDER DISCUSSION AT EU LEVEL OR IMPLEMENTATION TO ACHIEVE DECARBONISATION GOALS?

Renewable energy and electricity of heating, transport and industry are key pillars not only to achieve decarbonisation but also to improve energy independence, and competitive energy prices. The key pieces of the EU energy and climate legislative framework are:

• Fit for 55 Package: The comprehensive Fit for 55 legislative package adopted between 2021-2023, establishes the regulatory foundation for the 55% emission reduction target. All proposals except the Energy Taxation Directive have been adopted, creating an interconnected framework linking emissions trading, renewable energy deployment, energy efficiency, and carbon border adjustments.

• EU Climate Law, setting a 2040 EU climate target of 90% reduction in net greenhouse gas (GHG) emissions, and decarbonised European economy by 2050.

• REPowerEU, launched in May 2022, REPowerEU has evolved beyond crisis management to become a structural acceleration mechanism for the energy transition. The plan aims to eliminate Russian fossil fuel dependency before 2030 through supply diversification and accelerated clean energy deployment.

• The Clean Industrial Deal, presented in February 2025, aims to mobilise over €100 billion through boosting EU-level funding, leveraging private investments and enhancing State-aid. The Clean Industrial Deal focuses on energy-intensive industries and clean technologies, addressing high energy prices and intense global competition.

• The upcoming initiatives, in preparation by the Commission, that will continue to shape the energy transition are the EU Electrification Action Plan, the EU Heating and Cooling Strategy, the Strategic Roadmap for digitalisation and AI in the energy sector and the EU grids package.

D. HAS YOUR ORGANISATION CONDUCTED ANY RECENT ASSESSMENT OF THESE EVOLUTIONS (E.G. SCENARIO MODELLING, SYSTEM-LEVEL IMPACT STUDIES)? IF SO, COULD YOU BRIEFLY DESCRIBE THE FINDINGS?

The European Parliament Committee on Energy, Research and Industry (ITRE) recent own initiative reports show that while the EU has made significant progress in renewable deployment and energy efficiency, gaps remain in achieving 2030 targets.

The European Parliament's own-initiative report on "Electricity grids: the backbone of the EU energy system" (TA-10-2025-0136), highlights several important findings:

• The EU needs to invest €375-425 billion in distribution grids and overall, €584 billion in transmission and distribution electricity grids by 2030, as electricity consumption is expected to increase in coming years.

• There are grid performance issues to be addressed, as costs of managing transmission electricity grid congestion were €4.2 billion and nearly 30 TWh of renewable electricity were curtailed in 2023 due to insufficient grid capacity.

• The cross-border integration benefits from completing the EU energy market integration could result in €40 billion savings annually.

• Shortcomings in current Ten-Year Network Development Plan (TYNDP) for European electricity infrastructure result in investment falling short of cross-border interconnection needs.

• Grid-enhancing technologies can significantly increase efficiency of existing capacities and there is the need for accelerated digitalisation and smart grid deployment.

• Energy workforce must grow by 50% by 2030 to support renewable deployment and grid expansion.

• There is the need to revise TEN-E Regulation to improve planning processes, anticipate investment provisions under Electricity Market Design Regulation and streamline permitting procedures and public acceptance measures.

The European Parliament's own-initiative report on "Security of energy supply in the EU" (TA-10-2025-0146), main recommendations are:

• Calls for complete ban on Russian energy imports by 2027, including LNG and nuclear fuels.

• Emphasises need for revised EU energy security strategy reflecting geopolitical changes.

• Advocates for greater solidarity mechanisms and coordinated approach among Member States.

• Stresses importance of technological neutrality and diverse clean technology portfolio.

This report also includes considerations on nuclear energy:

• EU nuclear production declined 24% since 2014

• Several Member States committed to expanding nuclear as pillar of energy strategies

• Need to assess full lifecycle costs including construction, operation, waste management, and decommissioning

II. CONSEQUENCES OF TECHNOLOGICAL CHOICES

A. WHAT ARE THE MAIN TECHNICAL OR OPERATIONAL CHALLENGES ASSOCIATED WITH MANAGING A MORE DIVERSIFIED ENERGY MIX IN THE EU?

A more diversified EU energy mix has system-wide implications that reshapes how electricity networks operate and are managed. From the EU perspective, the main technical and operational challenges seem to be the following:

• Renewable integration: The transition to renewable-dominated electricity generation creates new operational complexities, not only in the grid management but also in the functioning of the electricity markets.

• Grid modernisation and infrastructure: over 40% of the EU's distribution grids are over 40 years old and require urgent updating to accommodate the demands of a decarbonised energy system. There is an important investment gap to be addressed.

• System adequacy and reliability: The EU needs over 100 GW of new clean firm power capacity by 2035 to ensure grid reliability and for managing the technical challenges of integrating variable renewable sources.

• Cross-border integration: The lack of full integration of the European electricity market continues to limit efficiency gains. Current interconnection levels fall short of optimising renewable resources across different climatic and geographical conditions, e.g. the limited electricity interconnection between Spain and France.

B. WHAT MEASURES ARE BEING IMPLEMENTED OR CONSIDERED TO ENHANCE DEMAND-SIDE FLEXIBILITY (E.G. TIME-OF-USE TARIFFS, DEMAND RESPONSE)?

Measures to enhance demand side flexibility are being considered in a broad context of ongoing and future policy initiatives, such as the upcoming EU grids package (expected in late 2025). The EU electricity system requires much more flexibility resources by 2030 to manage the increasing share of variable renewable generation. However, current deployment of demand-side flexibility seems slow:

• Smart meter deployment and market access: Despite the EU mandate, smart meter rollout remains incomplete across member states, limiting consumer ability to respond to price signals and participate in flexibility markets. A 2024 report reveals that most EU countries have yet to introduce legislative changes enabling demand to actively bid into wholesale markets, severely restricting explicit trading of flexible demand.

• Industrial demand response potential: While industrial demand response could represent 3% of EU peak demand by 2030, significant barriers persist. Energy-intensive industries, particularly aluminium and steel, possess substantial flexibility potential but face regulatory constraints and insufficient market incentives. Dynamic electricity tariffs show promise but encounter hurdles in implementation across Member States.

• Energy storage integration: According to industry, battery storage deployment must increase significantly in the coming years to support the increasing share of intermittent renewables in the grid.

• Regulatory framework development: Member states should deploy frameworks encouraging transparent, non-discriminatory and market-based procedures for flexibility services. However, progress remains uneven. The EU Commission mandated the development of network codes on demand response through coordination between the EU DSO Entity and ENTSO-E.

C. HOW IS THE EVOLUTION OF THE ENERGY MIX AFFECTING ELECTRICITY AND GAS INFRASTRUCTURE (E.G. GRID CAPACITY, RELIABILITY, CROSS-BORDER FLOWS)?

The evolution towards a renewable-based energy mix is fundamentally altering both electricity and gas infrastructure requirements, with implications on system design and operation.

• Transmission network adaptation: The shift from centralised fossil fuel generation to distributed renewable sources requires bidirectional power flows and advanced grid management capabilities. Current transmission systems, designed for 20th-century centralised generation, need comprehensive modernisation to handle variable renewable output and cross-border electricity trading.

• Distribution grid transformation: Distribution systems face strain as they accommodate increasing distributed generation, electric vehicle charging, and heat pump deployment. The integration of these technologies requires enhanced demand management and grid balancing capabilities that existing infrastructure often lacks.

• Gas infrastructure repurposing: The transition away from natural gas – which represented 20.4% of the EU energy mix in 2023 – creates both challenges and opportunities for existing gas infrastructure and the use of biomethane and hydrogen. The EU hydrogen strategy recognises potential for pipeline repurposing, though technical and regulatory complexities persist. Member states are developing strategies to balance gas phase-out timelines with industrial needs and heating transitions.

• Cross-border capacity constraints: Despite requirements under Regulation (EU) 2018/1999 for 15% interconnection capacity by 2030, several member states lag behind targets. The completion of Baltic states' integration into the continental European network in February 2025 demonstrated both the security benefits and technical complexities of cross-border integration.

D. WHAT ARE THE ANTICIPATED IMPACTS ON INDUSTRIAL VALUE CHAINS (E.G. MANUFACTURING CAPACITY, LOCALISATION, STRATEGIC DEPENDENCIES)?

There are structural changes across industrial value chains, with implications extending far beyond energy to encompass manufacturing competitiveness, supply chain security, and strategic autonomy. These changes became more visible with COVID supply chain disruption, the 2022 energy price crisis, and EU's energy and materials import and strategic dependencies, with key impacts being:

• Energy cost: European energy-intensive industries face competitive pressure due to energy costs. In 2024, industrial electricity prices in the EU reached €0.199 per kWh compared to €0.184 in Japan, €0.082 in China and €0.075 in the US. Prices in Europe are structurally higher due in large part to the marginal pricing model, which sets electricity prices at the level of the most expensive marginal producer, which is often natural gas power plants.

• Industrial relocation pressures: The combination of high energy costs and stringent environmental regulations creates incentives for industrial relocation to regions with lower energy costs and less ambitious climate policies. Energy-intensive industries, responsible for 22% of EU GHG emissions, face pressure to relocate production outside the Union.

• Raw materials and critical dependencies: The transition intensifies demand for critical raw materials, with aluminium and copper demand set to rise by 33% and 35% respectively by 2050. Current recycling capacity meets only 40-55% of Europe's aluminium and copper needs.

• Manufacturing capacity: The Net-Zero Industry Act mandates 40% EU manufacturing share for net-zero technologies by 2030, yet current production capabilities remain insufficient.

• Workforce and skills transformation: The energy transition requires substantial workforce expansion and reskilling. The energy sector workforce must grow by 50% by 2030 to support renewable deployment and grid expansion, with an estimated 2 million additional jobs required in electricity distribution by 2050.

The EU has responded with the Clean Industrial Deal, proposing over €100 billion in funding for EU-made clean manufacturing. The new Clean Industrial Deal State Aid Framework aims to accelerate approval of support measures whilst allowing member states to reduce electricity costs for energy-intensive users in return for decarbonisation investments.

III. SOCIAL ACCEPTABILITY OF THE ENERGY TRANSITION

A. HOW WOULD YOU CHARACTERISE THE LEVEL OF PUBLIC ACCEPTANCE OF THE ENERGY TRANSITION IN THE EU?

Public support for the EU's energy transition is in general strong, but there are growing concerns about distributional impacts. The Eurobarometer publishes frequent polls related to energy and climate. Over the last couple of years these polls show consistent support for climate change (85% of Europeans consider it a serious problem), even higher support (88%) for renewable energy action and strong preference for EU coordination on energy (77%). However, recent trends emerge like for example energy affordability concerns (2023) and asking to prioritise reducing energy costs (2024).

B. TO WHAT EXTENT HAS THE ENERGY PRICE CRISIS OF 2022 INFLUENCED PERCEPTIONS OF ENERGY POLICIES AND CLIMATE COMMITMENTS?

The energy price crisis of 2022 strengthened public support for renewable deployment and security of supply, so in fact the war in Ukraine reinforced rather than weakened the backing for the energy. Over 60% of Europeans have reduced energy consumption due to the 2022 crisis, adopting measures such as lowering heating temperatures, more conscious appliance use, and environmentally friendly mobility options.

C. ARE THERE SPECIFIC TECHNOLOGIES (E.G. WIND POWER, NUCLEAR ENERGY) THAT RAISE SIGNIFICANT CONTROVERSY OR PUBLIC RESISTANCE?

Despite general transition support, specific energy technologies continue to generate local and national controversies that threaten deployment schedules and political consensus. Wind energy sometimes faces local opposition, as well as the construction of new transmission lines. Nuclear energy continues to be a devise topic in the EU, however recent polls show increasing support in countries with operational nuclear power plants.

D. IS THERE AN ONGOING PUBLIC OR PARLIAMENTARY DEBATE REGARDING THE REALISM, COST, OR SOCIAL EQUITY OF THE ENERGY TRANSITION?

The ITRE Committee regularly addresses energy affordability, sovereignty, and efficiency through public hearings and legislative scrutiny. Parliamentary resolutions emphasise transparent decision-making processes and citizen participation as essential for maintaining public support throughout the transition, as clearly illustrated by the two recent own initiative reports listed above, and in particular the Electricity grids: the backbone of the EU energy system (TA-10-2025-0136),

The EUFORES Inter-Parliamentary Meeting 2025 brought together over 100 parliamentarians from EU27 national parliaments and the European Parliament to discuss renewable energy prospects under the Clean Industrial Deal framework. These gatherings attempt to maintain cross-party momentum for transition policies whilst addressing competitiveness concerns through industrial policy integration.

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FRANCE

Office parlementaire d'évaluation des choix scientifiques et technologiques (OPECST)

I. ENERGY MIX AND THE CARBON NEUTRALITY OBJECTIVE (2050)

A. HOW HAS THE STRUCTURE OF ENERGY DEMAND EVOLVED IN YOUR COUNTRY IN RECENT YEARS?

Between 2012 and 2024, final energy consumption in France fell by around 8.5%, from 1,613 TWh to approximately 1,498 TWh, continuing the long-term downward trend despite an economic recovery after COVID-19. The sharp decline observed in 2020 during the pandemic has been followed by a structural moderation of demand linked to energy efficiency policies, technological change, and, crucially, the energy price crisis of 2022–2023, which reinforced demand restraint through behavioral changes and demand moderation measures. Weather-corrected data indicate a notable decline in gas and oil demand, particularly in housing, service sector, buildings and industry, due to high prices and conservation campaigns.

In sectoral terms, the residential – tertiary sector is the largest final energy consumer, accounting for just over 40% of the total final energy consumption in recent years. Transport follows, representing roughly one-third of the final demand, while industry accounts for around one-fifth. Over the past decade, in absolute terms, transport demand has stabilized, whereas residential – tertiary demand has gradually declined, driven by improved building insulation, energy efficiency gains, and milder winters. Industrial demand, by contrast, has been more sensitive to economic cycles and experienced a noticeable contraction in 2022–2023 due to elevated energy prices[1].

From an energy carrier perspective, oil remains the largest contributor, but its share has fallen to around 42% in 2024, continuing its gradual decline. Electricity's share has risen steadily to around 27%, supported by the expansion of electric mobility, heat pumps, and digitalization. However, in absolute terms, electricity consumption has also decreased compared to earlier peaks, with weather-corrected consumption reaching 449.2 TWh in 2024, down from the mid-2010s levels[2]. Gas consumption has decreased significantly since 2021, especially in residential and tertiary uses.

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[1] *Ministère de la transition énergétique,* Bilan énergétique provisoire 2024 (SDES), *April 2025.* https://www.statistiques.developpement-durable.gouv.fr/bilan-energetique-de-la-france-en-2024-donnees-provisoires

[2] *RTE, Bilan électrique 2024 – Synthèse.* https://analysesetdonnees.rte-france.com/bilan-electrique-2024/synthese

B. WHAT IS THE CURRENT COMPOSITION OF THE ENERGY MIX, AND WHAT ARE THE KEY POLICY OBJECTIVES OR PROJECTIONS BY 2050 (E.G. SHARE OF FOSSIL FUELS, NUCLEAR, RENEWABLES)?

1. Current Composition of Energy & Electricity Mix

In 2024, France's primary energy production reached 1,564 TWh, up by 9.9% compared to 2023, largely reflecting the recovery of nuclear output. The structure of domestic production remains highly concentrated, with nuclear energy accounting for approximately 74% of total primary output. Renewable energies represented about 26%, including hydropower (5%), biomass and waste (17%), and wind and solar combined (4%). Primary fossil energy production is marginal (10 TWh), consisting mainly of crude oil extracted from the Aquitaine and Paris basins. This very limited domestic output underscores France's structural dependence on hydrocarbon imports[1].

From the perspective of electricity production, France's electricity generation in 2024 continues to be overwhelmingly low-carbon. According to RTE's "Electricity Global Assessment 2024" ("*Bilan électrique 2024*"), nuclear plants accounted for ~ 67% of production, with hydro at ~ 13.9%, and other renewables (wind, solar) contributing further shares. Fossil sources play only a marginal role in power generation[2].

2. Key Policy Objectives & Projections by 2050

France's energy and climate strategy aims for carbon neutrality by 2050, as legislated in the 2019 Energy and Climate Law. The strategy is structured through instruments such as the National Low-Carbon Strategy (*Stratégie nationale bas carbone*, SNBC) and the Multiannual Energy Programming (*Programmation pluriannuelle de l'énergie*, PPE), both of which are currently being updated to reflect new policy priorities and evolving decarbonisation pathways.

While the exact shares by 2050 remain to be crystallized through ongoing planning, several structural trajectories are emphasized:

- maintain significant nuclear power in the future mix, complementing renewables, to provide baseload, stability, and system inertia. The French Alternative Energies and Atomic Energy Commission (*Commissariat à l'énergie atomique et aux énergies alternatives*, CEA) points out that a future low-carbon mix requires a combination of nuclear and renewable energy technologies;

[1] *Ministère de la Transition énergétique,* op. cit.
[2] *RTE,* op. cit.

- dramatically expand renewable capacity, especially wind and solar, to meet growing electricity demand and replace residual fossil consumption in other sectors;
- reduce the share of fossil fuels in final energy (transport, heating, industry) via electrification, efficiency, and substitution (e.g. green hydrogen);
- in long-term scenario work (e.g. RTE's Energy Pathways to 2050), decarbonised supply and greater flexibility (storage, demand response) are essential to manage high shares of variable renewables.

C. WHAT TRANSFORMATION PATHWAYS ARE CURRENTLY UNDER DISCUSSION OR IMPLEMENTATION TO ACHIEVE DECARBONISATION GOALS?

France has committed to achieving carbon neutrality by 2050, in line with the Energy and Climate Law (2019)[1] and the French Energy and Climate Strategy (*Stratégie française pour l'énergie et le climat*)[2]. To meet these objectives, several transformation pathways are being implemented, combining supply-side decarbonization, demand reduction, and systemic change.

The expansion of low-carbon electricity supply to enable large-scale electrification of end-uses is a central pillar. The government plans to build six new EPR2 nuclear reactors, with an option for eight more, starting in the early 2030s. In parallel, ambitious targets for renewable energy expansion have been set. The installed capacity of solar photovoltaics is expected to increase from around 20 GW in 2023 to between 45 and 65 GW by 2035, with a trajectory aiming at around 100 GW by 2050. For offshore wind, the government has set the objective of reaching 18 GW in operation by 2035 and around 40 GW by 2050, supported by successive tenders and accelerated permitting procedures. Onshore wind deployment is also expected to accelerate, with an indicative target range of 40–45 GW by 2035[3].

Pathways on the demand side focus on energy sufficiency and electrification of end-uses, especially for transport (electric vehicles rollout, modal shift), buildings (heat pumps, renovation), and industry. The National Low-Carbon Strategy (*Stratégie nationale bas carbone*, SNBC) provides roadmaps for emissions reductions in each sector. Energy efficiency measures and behavioral changes are expected to play a decisive role, particularly in reducing fossil fuel consumption[4].

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[1] *Loi n° 2019-1147 du 8 novembre 2019 relative à l'énergie et au climat. https://www.legifrance.gouv.fr/dossierlegislatif/JORFDOLE000038430994/*

[2] *L'élaboration de la Stratégie française pour l'énergie et le climat. https://concertation-strategie-energie-climat.gouv.fr/lelaboration-de-la-strategie-francaise-pour-lenergie-et-le-climat*

[3] *Les grands enjeux de la PPE 3. https://concertation-strategie-energie-climat.gouv.fr/les-grands-enjeux-de-la-ppe-3*

[4] *Les grands enjeux de la SNBC 3. https://concertation-strategie-energie-climat.gouv.fr/les-grands-enjeux-de-la-ppe-3*

Infrastructure transformation is another priority. RTE, the French transmission system operator, and Enedis, the main distribution system operator, are leading large-scale investments to modernize the grid and integrate growing volumes of low-carbon electricity.

Finally, industrial decarbonization and strategic autonomy are key crosscutting themes. The France 2030 investment plan allocates €54 billion to scaling low-carbon technologies, hydrogen, batteries, and clean mobility[1].

D. HAS YOUR ORGANISATION CONDUCTED ANY RECENT ASSESSMENT OF THESE EVOLUTIONS (E.G. SCENARIO MODELLING, SYSTEM-LEVEL IMPACT STUDIES)? IF SO, COULD YOU BRIEFLY DESCRIBE THE FINDINGS?

In recent years, OPECST has produced several reports and briefing notes addressing energy transition issues.

One of the most recent assessments is the briefing note titled "Adapting Electricity Grids – Technological and Scientific Challenges" ("*Adaptation des réseaux électriques – enjeux technologiques et scientifiques*")[2]. This document examines how France's power grid must evolve to absorb greater shares of variable renewables. It emphasizes the challenges of grid stability, congestion, the need for demand response, and the role of storage and digital control systems.

In September 2023, OPECST published another briefing titled "A Comparison of Energy Storage Methods" ("*Comparer les modes de stockage de l'énergie*")[3]. This update refreshed a 2019 baseline analysis, factoring in evolving battery technologies, potential for hydrogen storage, and interlinkages with renewable output growth. It highlights that storage is becoming progressively central, but that cost trajectories, lifetime, and integration strategies remain critical uncertainties.

Another relevant work is the report on a public hearing titled "The Development of Innovative Nuclear Reactors in France" ("*Le développement des réacteurs nucléaires innovants en France*")[4], where OPECST gathered expert testimony on next-generation nuclear technologies (small and advanced modular reactors) and innovations in pressurized water reactors. The resulting report discusses technical challenges, safety, waste, and industry readiness.

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[1] *Understanding France 2030.* *https://www.info.gouv.fr/grand-dossier/france-2030-en/understanding-france-2030*

[2] *Adaptation des réseaux électriques : enjeux technologiques et scientifiques.* *https://www.senat.fr/rap/r24-707/r24-707.html*

[3] *Comparer les modes de stockage de l'énergie.* *https://www.senat.fr/rap/r22-932/r22-932.html*

[4] *Le développement des réacteurs nucléaires innovants en France.* *https://www.senat.fr/rap/r23-217/r23-217.html*

II. CONSEQUENCES OF TECHNOLOGICAL CHOICES

A. WHAT ARE THE MAIN TECHNICAL OR OPERATIONAL CHALLENGES ASSOCIATED WITH MANAGING A MORE DIVERSIFIED ENERGY MIX IN YOUR COUNTRY?

France's energy mix is becoming structurally more diversified. It combines a historically dominant nuclear fleet with substantial hydropower resources and rapidly growing shares of renewables (especially wind and solar), while progressively reducing the role of fossil fuels. This evolution creates significant technical and operational challenges for the electricity system, particularly in terms of grid integration, flexibility, planning, and system resilience.

The first challenge concerns the integration of variable renewable energy. While nuclear energy remains the backbone of electricity production (with 67% of generation in 2024), wind and solar are expanding steadily, together exceeding 16% of the electricity generation. This diversification requires enhanced flexibility, dynamic balancing, and better forecasting of intermittent output. The system must increasingly rely on the nuclear fleet's load-following capabilities, hydro storage, interconnections, and demand response to maintain balance in real time.

Second, France faces grid development and reinforcement needs. RTE has identified the major investments to adapt the transmission network to decentralised generation and new consumption patterns, including massive electrification of transport and heating, in its "Energy Pathways to 2050" ("*Futurs énergétiques 2050*") *scenarios*. Grid congestion in certain regions, delays in permitting, and connection backlogs are operational constraints[1].

Third, the ageing nuclear fleet creates both opportunities and operational challenges. Extending the lifetime of reactors requires careful planning of maintenance and refurbishment operations, while also managing emerging technical issues. This was illustrated in 2022, when the discovery of stress corrosion cracking on several reactors led to prolonged outages and extensive inspections across the fleet, sharply reducing nuclear availability[2]. Such situations can strain system adequacy during winter peaks, increasing reliance on imports, demand response, and other flexibility mechanisms to maintain security of supply.

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[1] *Energy Pathways to 2050 – Key results of the study ;* https://assets.rte-france.com/prod/public/2022-01/Energy%20pathways%202050_Key%20results.pdf

[2] *ASN Report 2022 – Stress corrosion phenomenon affecting the French nuclear power reactors* https://regulation-oversight.asnr.fr/annual_report/2022gb/12/

Finally, the diversification of the mix increases cybersecurity and digital system management challenges, given the proliferation of distributed assets and smart grid components. RTE and Enedis have both highlighted the need for advanced digital control and cybersecurity strategies to protect critical infrastructure.

B. WHAT MEASURES ARE BEING IMPLEMENTED OR CONSIDERED TO ENHANCE DEMAND-SIDE FLEXIBILITY (E.G. TIME-OF-USE TARIFFS, DEMAND RESPONSE)?

France has actively developed frameworks and mechanisms to mobilize demand response, load shedding, and tariff signals, seeking to turn electricity consumers into flexibility providers.

A central instrument is the balancing mechanism (*mécanisme d'ajustement*) operated by RTE. Under this scheme, consumption sites can bid reductions or injections in response to RTE orders, effectively competing with generation flexibility[1]. These demand-side offers are remunerated similarly to production in balancing markets. The Barometer of flexibility ("*Baromètre de la flexibilité*") shows increasing activation volumes of demand response, signaling growing uptake[2].

At the distribution level, Enedis is deploying local flexibility markets. It procures local flexibility services to relieve congestion on the low/medium voltage grid by temporarily modulating consumption in specific geographic areas. Interested actors (aggregators, consumers) may bid in calls for tenders to offer such services[3].

Historically, French regulation has supported demand response by enabling aggregator business models, removing barriers to participation across markets (day ahead, intraday, balancing) regardless of size or supplier relationship. This regulatory modernization has been in place since the early 2010s[4].

As for tariff instruments, France has a long tradition of time-of-use (TOU) pricing through the "heures pleines / heures creuses" (HP/HC) scheme. This system, which allocates eight off-peak hours at a lower tariff during the night and sixteen peak hours at the standard rate during the day, is now undergoing a significant reform under the new regulatory tariff framework. The French Energy Regulatory Commission (*Commission de*

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[1] *RTE – Valoriser vos flexibilités.*
https://www.services-rte.com/fr/decouvrez-nos-offres-de-services/valorisez-vos-flexibilites.html
[2] *Barometer of French demand-side flexibility.*
https://assets.rte-france.com/prod/public/2025-08/2024-10-21-barometre-flexibilites-consommation_eng-GB.pdf
[3] *Enedis – How to provide Local Flexibility Services*
https://www.enedis.fr/co-building-dso-local-flexibility
[4] *RTE – Demand-response, flexibility and smart grid planning: status and discussions in France*
https://iea.blob.core.windows.net/assets/imports/events/103/VEYRENC.pdf

régulation de l'énergie, CRE) has approved the repositioning of some off-peak hours into the afternoon (11h–17h), especially during the summer, to take advantage of the abundant and low-cost solar generation[1]. Under the new scheme, consumers will still have eight off-peak hours per 24 hours, with at least five consecutive hours at night, and a portion shifted to daytime slots. The rollout of the new HP/HC schedule is expected to begin in November 2025, and will be phased through 2027. Over 11 million of the 14.5 million households currently on HP/HC will see their off-peak hours repositioned[2].

C. HOW IS THE EVOLUTION OF THE ENERGY MIX AFFECTING ELECTRICITY AND GAS INFRASTRUCTURE (E.G. GRID CAPACITY, RELIABILITY, CROSS-BORDER FLOWS)?

The diversification of France's energy mix, marked by the gradual decline in fossil fuels, the revival of nuclear power, and the expansion of wind and solar, has significant implications for electricity and gas infrastructure, particularly regarding grid capacity, system reliability, and cross-border exchanges.

On the electricity infrastructure side, the shift in the energy mix is triggering major investment efforts. RTE has announced a €100 billion investment program for 2025–2040[3] to upgrade and expand the transmission grid, including new interconnections, high-voltage reinforcements, and offshore grid integration. In parallel, Enedis' Grid Development Plan (*Plan de développement du réseau*, published in January 2023)[4], outlines €96 billion of planned investments over 2022–2040 to modernize and adapt the distribution grid to rising renewable generation, electric mobility, and new flexibility services.

System reliability remains strong, underpinned by the stabilizing effect of France's substantial nuclear and hydroelectric capacity, but new operational challenges are emerging. The simultaneous integration of large shares of renewables requires greater flexibility and real-time balancing, supported by demand response, interconnections, and storage. RTE stresses that maintaining adequacy during winter peaks remains a key concern, particularly during nuclear maintenance periods[5].

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[1] *CRE – FAQ déplacement des HP/HC.* https://www.cre.fr/fileadmin/Documents/Communiques_de_presse/2025/250206_FAQ_HP-HC.pdf

[2] *CRE – Focus sur l'évolution du placement des heures creuses.* https://www.cre.fr/fileadmin/Documents/Communiques_de_presse/2025/250206_Annexe_CP_TURPE_7_HPHC.pdf

[3] *Strategic development plan for the French transmission grid (SDDR).* https://assets.rte-france.com/prod/public/2025-04/2025-04-28-sddr-executive-summary.pdf

[4] *Enedis – Network Development Plan for electricity distribution.* https://www.enedis.fr/new-electric-france-2027-and-2032-enedis-publishes-preliminary-document-its-future-network

[5] *RTE – Bilan électrique 2024.* https://analysesetdonnees.rte-france.com/bilan-electrique-2024/synthese

Cross-border electricity flows are becoming more structurally important. In 2024, France recorded record net exports of 89 TWh, reflecting the recovery of nuclear output and high renewable availability[1]. Reinforcing the interconnections with Spain, Italy, and Germany is a strategic priority to manage variability and enhance market integration.

On the gas side, the progressive electrification of end-uses and the decline in fossil gas demand are leading to reduced utilization of gas networks, raising questions about the economic model of existing infrastructure. Simultaneously, France is preparing for the injection and transport of renewable gases (biomethane, hydrogen), which require adaptation of existing grids and interconnections[2].

D. WHAT ARE THE ANTICIPATED IMPACTS ON INDUSTRIAL VALUE CHAINS (E.G. MANUFACTURING CAPACITY, LOCALISATION, STRATEGIC DEPENDENCIES)?

The transformation of France's energy mix is expected to generate profound impacts on industrial value chains, influencing manufacturing capacity and strategic dependencies in multiple sectors.

First, France's electrification and decarbonization trajectory is reshaping industrial priorities. The French Energy and Climate Strategy (*Stratégie française pour l'énergie et le climat*) and the France 2030 investment plan target the re-industrialization of strategic low-carbon technologies, including nuclear components, offshore wind, solar PV, batteries, hydrogen, and power electronics. This industrial policy is aimed at reducing Europe's heavy reliance on extra-European supply chains, notably in solar modules, batteries, and rare materials, while developing domestic manufacturing capacity.

In the nuclear sector, the EPR2 programe is expected to mobilize thousands of jobs across French civil engineering, heavy industry, and specialized manufacturing chains. Overall, the sector anticipates the creation of around 100,000 additional jobs by 2035 to meet the needs of both new reactor construction and the maintenance of the existing fleet[3].

In the renewables and grid sectors, France is seeking to strengthen its national industrial base while contributing to the development of a broader European clean technology value chain, in line with the EU Net-Zero Industry Act.

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[1] *RTE - La France a battu son record d'exports nets d'électricité en 2024.* *https://www.rte-france.com/actualites/france-battu-record-exports-nets-electricite-2024*
[2] *NATRAN – 2024 in review – gas markets and the energy transition.* *https://www.natrangroupe.com/en/medias/press-releases/2024-review-gas-markets-and-energy-transition*
[3] *Nucléaire : un nouveau contrat stratégique pour relancer la filière.* *https://www.vie-publique.fr/en-bref/299101-nucleaire-un-nouveau-contrat-strategique-pour-relancer-la-filiere*

This industrial strategy is embedded in the French Energy and Climate Strategy (*Stratégie française pour l'énergie et le climat*), the Multiannual Energy Programming (*Programmation pluriannuelle de l'énergie*, PPE), and the 2023 Renewables Acceleration Law. The government's solar initiative aims to build up to 10 GW of domestic photovoltaic module manufacturing capacity by 2030, while the offshore wind industrial base is expanding around major ports such as Le Havre and Saint-Nazaire, which are becoming hubs for assembly and manufacturing. In parallel, RTE and Enedis' €196 billion grid investment program to 2040 is expected to drive demand for cables, transformers, substations, and digital systems, creating opportunities for French manufacturers and European partners alike.

However, strategic dependencies remain significant. France continues to rely on imports for critical raw materials (lithium, rare earths) and much of its solar PV supply chain. Addressing these dependencies requires coordinated European action on supply diversification, recycling, and innovation.

III. SOCIAL ACCEPTABILITY OF THE ENERGY TRANSITION

A. HOW WOULD YOU CHARACTERISE THE LEVEL OF PUBLIC ACCEPTANCE OF THE ENERGY TRANSITION IN YOUR COUNTRY?

In France, public acceptance of the energy transition is relatively high, particularly in principle and when tied to climate, sovereignty, and job creation.

However, acceptance in principle has lately clashed with resistance in practice. The notion of "not in my backyard" (NIMBY) is manifest in local opposition to wind farm siting and debates over visual impact, noise, or ecological implications.

Some political actors have called for moratoria on renewable deployment or stepped back from Low Emission Zone (LEZ) regulation under pressure from voters, highlighting the tensions between environmental goals and perceived constraints on mobility (the National Assembly voted to suppress LEZ in certain contexts in 2025).

These pushbacks suggest that, while the broad narrative of the energy transition retains legitimacy in France, its local expression and regulatory imposition have increasingly been coupled with debate, contestation, and politicization.

B. TO WHAT EXTENT HAS THE ENERGY PRICE CRISIS OF 2022 INFLUENCED PERCEPTIONS OF ENERGY POLICIES AND CLIMATE COMMITMENTS?

The energy price shock of 2022, triggered by soaring natural gas and electricity wholesale costs in the wake of Russia's war in Ukraine, has acted as a stress test for French public attitudes toward energy policy and climate ambition.

At the policy level, France introduced a tariff shield (*bouclier tarifaire*) to cap electricity and gas price increases for regulated consumers. This intervention softened the visible impact of market volatility but also raised questions about fairness, budgetary cost, and long-term policy coherence[1].

Yet tensions persist: households under energy cost stress tend to question additional levies, carbon pricing, or infrastructure projects perceived to raise bills or provoke local externalities. In media debates, critics have seized on claims of "green taxes" or "transition overload", framing climate policies as burdensome in a high-cost environment. The shock made energy and economic issues more salient, fueling skepticism about the pace and costs of the transition.

C. ARE THERE SPECIFIC TECHNOLOGIES (E.G. WIND POWER, NUCLEAR ENERGY) THAT RAISE SIGNIFICANT CONTROVERSY OR PUBLIC RESISTANCE?

Wind energy in France enjoys broad support in principle: surveys show that typically more than 70% of French people view wind favorably[2]. Nevertheless, the deployment of wind turbines often meets local resistance on grounds of visual intrusion, noise, impact on the landscape or biodiversity, and procedural issues in siting. In many projects, opponents invoke ecological, aesthetic, or heritage arguments. For instance, local protests have disrupted the development pipeline of wind farm projects or led to legal challenges.

Nuclear has historically been more controversial. The key objections center on risk, waste management and aging reactor safety. The anti-nuclear movement (e.g. *Sortir du nucléaire*) has long mobilized around these concerns. Yet in recent years, public sentiment has become more favorable. A 2023 BVA/Orano poll found that 57% of respondents view nuclear as an asset for France, citing energy independence, stable supply, and job creation as positive attributes. Still, concerns persist: 53% mentioned non-recyclable waste,

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[1] *Energy shock and policy measures: the case of France – Jérôme Creel, Mathieu Plane and Raul Sampognaro.* *https://www.etui.org/sites/default/files/2023-11/Chapter2_Energy%20shock%20and%20policy%20measures%20the%20case%20of%20France_2023.pdf*

[2] *IFOP – L'image de l'énergie éolienne auprès des Français* *https://www.ifop.com/article/limage-de-lenergie-eolienne-aupres-des-francais*

49% reactor aging, and 46% accident risk as serious drawbacks[1]. Another survey by GIFEN/Harris in 2025 indicates that 75% of French people favor the continued use of nuclear energy; 54% support a combined development of nuclear and renewables[2]. 61 % have a good perception of nuclear energy in another 2025 survey by ENGIE/Ifop[3].

D. IS THERE AN ONGOING PUBLIC OR PARLIAMENTARY DEBATE REGARDING THE REALISM, COST, OR SOCIAL EQUITY OF THE ENERGY TRANSITION?

There is today an active public and parliamentary debate in France regarding the realism, costs, and social equity of the energy transition.

A key flashpoint has been the government's decision to adopt the next Multiannual Energy Programming (*Programmation pluriannuelle de l'énergie*, PPE), France's strategic energy plan, by decree without consulting Parliament. This move triggered strong criticism from deputies and senators who argued that strategic energy choices deserve full legislative debate.

In response, Senator Daniel Gremillet (LR) submitted a bill in April 2024 to define the national energy policy up to 2035, effectively preceding the PPE. The bill sought to legislate on nuclear revival, renewable targets, and fossil fuel reduction trajectories, and is currently progressing through the parliamentary legislative process[4].

Cost and social equity are also central. During a session of the National Assembly on 28 April 2025, some MPs challenged the government for not detailing the financial burden of the transition[5]. Critics question whether the planned acceleration of nuclear and renewables is technically and economically feasible, and whether households and industries can bear the costs fairly.

Overall, while the objective of the energy transition is broadly shared, the choice between legislative action or regulatory measures as well as questions of cost allocation and social fairness are the subject of vigorous and unresolved debate in France.

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[1] *Now more than ever, nuclear energy is an asset for the country according to the French public (BVA survey for Orano).* *https://www.orano.group/en/news/news-group/2023/december/now-more-than-ever-nuclear-energy-is-an-asset-for-the-country-according-to-the-french-public-bva-survey-for-orano*

[2] *GIFEN – The French are in favour of nuclear power: discover the significant results of a Harris survey commissioned by GIFEN and Bastille Magazine.* *https://www.gifen.fr/en/news/detail/the-french-are-in-favour-of-nuclear-power-discover-the-significant-results-of-a-harris-survey-commissioned-by-gifen-and-bastille*

[3] *Ifop, Énergies : que veulent vraiment les Français.* *https://www.ifop.com/article/etude-francais-perception-energies-renouvelables-2/*

[4] *Programmation nationale et simplification normative dans le secteur économique de l'énergie* *https://www.assemblee-nationale.fr/dyn/17/dossiers/DLR5L16N49849*

[5] *Assemblée nationale – XVIIe législature Session ordinaire de 2024-2025 – Première séance du lundi 28 avril 2025.* *https://www.assemblee-nationale.fr/dyn/17/comptes-rendus/seance/session-ordinaire-de-2024-2025/premiere-seance-du-lundi-28-avril-2025*

GERMANY

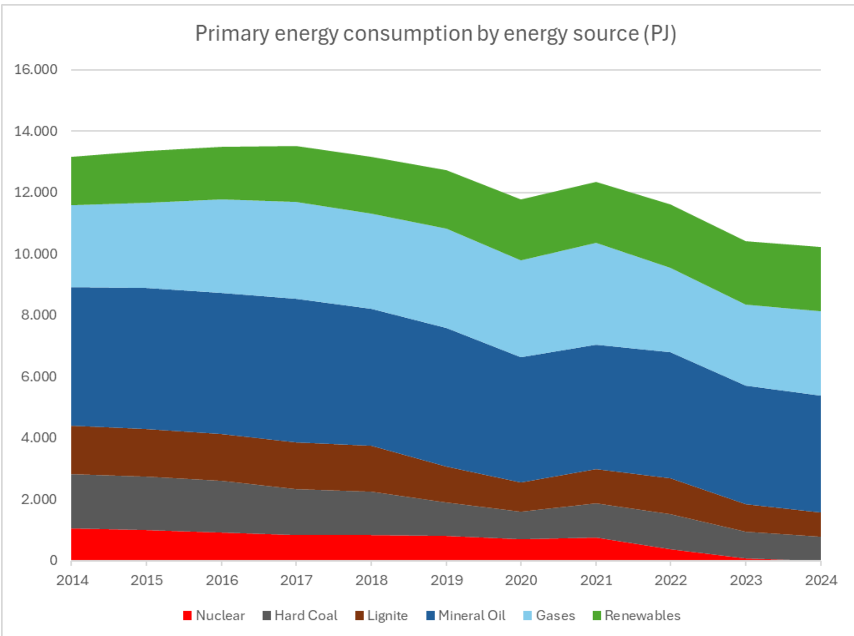
Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag (TAB)
Office of Technology Assessment at the German Parliament

I. ENERGY MIX AND THE CARBON NEUTRALITY OBJECTIVE (2050)

A. HOW HAS THE STRUCTURE OF ENERGY DEMAND EVOLVED IN YOUR COUNTRY IN RECENT YEARS?

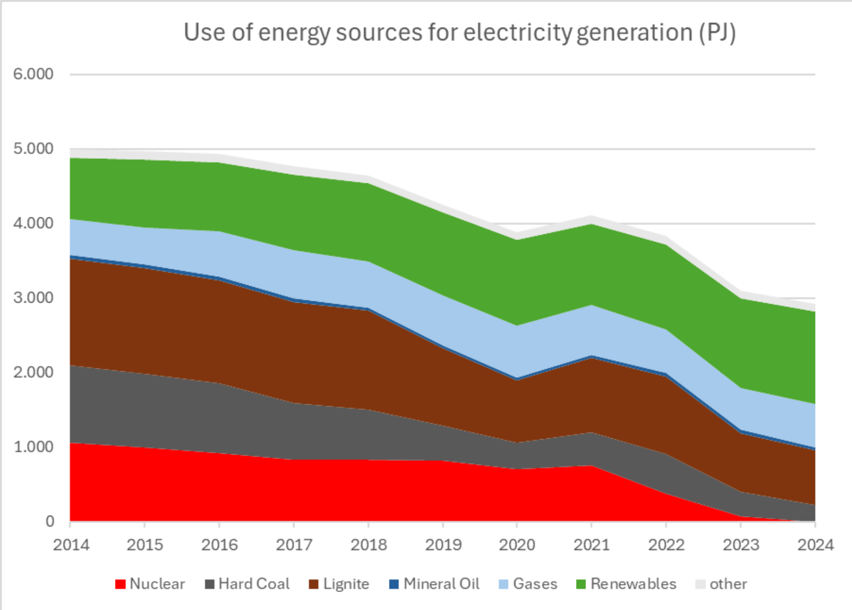
Over the last decade Germany's energy demand has undergone notable structural changes (Fig. 1)[1]. Total primary energy consumption declined by more than 20%, mostly driven by energy efficiency measures and shifts in industrial production. The decline in the electricity sector was even more pronounced, amounting to around 40% (Fig. 2).

Fig. 1:



[1] *All Figures: own representation of data by AG Energiebilanzen "Auswertungstabellen zur Energiebilanz 1990 bis 2024"* [*https://ag-energiebilanzen.de/daten-und-fakten/auswertungstabellen/*](https://ag-energiebilanzen.de/daten-und-fakten/auswertungstabellen/)

Fig. 2:



B. WHAT IS THE CURRENT COMPOSITION OF THE ENERGY MIX, AND WHAT ARE THE KEY POLICY OBJECTIVES OR PROJECTIONS BY 2050 (E.G. SHARE OF FOSSIL FUELS, NUCLEAR, RENEWABLES)?

Germany remains heavily dependent on fossil fuels, which account for around 80% of primary energy consumption (Fig. 3). The share of renewable energies has risen steadily and now stands at around 20%. In terms of electricity production the rise of renewables is even more pronounced, increasing from 16% in 2014 to 42% in 2024. Nuclear power which stood at 21% in 2014 was phased out in 2023.

Fig. 3:

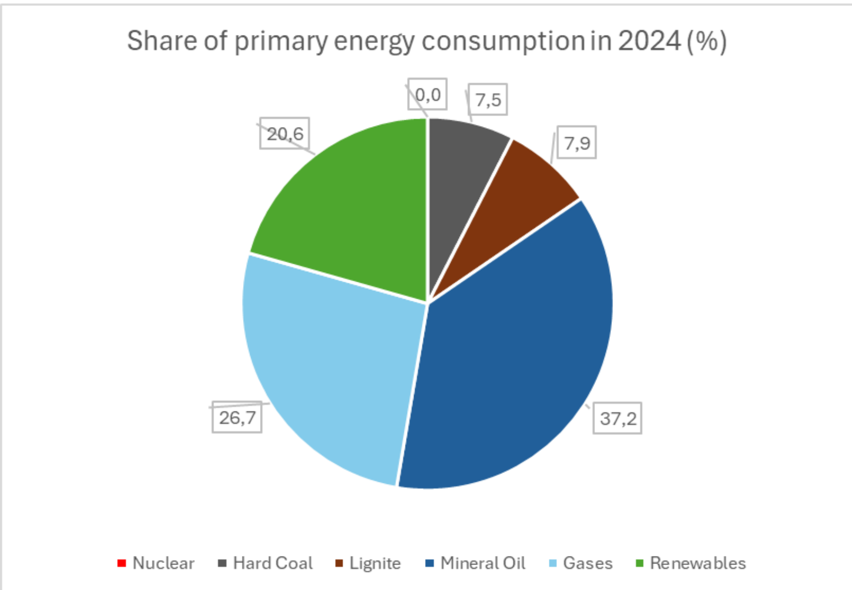
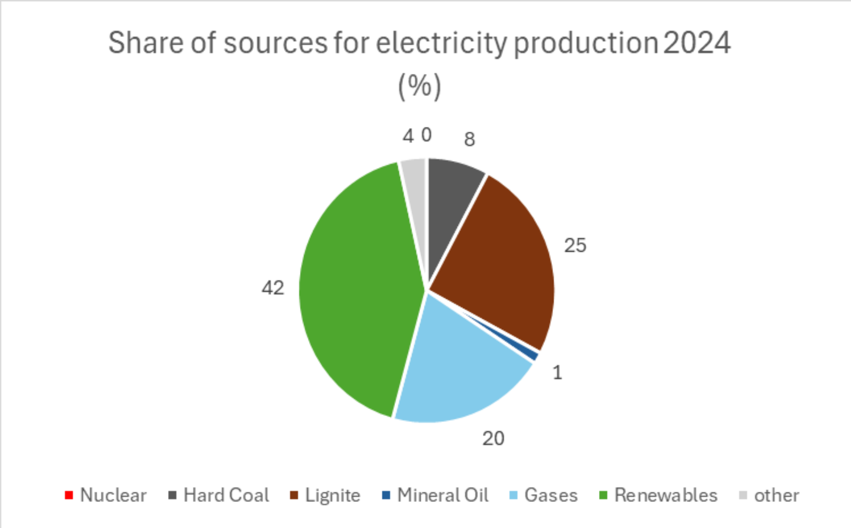


Fig. 4:



C. WHAT TRANSFORMATION PATHWAYS ARE CURRENTLY UNDER DISCUSSION OR IMPLEMENTATION TO ACHIEVE DECARBONISATION GOALS?

Germany's long-term energy and climate policy goals are to achieve climate neutrality (net zero greenhouse gas emissions) by 2045 (five years earlier than the EU target for 2050). To this end, there are plans to phase out coal-fired power plants by 2038. At the same time, the share of renewable energies in the electricity supply is to increase from the current 42% to 65% by 2030 and finally to 100% by 2045.

Energy efficiency plays a crucial role in achieving these goals. Significant improvements must be implemented at an accelerated pace, particularly in industrial processes and buildings. The modernization and digitalization of the power grid is also essential for enabling a large share of variable renewables.

Although Germany lifted its binding sector specific CO_2-reduction targets in 2024, each sector must make a significant contribution to the overall target. There are a number of sectoral strategies in discussion and/or implementation:

Transport sector

The transportation sector is notoriously difficult when it comes to reducing greenhouse gases. Today it is still largely dependent on fossil fuels (around 90%). In the effort to decarbonise they will have to be replaced by electricity in road transport, and by synthetic fuels in aviation and maritime transport[1]. Much greater efforts than before are needed to stay on track with the CO_2 reduction target. In the road transport segment, experts largely agree

[1] *See for example: TAB (to be published) "Sustainable and safe concepts for climate-friendly shipping".*

that basically all new cars need to be electric by 2030. To enable such growth in electric mobility, a faster deployment of charging infrastructure will be needed.

Heating Sector

The heating sector is responsible for almost 40% of all CO_2 emissions and its energy consumption is – similar to the transport sector – dominated by fossil fuels (around 80%). With the Heat Planning Act[1], Germany introduced an instrument to facilitate strategic planning of the decarbonisation of the heating sector at the local level. In the next three years, close to 11 000 municipalities will present their respective plans. These plans include the designation of heat supply areas, which show which type of heat supply is particularly suitable for a specific part of a municipality. It also sets goals for the share of renewable energy and waste heat that has to be fed into district heating networks: 30% by 2030 and 80% by 2040. Apart from district heating the other primary instrument for decarbonsiation is electricity particularly when used in heat pumps. However, the deployment of heat pumps in Germany is currently progressing slowly due to households' concerns about investment and operating costs.

Industry

Due to past decarbonisation efforts, industrial emissions have fallen by 41% since 1990. The Federal Climate Action Act[2] stipulates a further reduction of around 35% for industry by 2030 (compared to average emissions from 2010 to 2020). Transformation pathways for German industry include electrification, the use of hydrogen, and, beyond that, the use of Carbon Capture and Storage (CCS) for sectors with hard-to-abate emissions (like cement industry). This ambitious decarbonisation plan requires high investments in low-carbon industrial processes. To support this transition, the German government has provided subsidies amounting to billions of euros. For industries that compete globally, the transformation can only succeed if the European Carbon Border Adjustment Mechanism (CBAM) is implemented effectively.

Hydrogen produced with low carbon emissions is considered a key technology for the transformation of the energy system towards climate neutrality. Hydrogen can be used flexibly in many areas, including as a fuel and as a raw material for industrial processes. In its function as a storage medium, it can compensate for fluctuations in renewable electricity generation and can also serve as a link for sector coupling (electricity, heat, transport).

[1] *https://energiewende.bundeswirtschaftsministerium.de/EWD/Redaktion/EN/Newsletter/2023/11/Meldung/news1.html*
[2] *https://www.gesetze-im-internet.de/englisch_ksg/englisch_ksg.html*

Projections for Germany's future hydrogen demand amount to 200-350 PJ in 2030 and about 1800-5000 PJ in 2045[1]. The Government's hydrogen strategy aims to establish an electrolysis capacity of 10 GW by 2030 (corresponding to an annual production of around 95 PJ). However, Germany is currently lagging far behind these goals. So far, only 1% of the 10 GW has been realized. To accelerate this process and to stimulate demand, discussions are currently underway as to whether the criteria for climate-friendly hydrogen should be adjusted to also include so-called "blue" hydrogen (produced from fossil gas with carbon capture and storage).

D. HAS YOUR ORGANISATION CONDUCTED ANY RECENT ASSESSMENT OF THESE EVOLUTIONS (E.G. SCENARIO MODELLING, SYSTEM-LEVEL IMPACT STUDIES)? IF SO, COULD YOU BRIEFLY DESCRIBE THE FINDINGS?

TAB has repeatedly addressed many aspects of energy use in recent years:

■ **2023**

- Alternative technology pathways for reducing emissions in primary industry; https://www.tab-beim-bundestag.de/english/energy-and-environment_alternative-technology-pathways-for-reducing-emissions-in-primary-industry.php
- Innovative engines and fuels for more climate-friendly air transport; https://www.tab-beim-bundestag.de/english/projects_innovative-engines-and-fuels-for-more-climate-friendly-air-traffic.php
- Space-based energy production https://publikationen.bibliothek.kit.edu/1000161888
- Sustainable Cooling https://publikationen.bibliothek.kit.edu/1000158817

■ **2024**

- Integrated municipal heating and cooling generation https://publikationen.bibliothek.kit.edu/1000179500
- Towards a possible fusion power plant - knowledge gaps and research needs from the perspective of technology assessment https://www.tab-beim-bundestag.de/english/projects_towards-a-possible-fusion-power-plant-knowledge-gaps-and-research-needs-from-the-perspective-of-technology-assessment.php

[1] *Expertenkommission (2024): Monitoringbericht der Expertenkommission zum Energiewende-Monitoring. https://www.bmwk.de/Redaktion/DE/Publikationen/Energie/monitoringbericht-expertenkommission-zum-energiewende-monitoring.html*

■ **Ongoing**

- Sustainable and safe concepts for climate-friendly shipping https://www.tab-beim-bundestag.de/english/energy-and-environment_sustainable-and-safe-concepts-for-climate-friendly-shipping.php
- Opportunities and risks of hydrogen partnerships and technologies in developing countries; https://www.tab-beim-bundestag.de/english/energy-and-environment_opportunities-and-risks-of-hydrogen-partnerships-and-technologies-in-developing-countries.php
- Impact of offshore wind farms on the environment https://www.tab-beim-bundestag.de/english/energy-and-environment_impact-of-offshore-wind-farms-on-the-environment.php
- AI-based applications in decentralised electricity systems https://www.tab-beim-bundestag.de/english/energy-and-environment_ai-based-applications-in-decentralised-electricity-systems.php

II. CONSEQUENCES OF TECHNOLOGICAL CHOICES

A. WHAT ARE THE MAIN TECHNICAL OR OPERATIONAL CHALLENGES ASSOCIATED WITH MANAGING A MORE DIVERSIFIED ENERGY MIX IN YOUR COUNTRY?

To supplement a large share of renewable energies (wind, solar) in the electricity grid, there is a need for power plants that deliver flexible output to balance out fluctuations. These are primarily gas-fuelled power plants, which are to be converted to hydrogen at a later stage. Currently there is a lively debate in Germany about how much such capacity is needed and how a lock-in into natural gas technologies can be avoided.

In addition, storage options are needed to balance both short-term fluctuations (e.g. with batteries) and long-term supply/demand disparities (e.g. with hydrogen electrolysis).

B. WHAT MEASURES ARE BEING IMPLEMENTED OR CONSIDERED TO ENHANCE DEMAND-SIDE FLEXIBILITY (E.G. TIME-OF-USE TARIFFS, DEMAND RESPONSE)?

Germany is one of the laggards in the EU when it comes to the rollout of smart electricity meters: the proportion of households with smart meters is still in the single digits, while other countries have achieved much higher coverage. This is considered an important barrier to incentivising demand-side flexibility of household customers. Applications with significant flexibility potential include electric vehicles and heat pumps. To incentivise flexibility, all electricity providers are legally required to offer time-of-use-tariffs since the beginning of 2025. In commerce and industry there are some promising options for demand side flexibility, such as cooling and heating applications. Some of these are already being implemented as there are sufficient economic incentives to do so. However there is a legacy regulation in place which currently represents a considerable disincentive for flexible industrial demand. This is the so-called "Grid Charges Ordinance" which grants large consumers grid discounts for steady, baseload demand. Removing this concession would promote efficient grid operation but is feared to erode the competitiveness of industries that are already under severe pressure.[1]

C. HOW IS THE EVOLUTION OF THE ENERGY MIX AFFECTING ELECTRICITY AND GAS INFRASTRUCTURE (E.G. GRID CAPACITY, RELIABILITY, CROSS-BORDER FLOWS)?

The **gas sector** experienced a period of shock when the supply of Russian natural gas via pipelines was cut off after the start of the war of aggression against Ukraine. Within a very short time infrastructure was set up for the import of liquefied natural gas. At the same time, plans were drawn up for the construction of a hydrogen pipeline infrastructure to replace natural gas in the medium term.

To manage the energy transition in the **electricity sector** with rapid growth in variable distributed renewable generation, and significant electrification of important end-use sectors like transport and heating, the grid infrastructure needs to be used as efficiently as possible and substantially expanded. Currently, regional imbalances and insufficient grid capacity create large inefficiencies and hefty congestion management costs that are also reflected in grid fees.[2]

According to the electricity network development plan, 4,800 kilometers of new transmission lines are to be installed, in addition to 2,500 kilometers of existing connections that are to be reinforced. This is a major challenge that puts existing planning and approval procedures, including stakeholder participation, to the test.

D. WHAT ARE THE ANTICIPATED IMPACTS ON INDUSTRIAL VALUE CHAINS (E.G. MANUFACTURING CAPACITY, LOCALISATION, STRATEGIC DEPENDENCIES)?

To meet the goal of climate neutrality by 2045 many sectors of the German industry have to increase their efforts to decarbonise production processes. This is particularly critical for industries like cement, chemical and steel. For cement production CCS is the only viable technological option.

[1] IEA *https://www.iea.org/reports/germany-2025*
[2] IEA *https://www.iea.org/reports/germany-2025*

For the chemical and steel industry electrification and the use of hydrogen are the main measures.[1] As these industries face fierce international competition, they are struggling to keep their decarbonisation efforts on track. For example, in September 2025, the second major steel company announced that it would postpone or abandon its plans to start producing "green" steel. There is also some concern that production will be relocated to regions of the world where conditions for the production of green electricity or hydrogen are more favorable.

III. SOCIAL ACCEPTABILITY OF THE ENERGY TRANSITION

A. HOW WOULD YOU CHARACTERISE THE LEVEL OF PUBLIC ACCEPTANCE OF THE ENERGY TRANSITION IN YOUR COUNTRY?

In recent years climate change has been a top priority for the German general public. However, other issues currently take precedence, such as the economic situation, migration issues, and the challenges arising from Russian aggression in Ukraine and beyond.

General acceptance of the energy transition is still strong. In a recent poll, for example, over 80% of respondents were in favour of continued expansion of renewable energy sources)[2]. However, infrastructure projects like wind farms or transmission lines often face opposition on the local level.

B. TO WHAT EXTENT HAS THE ENERGY PRICE CRISIS OF 2022 INFLUENCED PERCEPTIONS OF ENERGY POLICIES AND CLIMATE COMMITMENTS?

There has been a noticeable shift in the public perception of measures proposed to reduce CO_2 emissions. The notion that they would place an excessive burden on industry and/or consumers is much more widespread today than it was a few years ago. One notable example of this is the EU goal of phasing out combustion engines, a goal that is currently discussed to being postponed or watered down.

On the other hand, current geopolitical upheavals have led to increased awareness of energy security and autonomy, which has boosted acceptance of renewable energies as a means of reducing dependence on fossil fuel imports.

[1] *TAB (2024): Alternative technology pathways for reducing emissions in primary industry. https://www.tab-beim-bundestag.de/english/projects_alternative-technology-pathways-for-reducing-emissions-in-primary-industry.php*

[2] *https://www.cleanenergywire.org/factsheets/polls-reveal-citizens-support-energiewende (11.9.25).*

C. ARE THERE SPECIFIC TECHNOLOGIES (E.G. WIND POWER, NUCLEAR ENERGY) THAT RAISE SIGNIFICANT CONTROVERSY OR PUBLIC RESISTANCE?

The fierce controversy surrounding nuclear energy, which prevailed in Germany for many years, has subsided somewhat since the last three nuclear power plants were shut down in April 2023. Some voices are calling for a return to nuclear power due to concerns about energy security, while others raise objections citing safety and waste issues. Among experts rebuilding nuclear capacity is widely considered economically and technically implausible.

In the case of wind energy, there is strong support on national level, but local resistance persists. Concerns include impacts on the landscape, noise pollution, and disruption to wildlife. Some political actors have made opposition to wind energy a central campaign issue. Similarly, resistance to the expansion of transmission grids and other infrastructure projects such as LNG terminals is evident.

D. IS THERE AN ONGOING PUBLIC OR PARLIAMENTARY DEBATE REGARDING THE REALISM, COST, OR SOCIAL EQUITY OF THE ENERGY TRANSITION?

There is an active and ongoing debate about costs and affordability: Concerns about rising electricity and gas prices and the financial burden on households and industry have led to calls for realigning energy policy.

To this end the Federal Ministry for Economic Affairs has commissioned a study to provide an update of the existing monitoring of the energy transition. This study[1] was published mid-September and will serve as a basis for shaping the future energy policy of the German government, which has committed itself to consistently focusing all areas on affordability, cost efficiency, and security of supply.

At the very least energy and climate policy goals are coming under increasing pressure in public and political debates, as evidenced by intense debates about postponing or weakening certain climate targets, such as the EU climate goal for 2040 and the phase-out of combustion engines from 2035.

[1] *EWI, BET (2025): Energiewende. Effizient. Machen – Monitoringbericht zum Start der 21. Legislaturperiode https://www.bundeswirtschaftsministerium.de/Redaktion/DE/Publikationen/Energie/energiewende-effizient-machen.html*

GREECE

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I. ENERGY MIX AND THE CARBON NEUTRALITY OBJECTIVE (2050)

A. HOW HAS THE STRUCTURE OF ENERGY DEMAND EVOLVED IN YOUR COUNTRY IN RECENT YEARS?

Between 2018 and 2023, the structure of Greece's total energy supply (TES)—used here as a proxy for total energy demand—underwent notable changes. Solid fossil fuels, primarily lignite, declined sharply from about 4,564 ktoe in 2018 to only 1,179 ktoe in 2023, reflecting the progressive phase-out of coal in power generation. Oil and petroleum products remained the dominant source of energy, fluctuating moderately but remaining close to their 2018 level (from 10,357 ktoe to 10,204 ktoe), which underscores the country's continued dependence on oil, particularly in the transport sector. Natural gas increased steadily until 2021, reaching a peak of 5,449 ktoe, but subsequently decreased to 3,973 ktoe in 2023 in response to price volatility and efforts to diversify supply. Renewables and biofuels followed an upward trajectory, rising from 3,114 ktoe in 2018 to 3,993 ktoe in 2023, supported by the sustained deployment of wind and solar energy. Electricity imports and exports fluctuated over the period but maintained a relatively minor role in the overall supply. Because total energy supply balances domestic production and trade flows, it closely mirrors the evolution of overall energy demand, even though it includes transformation losses and therefore slightly exceeds final consumption.

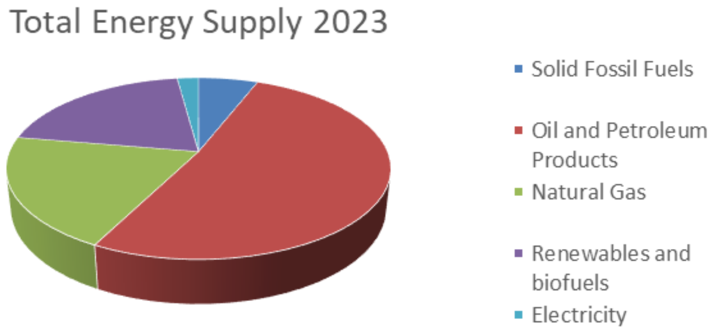
Total Energy Supply (TES)

Year	SolidFossilFuels	Oil and Petroleum Products	NaturalGas	Renewables and biofuels	Electricity
2023	1.179	10.204	3.973	3.993	422
2022	1.562	10.743	4.404	3.979	296
2021	1.711	9.492	5.449	3.838	317
2020	1.831	9.212	4.928	3.350	762
2019	3.196	10.670	4.489	3.172	855
2018	4.564	10.357	4.117	3.114	540

Table 1 – Total Energy Supply (ktoe)

B. WHAT IS THE CURRENT COMPOSITION OF THE ENERGY MIX, AND WHAT ARE THE KEY POLICY OBJECTIVES OR PROJECTIONS BY 2050 (E.G. SHARE OF FOSSIL FUELS, NUCLEAR, RENEWABLES)?

In 2023, Greece's total energy supply amounted to approximately 19,800 ktoe. Oil and petroleum products accounted for about 51% of this total, natural gas for roughly 20%, and renewables and biofuels for a similar share of around 20%. Solid fossil fuels represented about 6%, while net electricity imports contributed the remaining 2 percent. This composition illustrates a gradual transition towards cleaner energy sources, with a steady expansion of renewables and a significant reduction in the use of coal, even as oil remains the single largest component of the national energy mix.



C. WHAT TRANSFORMATION PATHWAYS ARE CURRENTLY UNDER DISCUSSION OR IMPLEMENTATION TO ACHIEVE DECARBONISATION GOALS?

This National Energy and Climate Plan is in principle Greece's strategic plan to achieve its GHG emission reduction targets. It has been based both on current data and on plausible projections for the evolution of the maturity and cost of green earth artefacts andhas been developed with the basic principle of minimising the cost of the energy transition for the intended result. This principle is reflected in the prioritisation of interventions according to the figure so that, where equivalents exist, the most mature and cheapest interventions are prioritised in order toachieve the objectives.

D. HAS YOUR ORGANISATION CONDUCTED ANY RECENT ASSESSMENT OF THESE EVOLUTIONS (E.G. SCENARIO MODELLING, SYSTEM-LEVEL IMPACT STUDIES)? IF SO, COULD YOU BRIEFLY DESCRIBE THE FINDINGS?

The National Energy and Climate Plan was prepared using the International Energy Agency (IEA) model for simulating energy systems TIMES and a model for simulating the operation of the electrical system of the National Technical University of Athens.

II. CONSEQUENCES OF TECHNOLOGICAL CHOICES

A. WHAT ARE THE MAIN TECHNICAL OR OPERATIONAL CHALLENGES ASSOCIATED WITH MANAGING A MORE DIVERSIFIED ENERGY MIX IN YOUR COUNTRY?

Greece is both a mountanous and insular country. Insularity makes the energy transition more difficult due to higher production and distribution costs, the absence of economies of scale, and the need for expensive transmission infrastructure such as submarine cables. The isolation of islands limits their integration into mainland grids, often forcing reliance on autonomous systems and imported fossil fuels, although their rich solar, wind, and marine resources offer significant potential for energy autonomy if supported by the right investments and policies. Mountainous regions face similar challenges, as difficult terrain increases the cost and complexity of building and maintaining infrastructure, while at the same time providing strong opportunities for renewable development through wind and hydropower. However, exploiting this potential requires careful environmental planning and substantial investment in transmission lines to connect remote sites with the national grid.

B. WHAT MEASURES ARE BEING IMPLEMENTED OR CONSIDERED TO ENHANCE DEMAND-SIDE FLEXIBILITY (E.G. TIME-OF-USE TARIFFS, DEMAND RESPONSE)?

Currently, there are two main types of electricity tariffs: the counter tariff (based on estimated consumption) and the settlement tariff (based on actual consumption).From January 2024, electricity tariffs are divided into four categories – blue, green, yellow, and orange – according to pricing. In addition, special tariffs remain in place for vulnerable groups, such as the Social Household Tariff (SHT).

The nationwide rollout of smart meters for all electricity consumers is expected to be completed between 2025 and 2030, enabling demand response and more accurate billing.

Gradually, and in parallel with the deployment of smart meters, suppliers are expected to introduce dynamic electricity pricing. These floating tariffs will adjust in line with wholesale market prices, either hourly or within specific time zones. Such tariffs will encourage consumers to shift their consumption patterns by reducing use during periods of high prices and increasing it when renewable energy generation is abundant.

C. HOW IS THE EVOLUTION OF THE ENERGY MIX AFFECTING ELECTRICITY AND GAS INFRASTRUCTURE (E.G. GRID CAPACITY, RELIABILITY, CROSS-BORDER FLOWS)?

Integrating large shares of variable renewables (wind, solar) requires enhanced system balancing, greater availability of flexible reserves, improved forecasting, and congestion management.

At the same time, substantial grid reinforcements and forward-looking network planning (both transmission and distribution) are necessary to strengthen interconnections – particularly with the islands – and to expand capacity for accommodating RES production.Additional flexibility is also required, through storage solutions, demand response mechanisms, and flexible mix energy generation, to safeguard the reliability of the power system.On the gas side, adaptation is essential to ensure security of supply by diversifying routes and sources, and by upgrading infrastructure to handle changing flows (e.g., LNG terminals and pipelines).Also, a large number of cross-border-international natural gas transmission projects are promoted, strengthening the diversification of energy sources and therefore the energy security of the rest of European countries.Finally, the gradual creation of a green hydrogen economy demands progressive infrastructure development and a reduction in production costs to become viable at scale.

D. WHAT ARE THE ANTICIPATED IMPACTS ON INDUSTRIAL VALUE CHAINS (E.G. MANUFACTURING CAPACITY, LOCALISATION, STRATEGIC DEPENDENCIES)?

National programmes such as the National Recovery and Resilience Planand related reform plans explicitly support the development of domestic value chains in green technologies, including measures that promote local manufacturing, for example in solar water heaters and photovoltaic components, thereby boosting industrial capacity in areas where Greece has comparative advantages. At the same time, government strategies, including the National Energy and Climate Plan and sustainable finance initiatives, acknowledge the country’s strategic dependencies on imported equipment such as turbines, inverters, and grid infrastructure, and promote financing tools and policies to reduce these vulnerabilities. Parallel to this, the Annual Progress Report, the Ministry of Finance, and the National Recovery and Resilience Plan highlight the importance of industrial electrification, digitalisation, and research and development, aiming to support industrial decarbonisation, strengthen competitiveness, and encourage the localisation of parts of the energy transition value chain.

III. SOCIAL ACCEPTABILITY OF THE ENERGY TRANSITION

A. HOW WOULD YOU CHARACTERISE THE LEVEL OF PUBLIC ACCEPTANCE OF THE ENERGY TRANSITION IN YOUR COUNTRY?

Greece's the National Energy and Climate Plan revision process and related planning include wide public consultation mechanisms (working groups, public consultation for NECP and maritime spatial planning for offshore wind projects), indicating institutional emphasis on public participation even though views vary locally.

B. TO WHAT EXTENT HAS THE ENERGY PRICE CRISIS OF 2022 INFLUENCED PERCEPTIONS OF ENERGY POLICIES AND CLIMATE COMMITMENTS?

The increase in prices brought about by the crisis affected a number of policies and created a need to reduce energy prices, protect vulnerable households, and limit cost increases for specific actions and infrastructure.

At the same time, the country is already experiencing the consequences of the climate crisis. Heat waves, intense fires, unprecedented floods created incalculable disasters. These impacts underline the urgent need for transition and intensify the necessary and imperative emphasis on ensuring the resilience of Greek society and economy.

The National Energy and Climate Strategy support the long-term strategic path for a climate-neutral economy, aiming to improve the competitiveness of the economy and businesses, create new jobs, strengthen the role of the consumer and overall operate competitive energy markets for the benefit of society.

C. ARE THERE SPECIFIC TECHNOLOGIES (E.G. WIND POWER, NUCLEAR ENERGY) THAT RAISE SIGNIFICANT CONTROVERSY OR PUBLIC RESISTANCE?

Wind power projects raise public concerns. Reactions often reflect anxieties about the alteration and degradation of the landscape, the environmental, social, political and cultural impacts of these interventions, the displacement of agricultural and tourist activities, the absence of public consultation, the problematic distribution of financial benefits and the change in the development orientation of the regions.

D. IS THERE AN ONGOING PUBLIC OR PARLIAMENTARY DEBATE REGARDING THE REALISM, COST, OR SOCIAL EQUITY OF THE ENERGY TRANSITION?

The two new National Marine Parks in the Southern Cyclades and the Ionian was open for public consultation until September 22nd, in accordance with national and EU legislation, for interested citizens and bodies to submit their comments and suggestions. These will be taken into account for the final formation of the Ionian National Marine Park and the South Aegean National Marine Park 1 – Southern Cyclades.

JAPAN

Research and Legislative Reference Bureau (RLRB), National Diet Library (NDL)

I. ENERGY MIX AND THE CARBON NEUTRALITY OBJECTIVE (2050)

A. EVOLUTION IN THE STRUCTURE OF ENERGY DEMAND

In fiscal year 2023, the final energy consumption in Japan decreased by 18.1% compared to fiscal year 2013. During this period, the demand for oil and coal declined significantly compared to electricity, resulting in an increase in the share of electricity in final energy consumption (electrification rate) to 27.5%[1]. According to the outlook by the Agency for Natural Resources and Energy (ANRE), part of the Ministry of Economy, Trade and Industry (METI), final energy consumption is expected to decrease by more than 10% by fiscal year 2040, mainly due to improvements in energy efficiency. Meanwhile, electricity demand is projected to start increasing from the 2023 level, driven by the growth of data centers and semiconductor manufacturing facilities. As a result, electricity demand may increase by 10–20% compared to fiscal year 2023, and the electrification rate is also expected to rise[2].

B. COMPOSITION OF THE ENERGY MIX AND POLICY OBJECTIVES

In fiscal year 2023, fossil fuels dominated Japan's primary energy supply, accounting for 80.7% — the largest share — comprising oil (35.7%), coal (24.4%), and natural gas (20.6%), whereas renewable energy accounted for 12.0% and nuclear power for 4.1%. In the same year, the power generation mix was also dominated by fossil fuel-based thermal power, which accounted for the largest share at 68.6% (natural gas 32.9%, coal 28.3%, and oil 7.4%). Renewable energy accounted for 22.9% (solar photovoltaic (PV) 9.8%, hydro 7.6%, biomass 4.1%, wind 1.1%, and geothermal 0.3%), while nuclear power accounted for 8.5%[3].

The government set the goal of achieving carbon neutrality by 2050 in October 2020 and outlined a roadmap for its realization. The latest 7th Strategic Energy Plan (decided in February 2025) sets the following targets for the 2040 power generation mix: renewable energy at 40–50% (PV 23–29%, hydro 8–10%, wind 4–8%, biomass 5–6%, geothermal 1–2%), thermal at 30-40%, and nuclear power at 20%. Regarding PV, the Plan targets the

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[1] *The Agency for Natural Resources and Energy (ANRE), "Energy Supply and Demand Results for Fiscal Year 2023 (Reiwa 5) (Confirmed Data)," April 2025, pp.7–8. (In Japanese)* https://www.enecho.meti.go.jp/statistics/total_energy/pdf/honbun2023fykaku.pdf.

[2] Ibid., *p.27.*

[3] Ibid., *pp.28, 35.*

introduction of 20 GW of perovskite solar cells by 2040. For offshore wind, it sets a target of forming 30-45 GW of projects, including floating types, by 2040. As for nuclear power, while efforts are underway to restart existing nuclear power plants (NPPs) that have remained shut down following the Fukushima Daiichi nuclear accident in March 2011, the government plans to proceed with concrete measures for replacing aging reactors, as many are expected to be decommissioned after 2040, with new advanced units[1].

C. TRANSFORMATION PATHWAY FOR ACHIEVING DECARBONIZATION GOALS

In order to achieve carbon neutrality by 2050, the widespread adoption of innovative technologies – many of which have not yet been deployed at scale – is essential. However, the timeline and scale of adoption vary significantly across technologies depending on factors such as maturity, supply chain readiness, and cost reduction. As a result, accurately predicting technological trends remains challenging at this stage. Therefore, ANRE has conducted an analysis of energy supply and demand for fiscal year 2040 based on five scenarios[2].

1) Renewable Energy Expansion Scenario	Significant cost reductions in technologies such as perovskite solar cells and floating offshore wind lead to expanded domestic deployment of renewable energy.
2) Hydrogen and New Fuels Utilization Scenario	Significant reductions in hydrogen production costs lead to expanded use of hydrogen and ammonia in thermal power generation, and of hydrogen, ammonia, synthetic fuels, and synthetic methane in non-electric sectors.
3) CO_2 Capture and Storage (CCS) Utilization Scenario	Increased CO_2 storage capacity and major cost reductions in capture, transport, and storage technologies lead to expanded CCS adoption in power generation and industry.
4) Innovative Technologies Expansion Scenario	Progress in a broad range of innovative technologies drives decarbonization across energy supply and demand sectors.
5) Technology Progress Scenario	Insufficient cost reductions in innovative technologies by fiscal year 2040 result in expanded deployment centered on existing technologies.

[1] *Following the Fukushima Daiichi nuclear accident, restarting NPPs that were shut down for regular inspections requires passing safety reviews under the new regulatory requirements set by the Nuclear Regulation Authority (NRA). In addition to this, although not a legal requirement, the formulation of evacuation plans and obtaining the consent of local governments are also considered necessary.*

[2] *ANRE, "Outlook for Energy Supply and Demand in FY2040 (Related Materials)," February 2025, p.6. (In Japanese)* https://www.enecho.meti.go.jp/category/others/basic_plan/pdf/20250218_03.pdf

D. ASSESSMENT OF THE EVOLUTION OF THE ENERGY MIX

RLRB-NDL does not conduct evaluations of the energy mix, such as scenario modeling or system-level impact studies, but it does provide information on assessments conducted by other organizations or experts to members of the National Diet.

II. CONSEQUENCES OF TECHNOLOGICAL CHOICES

A. CHALLENGES IN MANAGING THE DIVERSIFIED ENERGY MIX

As the amount of renewable energy – particularly PV – whose output fluctuates depending on weather, increases, the daytime electricity surplus grows. Until recently, output fluctuations have been adjusted using thermal power and pumped-storage hydroelectric power. However, these measures alone are no longer sufficient, leading to seasonal and time-dependent output curtailments for PV and wind power. Curtailment rates are particularly high in the Kyushu area[1], driven by three key factors: large-scale PV deployment relative to local demand, limited interconnection capacity, and a high share of inflexible nuclear power[2].

In response, in December 2023, ANRE formulated countermeasures, including demand-side actions such as demand response (DR), supply-side adjustments such as modifying thermal plant minimum output, and efforts to strengthen cross-regional interconnection[3].

B. MEASURES TO ENHANCE DEMAND-SIDE FLEXIBILITY

In Japan, DR primarily involves shifting factory operating hours in the industrial sector. However, adjusting operating schedules and changing employee work shifts are often burdensome. As a result, on-site generation and battery storage are increasingly viewed as key DR resources. There is also increasing interest in integrating large electricity consumers – such as data centers – into DR programs, e.g., by shifting computing loads to areas with surplus PV generation.

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[1] *It is the area served by Kyushu Electric Power Transmission and Distribution Co., Inc., located in the southwest of the Japanese archipelago and facing Korea across the sea.*

[2] *Nuclear plants are technically difficult to adjust in small increments over short periods, and once output is reduced, it cannot be easily restored. As a result, nuclear power is prioritized over variable renewables like PV and wind (ANRE, "Curtailment of Renewable Energy: Enabling Greater Renewable Integration," 7 September 2018. (In Japanese). https://www.enecho.meti.go.jp/about/special/johoteikyo/kyushu_syuturyokuseigyo.html).*

[3] *ANRE, "Initiatives to Reduce Curtailment of Renewable Energy Output and Related Efforts", 24 May 2024, pp.17–28. (In Japanese). https://www.meti.go.jp/shingikai/enecho/shoene_shinene/shin_energy/keito_wg/pdf/051_01_00.pdf*

On the residential side, efforts are also underway to leverage household-based distributed DR resources, such as remotely controllable heat pump water heaters and household storage batteries. Electric utilities offer remote control services that shift hot water production from nighttime to daytime hours, when PV generation is abundant – often combined with discounted electricity rates[1]. Given the small scale of individual household DR resources, aggregating and managing them collectively through aggregators is essential. To facilitate this, ANRE is working to standardize communication protocols and control interfaces for distributed DR resources.

C. IMPACTS OF THE EVOLUTION OF THE ENERGY MIX ON INFRASTRUCTURE

Japan's ten regional electric utilities – historically granted monopoly status – developed generation and transmission infrastructure to meet demand within their respective service areas. As a result, cross-regional interconnection lines remain relatively underdeveloped, even today, despite ongoing electricity market liberalization. The large-scale deployment of renewable energy – marked by output variability and uneven geographic potential – is expected to make supply-demand balancing increasingly difficult within individual regional service areas. This highlights the need to reinforce cross-regional interconnection lines, particularly from Hokkaido or the Tohoku area[2], where offshore wind development is anticipated, to the Tokyo area, a major demand center. Although approximately 1.2 GW of transmission capacity was added over the past decade, the 7th Strategic Energy Plan calls for more than 10 GW of additional capacity over the next ten years – an increase of more than eightfold. The government has expressed its intention to consider institutional measures to address challenges such as financing.

[1] Ibid., *p.19; "Hokuriku Electric Launches Daytime Heating for Eco-Cute to Reduce Renewable Energy Curtailment," Megasolar Business Plus, 3 March 2024. (In Japanese)* *https://project.nikkeibp.co.jp/ms/atcl/19/news/00001/04008/*

[2] *The Hokkaido area, served by Hokkaido Electric Power Network, Inc., is located in the northernmost part of the Japanese archipelago. The Tohoku area, served by Tohoku Electric Power Network Co., Inc., is located to the south of the Hokkaido area and to the north of the Tokyo area.*

D. IMPACTS ON INDUSTRIAL VALUE CHAINS

Battery technology is recognized as a key enabler for achieving carbon neutrality by 2050. The global battery market – both for automotive and stationary applications – is projected to expand substantially. However, Japan's global share of automotive lithium-ion batteries (LiBs) for electric vehicles (EVs) declined markedly – from 51.7% in 2015 to just 8.5% in 2022[1].

METI expects the steady global expansion of Japanese EVs, along with the recovery of Japan's global share of automotive LiBs. In August 2022, METI formulated the "Battery Industry Strategy," including quantitative targets for domestic and global manufacturing capacity by 2030. Furthermore, in an effort to strengthen supply chain resilience, METI aims not only to secure mining interests in battery metals such as lithium, nickel, and cobalt – key raw materials for batteries – but also to establish midstream refining processes domestically or in partner countries to the greatest extent possible[2]. In December of the same year, batteries and critical minerals (including battery metals) were designated as "specified critical materials" under the Economic Security Promotion Act. The Japanese government is now supporting the development of production facilities, technological innovation, mineral exploration, mine development, and refining operations.

III. SOCIAL ACCEPTABILITY OF THE ENERGY TRANSITION

A. PUBLIC ACCEPTANCE OF THE ENERGY TRANSITION

In a public opinion survey conducted by the Japan Atomic Energy Relations Organization (JAERO) between September and October 2024, respondents were asked, with multiple answers allowed, which types of energy they believe Japan should prioritize and develop in the future. A majority of respondents selected renewable energy sources such as PV (69.3%) and wind power (59.5%), while fewer supported the continued use of coal-fired power (8.7%), natural gas-fired power (16.9%), or nuclear power (22.4%). When asked how Japan should approach nuclear power generation in the future, the largest share of respondents (39.8%) selected "Continue using it for the time being, but gradually phase it out," followed by "Don't know" (33.1%). "Abolish it immediately" was selected by 4.9%, while 13.2% chose "Maintain the pre-Great East Japan Earthquake level of nuclear power generation,"

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[1] *Hideto Mayanagi, "Winning Strategies for Japan's Battery Industry and Efforts to Strengthen the Supply Chain: Challenges and Scenarios for Enhancing Competitiveness," DBJ Quarterly, No.55, July 2024, p.5. (In Japanese);* https://www.dbj.jp/pdf/co/info/quarterly/no_055_01.pdf

[2] *Public-Private Council for Strategic Review of Storage Battery Industry, "Battery Industry Strategy," August 2022, pp.14, 18. METI Website (In Japanese);* https://www.meti.go.jp/policy/mono_info_service/joho/conference/battery_strategy/battery_saisyu_torimatome.pdf*; Battery metals are geographically concentrated in a limited number of countries. The refining process also tends to be concentrated in China, where manufacturing costs are low.*

and 5.1% indicated that the use of nuclear power "should be increased." In response to a question about opinions on restarting existing NPPs (multiple answers allowed), some respondents expressed support, citing reasons such as "Considering the stable supply of electricity, restarting is necessary" (34.4%) and "Considering measures against global warming, restarting NPPs is necessary" (20.4%). By contrast, negative views were expressed, including "The public has not been convinced about moving forward with restarts" (40.6%) and "In a situation where there is no prospect for the disposal of radioactive waste, restarts should not be carried out" (27.0%)[1].

B. IMPACT OF THE ENERGY PRICE CRISIS

Compared with Europe and the United States, Japan experienced a smaller rise in energy prices in 2022. Nevertheless, the government continues to provide subsidies. The first is a subsidy aimed at lowering the price of fuels such as gasoline, which has been in place since January 2022[2]. The second is a subsidy to reduce electricity and gas charges, implemented from January 2023 to May 2024 and subsequently continued on a limited basis during the winter and summer seasons. In particular, the former fuel subsidy has been criticized by experts and senior government officials, who argue that it "hinders the shift from gasoline-powered vehicles to EVs" and that "it would be more beneficial to the public if the funds were redirected to supporting the development of decarbonization technologies." Despite such criticism, public demand remains strong for the government to prioritize measures against rising prices. Politically, attention has shifted toward a permanent reduction in the gasoline tax, which is viewed as having a greater and more enduring impact in easing the public burden than temporary subsidies.

Meanwhile, in response to decarbonization and energy security imperatives, the government reoriented its nuclear power policy. One such shift was a legal amendment passed in May 2023, which relaxed the operational limit on NPPs, previously capped at 60 years. Another was the adoption of the 7th Strategic Energy Plan in February 2025, which set forth a policy of "maximizing the use" of nuclear energy. Until then, the prevailing policy had been to "reduce the dependence on nuclear power as much as possible." One factor contributing to this reorientation was the growing public support for restarting NPPs.

[1] *JAERO, Public Opinion Survey on Nuclear Power (FY2024) – Survey Results, pp.33, 35, 38. (In Japanese)* https://www.jaero.or.jp/_files/poll/results_2024.pdf

[2] *ANRE, "Fixed-amount fuel price reduction measures" (In Japanese)* https://nenryo-teigakuhikisage.go.jp/

C. CONTROVERSIAL OR PUBLICLY RESISTED TECHNOLOGIES

Regarding nuclear energy, earthquakes remain a major point of dispute. For example, in a civil action brought by local residents challenging the continued operation of the Tokai No. 2 NPP, the anticipated seismic intensity emerged as a central point of contention. In March 2021, the Mito District Court ordered the suspension of its operations, citing insufficient evacuation plans (the case is currently pending at the Tokyo High Court). Although the Tokai No. 2 plant received regulatory clearance from the Nuclear Regulation Authority (NRA) in November 2018, the ruling has delayed its restart. As another example, in November 2024, following a nine-year review, the NRA denied the application for restarting Unit 2 of the Tsuruga NPP, on the grounds that the presence of an active fault beneath the plant could not be definitively excluded. In the aforementioned JAERO public opinion survey, when asked whether NPPs pose a safety risk in a seismically active country like Japan, 58.0% answered "yes" or "somewhat yes," significantly exceeding the 8.3% who answered "no" or "somewhat no[1]."

Regarding PV, rapid expansion has triggered growing tensions with neighboring residents, and opposition to new installations is increasingly observed. Many residents have raised concerns that land clearing for solar panel installation may increase the risk of landslides on mountain slopes. Further concerns have been raised regarding the potential contamination of water sources resulting from panel damage or improper disposal. An increasing number of local governments have enacted ordinances governing PV project implementation, such as those requiring operators to obtain prior approval from municipal authorities before commencing operations. Comparable concerns have emerged in relation to onshore wind power projects, which have encountered resistance from residents and municipal authorities citing potential impacts of deforestation on water resources and landscape integrity, resulting in the cancellation of certain projects.

D. DEBATE REGARDING THE REALISM, COST, OR SOCIAL EQUITY OF THE ENERGY TRANSITION

A defining feature of Japan's energy policy lies in its strategic objective of decarbonizing thermal power generation through the deployment of hydrogen, ammonia, and CCS. However, critics have pointed out that the cost of power generation at thermal plants employing these technologies may exceed those of PV and wind power by a factor of two to three, and that the technical and geographical feasibility of CCS remains uncertain in earthquake-prone Japan. With respect to the 2040 target for nuclear power generation, which envisions nuclear contributing 20% of the power generation

[1] *JAERO*, op. cit.*(13), p.49.*

mix, critics contend that the target is unrealistic, as it would necessitate the operation of a substantial number of both existing and under-construction nuclear facilities. These issues have also been the subject of debate in the National Diet.

With respect to social equity, it has been pointed out that current decarbonization policies, such as schemes that impose renewable energy surcharges on the public, are exacerbating energy poverty[1]. In the context of carbon pricing, some experts have called for measures to alleviate the burden on low-income households, whose energy costs account for a relatively high share of their income[2]. In the National Diet, discussions have arisen – under the perspective of 'just transition' – on how to address unemployment expected to result from future industrial restructuring.

[1] *"Energy-saving subsidies benefit high-income earners – Interview with Moegi Igawa, Assistant Professor at Doshisha University, expert on 'energy poverty'", The Mainichi Shimbun, 31 December 2024. (In Japanese)*

[2] *"Reducing the burden of carbon pricing through cash-back while promoting decarbonization – Canada returns 90% of revenues to citizens," The Asahi Shimbun, 10 July 2024. (In Japanese) https://www.asahi.com/articles/ASS782GFLS78ULBH006M.html*

LITHUANIA

Committee for the Future of the Seimas

I. ENERGY MIX AND THE CARBON NEUTRALITY OBJECTIVE (2050)

A. EVOLUTION OF ENERGY DEMAND

Lithuania's energy demand structure has undergone significant transformation in recent years, driven by increased electrification, electric mobility adoption, and heat pump deployment. The country is experiencing substantial growth in electricity consumption, particularly from renewable sources. In 2024, renewable energy sources accounted for 35.1% of final energy consumption and 47.01% of electricity consumption. The demand evolution reflects Lithuania's strategic shift toward an electricity-based economy, with projections indicating continued growth to support full decarbonisation by 2050.

B. CURRENT ENERGY MIX AND 2050 OBJECTIVES

Current Status (2024):

- Total installed wind and solar capacity: 5.1 GW (six-fold increase since 2020)
- Over 160,000 prosumers with combined capacity exceeding 2.1 GW
- 7 operational biomethane plants supplying the grid
- Complete independence from Russian energy imports (gas, oil, electricity)

2030 Targets:

- 100% electricity generation from renewable sources
- 55% share of renewables in final energy consumption
- Solar capacity target: 4,100 MW (more than 50% already achieved)
- Onshore wind target: 4,500 MW (more than 50% already achieved)
- At least 10 additional biomethane plants producing ~1.4 TWh annually

2050 Vision: Lithuania aims to become a net energy exporter with a climate-neutral energy sector, creating high value-added energy industry. Strategic objectives include:

- Full climate neutrality through zero-emission electricity and fuels
- Extensive offshore and onshore renewable deployment
- Hydrogen economy development (up to 8.5 GW electrolysis capacity, 732,000 tonnes green hydrogen production)
- Possible deployment of 0.5-1.5 GW Small Modular Reactors (SMRs) for system balancing

C. TRANSFORMATION PATHWAYS

Lithuania's decarbonisation strategy rests on three pillars:

Energy Security Infrastructure: Following decades of Soviet dependence, Lithuania has achieved complete energy independence through strategic projects:

- LNG terminal "Independence" in Klaipėda
- Gas interconnection with Poland (GIPL, operational since May 2022)
- Electricity interconnections: LitPol Link (Poland), NordBalt (Sweden)
- Oil terminal and refinery infrastructure
- Grid synchronisation with Continental Europe (February 9, 2025), ending 60+ years of dependence on the Russia-controlled BRELL ring

Renewable Energy Expansion: Accelerated deployment of wind and solar capacity, supported by:

- Favourable natural conditions and access to Baltic Sea offshore resources
- Production levy model redistributing benefits to local communities and residents
- Renewable energy community framework engaging citizens directly
- Strategic focus on both distributed generation (prosumers) and utility-scale projects

System Flexibility and Integration: Development of:

- Energy storage facilities and demand-side management
- Green hydrogen infrastructure, including the North-Baltic Hydrogen Corridor (6 EU countries, operational target: 2033)
- Enhanced grid infrastructure for variable renewable integration
- Cross-border cooperation strengthening regional energy markets

D. RECENT ASSESSMENTS

Key studies informing Lithuania's strategy:

- **National Energy Independence Strategy (NEIS) 2050:** Comprehensive roadmap for climate-neutral energy system
- **National Energy and Climate Action Plan (NEKSVP):** Five-dimensional framework including energy security, efficiency, market development, innovation, and climate mitigation
- **DNV Study on SMRs:** Preliminary assessment of fourth-generation SMR deployment potential (~2040 operational start)
- **Hydrogen Development Guidelines 2024-2050:** Analysis projecting €2.2 billion investment by 2030, €14.4 billion by 2050, creating up to 20,000 jobs

A significant achievement: In 2025, Lithuania recorded 47 days when domestic electricity generation exceeded demand (compared to just 5 days in 2024), with 4 days powered entirely by renewables.

II. CONSEQUENCES OF TECHNOLOGICAL CHOICES

A. TECHNICAL AND OPERATIONAL CHALLENGES

Managing Lithuania's increasingly diversified energy mix presents several challenges:

Grid Balancing: Integration of variable renewable sources (wind and solar now exceeding 5 GW) requires sophisticated balancing mechanisms. The system must accommodate significant generation fluctuations while maintaining stability and reliability.

Infrastructure Modernisation: The February 2025 synchronisation with Continental Europe required extensive technical upgrades:

- Over 40 projects implemented (20 in Lithuania)
- New transmission lines, substation modernisation, synchronous compensators
- Advanced control systems for frequency management
- Total programme value: €1.6 billion (€1.2 billion EU CEF funding)
- Lithuania's share: €700 million (€460 million EU support)

System Flexibility: The transition to high renewable penetration necessitates:

- Dispatchable generation capacity (potentially SMRs post-2040)
- Large-scale energy storage solutions
- Demand-side flexibility mechanisms
- Regional cooperation for cross-border balancing

B. DEMAND-SIDE FLEXIBILITY MEASURES

Lithuania is implementing several flexibility-enhancing measures:

- **Prosumer Development:** Over 160,000 prosumers actively participate in energy management
- **Energy Communities:** Framework enabling local communities to develop shared renewable projects
- **Smart Grid Technologies:** Advanced metering and control systems deployment
- **Load Management Solutions:** Integration of demand response capabilities with renewable generation patterns

The production levy model redirects revenues from large-scale renewable generators to communities and nearby residents, fostering local acceptance and engagement.

C. INFRASTRUCTURE IMPACTS

Electricity Networks: The synchronisation project dramatically enhanced grid capability:

- Independent frequency control without Russian dependency
- Improved reliability and resilience against disruptions
- Enhanced capacity for bidirectional flows
- Better integration of distributed generation

Cross-Border Flows: Strengthened interconnections enable:

- Energy export opportunities to Poland and Sweden
- Regional market integration and price convergence
- Shared balancing resources across Baltic and Nordic regions
- Strategic energy corridor development toward Central Europe

Gas Infrastructure:

- GIPL interconnector ensuring diversified supply routes
- LNG terminal capacity supporting regional security
- Emerging hydrogen infrastructure (North-Baltic Corridor) for future energy vectors
- Biomethane injection points expanding renewable gas options

D. INDUSTRIAL VALUE CHAIN IMPACTS

Manufacturing and Localisation:

- Renewable energy industry creating approximately 7,000 jobs by 2030, 20,000 by 2050
- Emerging hydrogen economy requiring €2.2 billion investment by 2030
- Potential nuclear supply chain development if SMR pathway pursued
- Growth in energy technology services and smart grid solutions

Strategic Dependencies: Lithuania actively addresses technology dependencies through diversified renewable equipment supply chains, EU-based hydrogen technology partnerships, US-Lithuanian cooperation on nuclear technology (government agreement signed), and memorandum with Italy's Newcleo on fast neutron reactor technology assessment.

Critical Infrastructure Protection: Lithuania, Latvia, Estonia, and Poland jointly developed the **Flagship Model of Excellence** for energy infrastructure protection, based on four pillars: deterrence, detection, protection (including UAV detection, electronic protection, security perimeters), and recovery capabilities with critical component reserves.

Since late 2023, multiple incidents damaged Baltic Sea infrastructure (Balticconnector pipeline, Estlink 2 cable, C-Lion1 and BCS East-West Interlink data cables), costing ~€40 million in repairs but €200-250 million in increased energy costs to consumers. Lithuania advocates for a dedicated Power Protection Vehicle (PPV) funding mechanism within the EU's 2028-2034 Multiannual Financial Framework.

III. SOCIAL ACCEPTABILITY OF THE ENERGY TRANSITION

A. PUBLIC ACCEPTANCE LEVEL

Lithuanian society demonstrates strong support for energy transition:

- 76% support renewable energy expansion as strengthening national independence
- Over 75% approval for strategic decisions: complete rejection of Russian gas, synchronisation with Continental Europe, electricity interconnections with EU neighbors
- 44% willing to pay more for clean energy
- 16-fold increase in prosumer participation (from 10,000 in 2020 to 160,000+ in 2024)

This broad acceptance stems from clear understanding that energy security and climate goals are mutually reinforcing, particularly in the current geopolitical context.

B. IMPACT OF 2022 ENERGY CRISIS

Lithuania's experience during the 2022 crisis was uniquely positive. As the first EU member state to completely terminate gas, oil, and electricity imports from Russia (both de jure and de facto), Lithuania demonstrated that energy independence is achievable without significant supply disruptions or consumer impact.

This successful transition strengthened public confidence in energy policy. The timely completion of critical infrastructure (LNG terminal "Independence", diversified electricity interconnections, GIPL gas interconnector launched May 2022) meant Lithuania was prepared when the crisis struck, reinforcing political consensus on energy security priorities.

C. TECHNOLOGY CONTROVERSIES

Wind and Solar Energy: Broadly accepted with minimal resistance. The production levy model (operational since 2024) effectively addresses local concerns by redistributing revenues from commercial renewable generators to community organisations for social, environmental, and economic projects, and direct payments to residents living near installations. This mechanism has significantly reduced local opposition.

Small Modular Reactors (SMRs): The approach is cautious and evidence-based. A government-working group was established in 2025 to assess deployment feasibility, awaiting real-world data from Western projects (Canada's BWRX-300 at Darlington ~2029, US demonstration reactors). The focus is on business model viability, cost analysis, safety framework, and fuel supply security. Decision is contingent on actual electricity demand growth and renewable integration experience, with preliminary timeline of possible 0.5-1.5 GW deployment around 2040 if justified.

Hydrogen Technology: While strategically important, hydrogen faces economic challenges. Lithuania's largest fertilizer producer (Achema) cancelled its green hydrogen project in 2024 due to market uncertainties and unfair competition from Russian "grey hydrogen" fertilizers. Concerns exist about high costs, unclear ammonia sector decarbonisation strategy, and technological maturity.

D. PUBLIC DEBATE ON REALISM AND SOCIAL EQUITY

Parliamentary and public discourse focuses on:

Affordability and Distribution: The production levy model ensures local communities benefit from renewable projects. The energy community framework enables collective investment and shared benefits. There is concern about protecting vulnerable consumers from energy poverty.

Infrastructure Security Costs: Growing awareness that critical infrastructure protection requires substantial investment. Support exists for joint Baltic-Polish initiatives and EU funding mechanisms (proposed PPV), with recognition that security costs are necessary given demonstrated threats.

Pace and Feasibility: General consensus that 2030 renewable targets are achievable (already over 50% progress on wind/solar goals). More uncertainty exists about hydrogen timeline and SMR decisions. Emphasis is on evidence-based policy adjustments.

Democratic Legitimacy: Lithuania's energy policy benefits from remarkable political stability and continuity across decades and different governments. This long-term strategic consistency has enabled complex, expensive decisions that proved essential for security and successful transition, strengthening public trust in energy policy institutions and ambitious climate commitments.

This contribution has been prepared based on the memorandum provided by the Ministry of Energy of the Republic of Lithuania for the EPTA Conference.

LUXEMBOURG

Cellule scientifique de la Chambre des Députés

I. ENERGY MIX AND THE CARBON NEUTRALITY OBJECTIVE (2050)

A. HOW HAS THE STRUCTURE OF ENERGY DEMAND EVOLVED IN YOUR COUNTRY IN RECENT YEARS?

Due to its small size (2,586 km2) but dynamic economy with a GDP of approx. USD 140,000 per capita, the Grand Duchy of Luxembourg is heavily dependent on foreign countries, importing nearly 88% of its primary energy needs. Nevertheless, the energy intensity of its economy has been divided by two since 2000. Luxembourg has total energy- related annual CO_2eq emissions of 7 Mt (2022 values), representing 0.02% of global emissions, with a decrease of 16% compared to 2000.

Electricity

The total electricity consumption in 2024 was 6,340 GWh, corresponding to a 3.2% decrease compared to the years before the sanitary and energy crises, and an electricity consumption per capita reduced by 27% compared to 2000. During the same period, a population increase from approx. 440,000 residents in 2000 to approx. 680,000 in 2024 must be noted.

Natural gas

Luxembourg is importing its natural gas exclusively from Belgium, with a total of 6,705 GWh in 2024. Before the sanitary and energy crises, the demand in natural gas was 25% higher. Industry is by far the highest natural gas consumer (65%). On the residential side, the installation of gas heating is being phased out and shifting to an electrified model with heat pumps, coupled to domestic PV modules.

(Sources: Institut luxembourgeois de régulation - ILR; International energy agency - IEA; National energy and climate plan – NECP)

B. WHAT IS THE CURRENT COMPOSITION OF THE ENERGY MIX, AND WHAT ARE THE KEY POLICY OBJECTIVES OR PROJECTIONS BY 2050 (E.G. SHARE OF FOSSIL FUELS, NUCLEAR, RENEWABLES)?

Luxembourg has a fossil fuel intensive energy mix driven by a high demand for transportation fuels, notably from transiting freight trucks and commuters. Despite this demand, the country is committed to reducing emissions. Its Climate Law and National Energy and Climate Plan (NECP) set targets for a 55% emission reduction by 2030 and climate neutrality by 2050.

By 2030, the part of renewable energy sources in the final consumption is ought to attaign 37%, together with an energy efficiency improvement and a subsequent decrease in consumption of 42%.

The government has adopted numerous measures to push for energy transition, including a carbon tax which was introduced in 2020 and encouraging renewable generation through subsidies and auctions. Several programmes also support energy efficiency in buildings, industry and transportation.

The overall strategy of Luxembourg's energy policy is to shift towards utmost electrification of all sectors, including industry, mobility, heating of buildings, etc. The last electric power generation unit relying on natural gas was closed in 2016.

Energy pix

The 2024 energy mix is composed of 56.3% oil products, 17.6% electricity, 15.5% natural gas, 5.9% biofuels and waste, 3.9% heat and 0.8% coal.

Final consumers are mainly transport (51%), industry (16.5%), residential (15.2%) and commercial and public services (14.9), while agriculture only accounts for 0.8% of the total energy demand. This again is the result of the specificty of Luxembourg as a central European transit location and services-intensive economy.

Electricity demand

The country's electricity demand reached 5,997 GWh in 2024, excluding the 343 GWh of autoconsumption (industry and household). Industry evidently was the highest consumer with a share of 55%, followed by commercial and public services (28%), and residential (17%).

A total of 4,915 GWh of electricity were imported in 2024 from neighbouring countries, representing 77.5% of the total electricity demand. Before the COVID-19 pandemic, 84.1% of electric energy was imported. Germany is the main electric energy supplier (57%), followed by Belgium (25%) and France (18%). Due to this specificity, it is difficult to calculate the exact mix and origins of energy flows towards Luxembourg.

The final commercial mix of electricity can more easily been calculated: it was composed in 2022 of 62.6% renewables, 30.3% were of fossil origin, whereas only 6.3% were provided upon nuclear power generation. Compared to 2009, the carbon footprint of electricity in Luxembourg has been divided by four (2022 data).

Electricity production

Luxembourg's proper electricity production accounts for 22.5% of the total needs, with a steep increase of the domestic power generation due to ever higher numbers of electric PV installations – which tripled in 2024 compared to 2023 – and wind power units (467 GWh in 2024). The part of renewable energy sources in the local production is of 88%. The 1,333 GWh of renewable energy produced in 2024 exceed the total consumption of households.

(Sources: Institut luxembourgeois de régulation - ILR; International energy agency - IEA; National energy and climate plan - NECP)

C. WHAT TRANSFORMATION PATHWAYS ARE CURRENTLY UNDER DISCUSSION OR IMPLEMENTATION TO ACHIEVE DECARBONISATION GOALS?

Luxembourg is at a pivotal moment in its energy transition. While the current Coalition agreement 2023-2028 and the NEPC set the political basis, the strategic implementation has still to be driven forward, given the structural, economic and demographic constraints of the country.

A national consultation – *simple-fast-renewable* – with stakeholders of the energy, climate, sustainability, governmental, municipal, craftmenship and industrial sectors was initiated in early 2025. The national consultation aimed at accelerating and simplifying the deployment of renewable energies in Luxembourg in order to strengthen resilience and contribute to climate protection with a minimal impact on people and the environment. The outcome was a proposal of 51 measures for a swift energy transition and the consolidation of Luxembourg's increased energy independence. The suggestions of measures span over five categories:

(i) Simplified and digitised procedures;

(ii) Mobilisation of land and land use for initiatives such as agri-PV, valorisation of zones alongside motorways and railroads;

(iii) Increased and adapted financial support for consumption and production shifts;

(iv) Citizen participation and involvement of municipalities; information and sensibilisation;

(v) Strengthening of the electricity grid.

Moreover, Luxembourg is shaping and progressively deploying a green hydrogen strategy. Specific targets are the heavy industry (e.g. steel, aluminium, chemicals, cement) and freight. The Taskforce H2 Luxembourg is mandated to set the legal framework, to identify strategic opportunities, to cooperate with EU member states, to conduct research and innovation, in order to realise the necessary instruments for a renewable hydrogen market.

(Sources: Accord de coalition 2023-2028; National energy and climate plan - NECP; Fondation IDEA - Article F. Meys; National consultation "simple-fast-renewable"; Stratégie hydrogène du Luxembourg)

D. HAS YOUR ORGANISATION CONDUCTED ANY RECENT ASSESSMENT OF THESE EVOLUTIONS (E.G. SCENARIO MODELLING, SYSTEM-LEVEL IMPACT STUDIES)? IF SO, COULD YOU BRIEFLY DESCRIBE THE FINDINGS?

On the topic of the energy transition, the research service of the Parliament of Luxembourg has recently published a research paper on CO_2 taxation an its consequences on behavioral and socio-economic changes, specifically concerning transport and the commerce of fuel products. Modelisations and projections towards 2030 were included by varying the amount of CO_2 taxes. Societal acceptance, the potential impact of CO_2 taxation on attaining climate change goals, and the distribution of CO_2 tax incomes for environmental and social initiatives were investigated. A comparison with other European countries was performed, and the possibility for a "globally" harmonised CO_2 taxation system was discussed.

Moreover, the *Cellule scientifique*, in collaboration with the University of Luxembourg, inquired about the potential of agri-PV in a dedicated Chapter of a research document on the interplay of agriculture and environmental issues. Different agri-PV (pilot) systems and their benefits to farmers beyond generation of electricity, the enhancement of land use efficiency and the potential of the technology in providing energy security are described, as well as the role of agri-PV in protecting biodiversity and ecosystems.

(Sources: Carbon taxation - Cellule scientifique; Agriculture and environment - Agri-PV - Cellule scientifique)

II. CONSEQUENCES OF TECHNOLOGICAL CHOICES

A. WHAT ARE THE MAIN TECHNICAL OR OPERATIONAL CHALLENGES ASSOCIATED WITH MANAGING A MORE DIVERSIFIED ENERGY MIX IN YOUR COUNTRY?

Luxembourg's NECP envisages a 200% increase in renewable electricity, a 340% increase in renewable heat and a 280% increase in renewable fuels by 2040. This considerable growth will have a major impact on the country's energy landscape. The growth in renewable electricity will be driven mainly by the development of wind, solar and biomass energy. As a result, by 2040, some 75% of national production will be covered by highly variable sources requiring smart electricity grids to ensure stability of supply and energy storage. Due to the size of the country and the steady demographic development, the continued dependency on electricity imports will require an expansion and modernisation of the electricity grid.

A foresight scenario

The energy transition has the additional effect of profoundly changing the role of electricity consumers. This is in addition to the transformation of existing transport and distribution infrastructure and the creation of centralised renewable energy facilities such as wind and solar power. Yesterday's simple electricity consumers are becoming today's "prosumers" and "flexsumers" (citation T. Eischen), who not only generate their own electricity, consume part of it, feed the surplus into the grid and, together with local storage systems, can provide flexibility to the electricity system. These changes in roles introduce a new complexity into the electricity system, which can only be managed by digitising the entire system.

The redefinition of the customer profile is coupled to the redefinition of the roles of network operators and suppliers. Network operators, otherwise responsible for distributing electricity, are becoming dynamic operators who digitally manage a decentralised system, balancing renewable production and consumption in real time. Suppliers, formerly focused on selling electricity to consumers, are shifting into energy service providers. In addition to managing the flexibility and integration of renewable energies, they offer complete solutions such as the installation of photovoltaic panels, heat pumps, batteries and charging stations. In addition, they support the creation of energy communities, enabling consumers to produce, share, store and consume their own energy collectively and in an optimised manner.

(Sources: National energy and climate plan - NECP; Fondation IDEA - Article T. Eischen; CREOS Network development plan 2024-2034 - Electricity Transmission Grid)

B. WHAT MEASURES ARE BEING IMPLEMENTED OR CONSIDERED TO ENHANCE DEMAND-SIDE FLEXIBILITY (E.G. TIME-OF-USE TARIFFS, DEMAND RESPONSE)?

Luxembourg's electricity providers have recently introduced – through a government initiative – a new network use tariff structure based on daytime- and intensity-dependent use of eletricity in the residential and small tertiary sectors. As an example, a household that charges its battery electric vehicle (BEV) in the evening when peak consumptions most likely occur throughout the country, the customer will be charged more than if the BEV is reloaded during low consumption periods on other daytime periods.

Several further electricity production and consumption models are actively promoted (cf. *Section 2.1*):

(i) Autoconsumption of renewable energy produced locally/privately;

(ii) Proximity energy sharing models, i.e. electricity sharing groups;

(iii) Decentralised energy production & consumption (e.g. agri-PV);

(iv) Local battery storage;

(v) Improved peak production and peak consumption management through digitalisation.

Subsidies for PV, household battery storage and heat pumps will (continue to) be offered. In the industry sector, financial incitation programmes for decarbonising on-site production and consumption also exist.

(Sources: We Share Energy; A new network use tariff - MyILR; Step up for your energy transition | Klima-Agence)

C. HOW IS THE EVOLUTION OF THE ENERGY MIX AFFECTING ELECTRICITY AND GAS INFRASTRUCTURE (E.G. GRID CAPACITY, RELIABILITY, CROSS-BORDER FLOWS)?

CREOS Luxembourg, the country's electricity Transmission system operator (TSO; 220 kV high-voltage) and Distribution system operator (DSO; 65kV, 20kV and 400V), has elaborated a network development plan for the decade from 2024 to 2034, with an outlook towards 2040. This is a strategic roadmap to ensure efficient energy supply for the coming decades, following the four objectives of security of supply, sustainable development, cost efficiency and innovation.

The electricity transmission grid will have to be expanded and upgraded in the next years, in order to cope with the future increasing peak power demands, due to electrification of the mobility sector, the widespread adoption of heat pumps, decarbonisation of industrial processes and national hydrogen production. In 2023, the peak load on the electricity grid reached

824 MW, and is expected to rise to no less than 3,200 MW by 2040. Therefore, the first priority is the CREOS 380 project, an ambitious plan to expand transmission lines to a 380 kV level (220 kV today), especially with the connection to Germany, the main exporter of electricity towards Luxembourg.

A complete digitalisation will be needed to manage the diversified and increasingly volatile profiles of production and consumption of electricity. Cybersecurity will also play a crucial role in grid safety and security.

Concerning natural gas, currently an essential player in the energy supply, a significant reduction in consumption is to be expected over the next decade in order to achieve climate goals. The existing infrastructure will need to be redesigned. The two options are a progressive deinvestment or the transformation of the distribution grid for new vectors such as hydrogen or biogas.

In forecast to 2030, the country's investments in the energy transition will reach over 8.4 billion euro, corresponding to more than 1.2% of the annual GDP. More than half of the budget will be dedicated to the transport sector, while more than 1.6 billion euro will be invested in renewable energies such as PV and wind power.

(Sources: CREOS Scenario report 2040; CREOS Network development plan 2024-2034 - Electricity Transmission Grid; Transition énergétique: 8,4 milliards devront être investis d'ici 2030 - Virgule; Fondation IDEA - Article T. Eischen; Fondation IDEA - Article G. Trauffler; Stratégie hydrogène du Luxembourg)

D. WHAT ARE THE ANTICIPATED IMPACTS ON INDUSTRIAL VALUE CHAINS (E.G. MANUFACTURING CAPACITY, LOCALISATION, STRATEGIC DEPENDENCIES)?

Electrification of industrial processes and decarbonisation of the industry is a question of feasibility, deployment in time, transition phase management and most importantly competivity. The energy transition should be seen as a strategic opportunity to bolster industrial competitiveness, through improvement of efficiency and resilience. Luxembourg's industrial sector contributes to approx. 7% of the country's GDP, employs around 12% of the total workforce, and the steel industry itself accounts for approx. 15% of the total export value. High energy prices and volatility, as well as the energy infrastructure challenges for the future intensify industry's vulnerability. But in the same time it presents opportunities for change, if well accompanied and strategically planned. Adopting self- generation and on-site use of electricity, streamlining permitting processes for renewable energy projects, establishing national funds for high-impact technologies are a few examples of the action plan for a swift energy transition in the industrial sector. Luxembourg's parliament voted in 2025 for an industrial decarbonisation investment plan of 420 M€ for the period 2026-2038.

Concerning competitiveness, adoption of renewable hydrogen as the main industrial energy carrier is still a bottleneck, as the price of green hydrogen is two to three times higher than blue hydrogen and four to six times higher than fossil energy carriers, mainly oil and gas. Even efficient H_2 production sites and cross-boarder distribution grids will not counteract this fact in the nearer future.

Further, Luxembourg has developed a "Vision ECO2050" scenario model that takes into account the demographic, industrial, infrastructural and technological development troughout the next decades. The concept is divided in ten key pillars for the future development of the country's economy, and include southern-concentrated industrial hubs, progressively electrified heavy industry, a H_2 strategy, electrified multimodal transport, circular economy models, new recycling & revalorization strategies, concentration of data center hubs, innovation campuses, development and attraction centres, FinTech, HealthTech and CleanTech hubs, etc.

(Sources: Vision ECO2050; Fondation IDEA - Article G. Trauffler; Les députés votent 420 millions d'euros d'aides pour décarboner l'industrie - Virgule)

III. SOCIAL ACCEPTABILITY OF THE ENERGY TRANSITION

A. HOW WOULD YOU CHARACTERISE THE LEVEL OF PUBLIC ACCEPTANCE OF THE ENERGY TRANSITION IN YOUR COUNTRY?

Public acceptance rises beyond trust in new systems. In Luxembourg, the majority of the population seems to be in favor of the energy transition and climate action, as shown in surveys over the last 10-15 years. The transition should be fair and equitable, and provide stability around people's and family's everyday life. Many information campaigns have been organised, and the national Climate Agency guides individual households, cooperatives and businesses on their way to climate-friendly and decarbonised solutions. Sustainable energy systems-related education is also on its way, e.g. through the "Solar@School" campaign from Eurosolar.

(Sources: Résultats sondage national : les luxembourgeois·es veulent des économies d'énergie et de ressources - CELL; Public opinion on climate change action in Luxembourg - OPC Report 2025: Transition énergétique: le Luxembourg convaincu et impliqué - Paperjam News; Step up for your energy transition - Klima-Agence; Energy transition article - Eurosolar)

B. TO WHAT EXTENT HAS THE ENERGY PRICE CRISIS OF 2022 INFLUENCED PERCEPTIONS OF ENERGY POLICIES AND CLIMATE COMMITMENTS?

Perceptions are not only a consequence of energy prices, as has been noticed in Luxembourg, where the government covered for the supplementary costs for households and businesses from 2022 to 2024. The Luxembourg population nevertheless got aware of energy savings, and were introduced to the energy transition and the progessive phasing out of natural gas and other fossil energy sources. Ongoing subsidies for climate- friendly mobility, construction, renovation and heating also encourage people to co-invest in the energy transition. The proportion of full electric vehicles has risen to nearly 20%, the number of private PV installations has more than tripled within one year, and heat pumps are the new standard for heating.

Since 2025, state subventions only cover 50% of the exceeding amounts in electricity prices anymore, and the electricity bill of households is likely to rise by 30%. Nevertheless, the population seems to adhere to these important shifts – the low-income households receiving additional help from the government.

As mentioned above, citizen participation and sensibilisation campaigns will also be in favor of people's adhesion to the new concepts of living and consuming energy in relation to climate change.

(Sources: Fondation IDEA - Article T. Eischen; Energy transition article - Eurosolar; National consultation "simple- fast-renewable"; Step up for your energy transition - Klima-Agence; State contribution to electricity costs for households - Ministry of the Economy;)

C. ARE THERE SPECIFIC TECHNOLOGIES (E.G. WIND POWER, NUCLEAR ENERGY) THAT RAISE SIGNIFICANT CONTROVERSY OR PUBLIC RESISTANCE?

Luxembourg's population is particularly hostile to nuclear energy. A nuclear power plant (NPP) is situated on the French border to Luxembourg. The Cattenom NPP, the third biggest in France with a power capacity of 5,200 MWe, has been deployed at the end of the 1980's. Since then, Luxembourg's population, neighbouring municipalities, the government and the parliament (more than 120 parliamentary questions since 2005) regularly contest the long- term reliability and safety of the NPP, and claim for its closure. However, Luxembourg's continued opposition to nuclear energy could also bear a "substantial competitive risk for the country and its industry sector", according to Gaston Trauffler from the FEDIL, a multisectoral business federation of industrials and entrepreneurs.

(Sources: Le Luxembourg adopte une position critique à l'égard de la prolongation de la durée de la centrale nucléaire de Cattenom – Le gouvernement luxembourgeois;

Une trentaine de communes luxembourgeoises s'allient contre le nucléaire - RTL Infos; Quelle part le nucléaire représente-t-il dans l'électricité du Luxembourg? - Virgule; Centrale nucléaire de Cattenom - Wikipédia; Fondation IDEA - Article G. Trauffler)

D. IS THERE AN ONGOING PUBLIC OR PARLIAMENTARY DEBATE REGARDING THE REALISM, COST, OR SOCIAL EQUITY OF THE ENERGY TRANSITION?

The climate emergency, claiming for energetic efficiency and renewable energies, is now enshrined in the Constitution of Luxembourg (Article 41). An "energy transition" bill (PL8317) was introduced to the Chamber of Deputies at the end of 2023. The project for the new law is still under discussion, and exchanges with many stakeholders ongoing.

At a regularly basis, parliamentary questions for the government arise on the topic of energy transition, e.g. on the decarbonisation strategy of Luxembourg's (steel) industry (QP 2025/2518), a platform for climate action and energy transition (QO 2023/81) or nuclear energy (QP 2023/7754).

A large climate debate with citizen participation occured in 2022/2023 – the "Klima-Biergerrot" - and enabled to discuss proposals from the civil population with political decision makers. This government-initiated project resulted in 56 recommendations for combating global warming in Luxembourg.

(Sources: Bill 8317 Energy Transition; Final report - Klima Biergerrot)

THE NETHERLANDS

Rathenau Instituut
Authors: Allerd Nanninga, Vincent Lagendijk, and Rinie van Est

I. ENERGY MIX AND THE CARBON NEUTRALITY OBJECTIVE (2050)

A. THE DEVELOPMENT OF THE ENERGY MIX IN THE NETHERLANDS

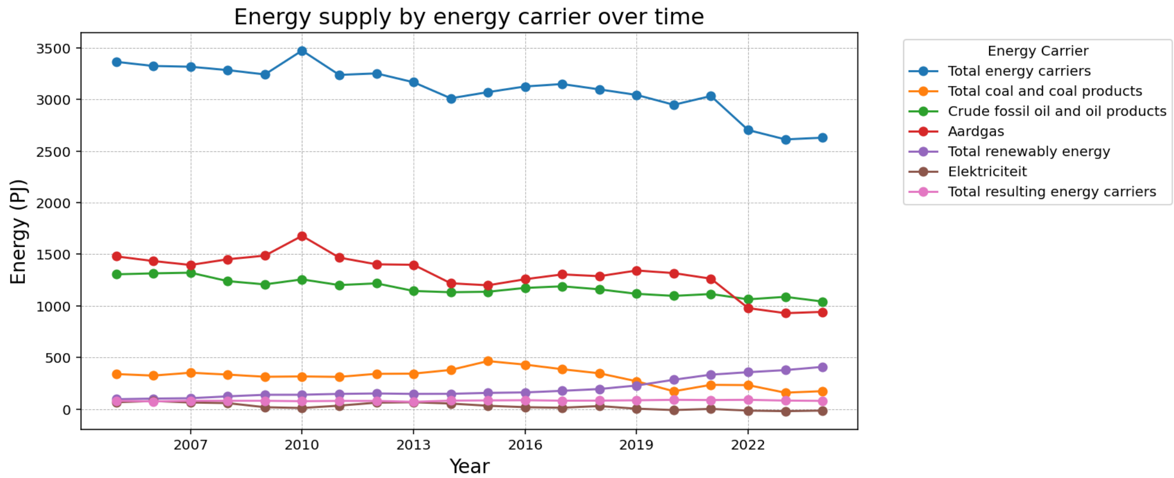
In the Netherlands, 80% of the total energy demand comes from three sectors. A third of the total is consumed by industry, whereas transport and housing both take up about a quarter. The remaining 20% of the energy consumption comes from other sectors, such as agriculture and services (see figure 1; CBS, n.d.).

Dutch industry predominantly uses natural gas, oil and electricity. Coal is used to a much lesser extent but does represent a large portion of industry's greenhouse gas emissions. Over the last two decades, both industrial electricity and gas usage have declined with about 24%. Coal and oil consumption is similar to that in 2005, albeit after a brief increase followed by a decline. The relative share of coal and oil has increased over the last two decades.

The overall energy consumption of households has decreased by around 26%. This decline is largely attributable to a decrease in the use of natural gas, on which households rely most. Electricity consumption has remained relatively stable over the past two decades (CBS, n.d.). Meanwhile, the adoption of renewable energy in households has grown, particularly through residential heat pumps, which reached an estimated 2 million units by the end of 2024 (CBS, 2025b).

The transport sector predominantly relies on oil. Like in the other sectors, the total energy use has declined, and in this sector with about 17% over the last two decades. In 2005, oil made up about 99% of the total energy mix for transport. This has dropped to 86% in 2024. In 2024, biofuel made up for about 9% (CSB, 2025), and (renewable) electricity about 4% of the energy mix (CBS, n.d.). The amount of electricity use for transport has doubled since 2020, mainly due to the recent growth in fully electric vehicles which rose to roughly 600,000 in early 2025 (CBS, 2025b).

Over the last two decades, the total energy use in the Netherlands has decreased with about 22%. The largest decline concerned natural gas, and most of that was in recent years. This decline coincides with the gradual closure of the Groningen gas reserves, for a long time the largest gas field in Europe. At the same time, there was a rapid growth of renewables to about 20% of the total energy production in 2024, accounting for more than halve of the Dutch electricity production (CBS, 2025a). Towards 2050, the government expects the electrification of supply and demand to continue to 50 or even 70% (IBO, 2025, p. 14). Another important development was a law banning the use of coal for electricity production, adopted in 2019 and in full effect in 2024. Moreover, the Netherlands operates one single nuclear power plant in Borssele, which contributes about 3% of total electricity generation (IAEA, 2024).



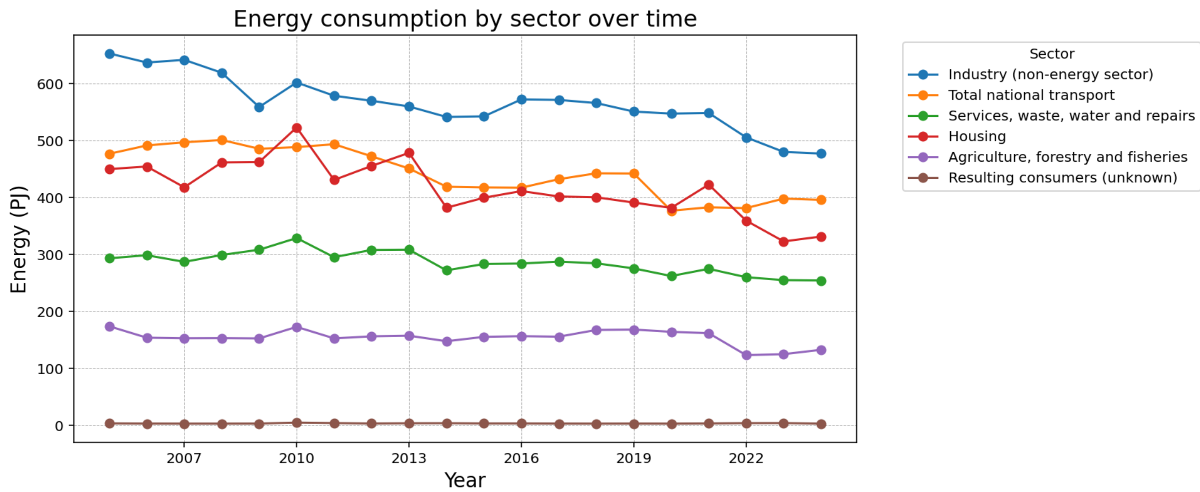


Figure 1 and 2. Authors' graph of the energy supply and consumption in the Netherlands (following data from the national statistics office: StatLine - Energiebalans; aanbod en verbruik (CBS, n.d.))

B. KEY POLICY OBJECTIVES AND TRANSFORMATION PATHWAYS TO DECARBONISE THE ENERGY SYSTEM

In 2019 the Dutch government concluded a Climate Agreement with representatives from all major economic sectors. The aim was to reduce greenhouse gas emissions, with 49 percent by 2030 compared to 1990 levels, and carbon neutrality in 2050 (Ministerie van EZK, 2019).

In 2022, a new coalition (Rutte III) took a more active role in steering the energy transition towards achieving the climate agreements. This government intensified efforts to reduce emissions through a variety of instruments. It imposed a national carbon tax on top of the EU Emissions Trading Scheme, restructured energy taxes to favour electricity, and negotiated tailored agreements with major industrial actors to cut emissions. Public funding supported renewable energy deployment, hydrogen production and infrastructure, while mission-driven research and top-sector policies drove low-carbon innovation (Adriaansens, 2023). The government reserved space for energy infrastructure through a national programme and regional strategies that involved stakeholders, and invested heavily in electricity grids, hydrogen networks and charging infrastructure. Incentives for insulation, heat pumps and induction cooking helped households to move off gas, while tax breaks and charging facilities promoted the uptake of electric vehicles. The government also financed carbon capture and storage (CCS) projects such as Portos, with further CCS planned to meet climate targets and address residual emissions.

In 2023 the new Rutte IV cabinet published a vision on the energy system towards 2050 (Ministerie van EZK, 2023). This vision presents a clear break with the existing fossil fuel-based energy system which had been in development for generations. It aims to maximise renewable energy supply, improve energy efficiency, ensure alignment in spatial planning and infrastructure, fosters international cooperation and encourages engagement with stakeholders from all levels. Central to the vision are four energy value chains: Electricity, hydrogen, carbon carriers and heat.

Meanwhile, rising energy prices, accelerated in the wake of geopolitical tensions and reduced gas supplies from Russia after its full-scale invasion of Ukraine, raised concerns in the Netherlands about global competitiveness of the energy intensive industries, and energy poverty for households. In the political discussion, attention shifted to strategic autonomy and energy independence. Although decarbonisation remained important, it faded from focus in the wake of the international developments.

While most instruments that were implemented during Rutte III were kept in place, attention gradually moved further towards maintaining a level playing field compared to other European countries and to retain domestic industry. Moreover, expanding the capacity of the electricity grid had become a pressing issue, as congestion threatened to slow down the rollout and exploitation of new wind farms, solar parks, and the adoption of electric technologies, like electric vehicles and heat pumps.

Since taking office in July 2024, the Schoof cabinet adjusted or withdrew some earlier employed measures to steer the energy transition. For example, in an effort to curb a potential industrial exodus, the government scrapped the additional CO_2 tax and brought back an ETS compensation measure that lightened the financial burden on energy-intensive industry stemming from the ETS. Moreover, this cabinet announced further steps to extend the lifetime of the Borssele nuclear power plant (Ministerie van KGG, n.d.), and anticipated nuclear expansion to secure low carbon power (Rijksoverheid, n.d.).

In September 2025, the Dutch Environmental Assessment Agency assessed that the Netherlands, with current and intended policy, was not on track for meeting the climate goal. Instead of 55%, the reduction in 2030 is expected to be between 44 and 52% (PBL, 2025).

II. CONSEQUENCES OF TECHNOLOGICAL CHOICES

The energy infrastructure has become the bottleneck in the Dutch energy transition (IBO, 2025). The task ahead for the Netherlands is to ensure that renewable energy can be used to decarbonize households, industry and transport. In the following section we will illustrate two important challenges ahead for the Netherlands and show how these also requires the governance to be reconsidered.

A. THE ELECTRIFICATION DILEMMA

A first major challenge is that the electrification leads to congestion on the high- and medium-voltage networks. The rapid deployment of renewables and the high rate of adoption of electric alternatives outpaces the current grid capacity. Moreover, the transmission and distribution network must also be adapted to accommodate variable flows and bi-directional exchanges. As long as the networks lack the necessary capacity, households, small and medium-sized enterprises (SMEs), and more energy-intensive industries cannot electrify at the speed required to meet the climate goals.

However, the combination of a decline in conventional controllable power (e.g. gas- or coal fired power plants) together with an expected increase of electricity demand, is also expected to become the main source of grid-balancing challenges after 2030. As more renewable electricity comes online in the coming years, supply and demand imbalances will require greater efforts to maintain stability. Beyond 2030, the grid operator anticipates increasing risks to electricity supply (TenneT, 2025).

The government is taking measures to mitigate the current congestion and energy imbalances. For example, by investing in additional grid capacity, grid reinforcement, and storage, and aims to further enable options for more flexible consumption. However, these measures have not yet led to sufficient improvements, nor are they expected to be enough to mitigate the foreseen issues. According to the grid operator, another option to improve the security of supply, is to slow down the rate of electrification (TenneT, 2025).

An additional issue with the governments' infrastructure investments is that they face scarcity in several respects (IBO, 2025). There is a shortage of skilled labour, and building the installations takes time – which is in short supply. Therefore, making efficient use of the current infrastructure is crucial. The need for increased efficiency, offers opportunities for alternative solutions, such as digitalisation, new market models, and international trade. As such, the government and grid operators proposed measures to optimise the use of the existing energy grids, which include promoting flexible energy use among households and industry, developing energy hubs, investing in decentralisation, and improving the decision-making process to accelerate implementation. Many of these regulatory and legislative changes are slowly coming into effect (IBO, 2025, p. 13, 63).

Lastly, the role of decentralised energy supply is expanding. This development has been driven from the bottom up, particularly in the form of individual households, small businesses and energy collectives. The government recently acknowledged these decentralised energy initiatives as a possible remedy for network congestion, while fostering civil participation and local ownership, and aligning the energy system with broader spatial developments (Ministerie van KGG, 2025).

B. DECARBONISING THE ENERGY-INTENSIVE INDUSTRY

A second major challenge is industrial decarbonisation. In 2022, the government and industry started engaging in discussions about tailoring the decarbonizing of major emitting industrial sectors such as steel, chemicals, and ammonia production (Adriaansens, 2023a), with so far limited success. Decarbonising energy intensive industries turns out to be challenging, for various reasons.

First, unlike households and transport, which electrify gradually and in a decentralised way, industry would shift large energy demands from fossil to renewable sources at once. This requires sufficient renewable supply, alignment in time, and enabled by adequate infrastructure. Second, low carbon alternatives to high-temperature industrial applications remain technically challenging. For instance, hydrogen and electrification are complex and/or costly in both production and transport, while the use of biomass has in the past led to societal resistance. Third, there is a dilemma within the pricing of renewable energy carriers: They must be high enough to make investments in the renewable molecules (e.g., wind, electrolysis, and infrastructure) attractive, but low enough for energy-intensive industries to remain competitive on the international markets. A fourth complication is that the future industrial energy demand remains uncertain. This makes it difficult for governments, and infrastructure providers, to anticipate well on the future demand.

C. CHALLENGES OF GOVERNING THE ENERGY TRANSITION

As the technical system changes, the governance structure must also be adapted. We illustrate the governance challenges using two examples. Other societal issues are discussed in the subsequent section.

One governance challenge is to weigh the interest of current and future generations. Consider for example the distribution of costs for the energy transition. Currently, costs are front-loaded, while expected benefits, such as reduced emissions and knowledge intensive jobs, arrive later. In other words, Dutch taxpayers are financing research, grids, storage, and industrial retrofits without yet seeing returns (IBO, 2025). Moreover, rising energy prices can place a particular strain on citizens already facing energy poverty. Opportunity costs add another layer of concern: money spent on the energy transition cannot simultaneously be allocated to healthcare, welfare, or education. The issue extends beyond national borders, as Dutch grid investments also contribute to wider European prosperity, suggesting that costs and benefits could be shared internationally. Currently, the mechanisms to ensure a fair national and international distribution are still lacking (IBO, 2025), and the government is looking into ways to address a fair allocation of costs and benefits.

Another challenge is to keep policy consistent between successive political parties, while remaining sensitive to a changing environment. Various Dutch renewable energy projects have led to societal protest and political opportunism. These developments in turn led to policy inconsistencies between successive governing coalitions. For example, where one government increases investments, a subsequent cabinet scaled these down. According to publicist Remco de Boer (2024) uncertain government priorities, policy and investment, undermines investor confidence and therewith lead to delays and increasing cost of the energy transition (De Boer, 2024).

III. THE SOCIAL ACCEPTABILITY OF THE ENERGY TRANSITION

A. DUTCH PUBLIC ACCEPTANCE OF THE ENERGY TRANSITION

Dutch society on the whole seems to support an energy transition. This is not surprising, as 65% worries about climate change (Klösters et al., 2022, p. 3). A minority, however, does not see the necessity for change, because they do not believe in climate change (4%) or that humans can no longer stop climate change (16%) (CBS, 2023, pp. 15–16).

About half of the Dutch feel the use of oil and gas should be reduced (respectively 47% and 48%). There is significant support for increasing the reliance on solar and wind energy (respectively 78% and 69%), and to a lesser extent nuclear energy (36%). While the former two slightly decreased as compared to 2020, the support for nuclear increased (CBS, 2023, p. 23). The Dutch also appreciate efforts to conserve energy, e.g. by insulating houses (Klösters et al., 2022, pp. 53 & 67).

Main reasons for citizens to support an energy transition are to decrease energy interdependency, and counter climate change as well as rising energy prices (Van der Werf & de Kleijn, 2022, pp. 12 & 18). The latter was boasted by the experiences of the 2022 energy price hikes. The possible higher energy costs associated with a transition are a concern, however.

B. VARIOUS FORMS OF OPPOSITION

Dutch citizens do often oppose renewable energy projects once these are in their immediate surroundings or when they threaten their general well-being (CBS, 2023, pp. 28–29). Opposition reflects a variety of worries concerning the impact of technology on the landscape, environment and health, but also safety, costs and the decision-making process.

One reason for protest are concerns about how new energy facilities might alter the surrounding landscape. Dutch nuclear ambitions are a point in case. The last two governments have announced plans for new nuclear facilities (*Coalitieakkoord*, 2021; Rijksoverheid, 2024). The preferred location for new nuclear power stations is Zeeland, the country's most pro-nuclear province (CBS, 2023, pp. 24–25). Nevertheless, local citizens are voicing concerns. Residents are worried about how new power plants and transmission lines will impact the landscape, ecosystems and biodiversity, and about the disruptions resulting from the lengthy construction period (De Borselse Voorwaarden Groep, 2023).

Another reason for local opposition concerns health and the environment. Take the case with planning new onshore wind parks. Citizens often cite potential health hazards, and the impact on birds, and above all, the challenge of fitting all of the installations into an already crowded landscape (Klösters et al., 2022, p. 36). It is therefore not surprising that the government prefers to expand offshore wind capacity instead (Ministerie van EZK, 2019a). Offshore wind farms, however, raise concerns too , for example about the impact on the marine ecosystems, but to a lesser extent for their impact on the landscape (Klösters et al., 2022, p. 36).

Another reason for opposition are the costs associated with the energy transition. Citizens worry about higher prices resulting from the energy transition. These concerns grew after the experiences with the 2022 energy crisis (Klösters et al., 2022, p. 35). Higher prices are also a major concern for the (energy-intensive) industry and SMEs.

Safety is another concern. A clear example is the long-running unrest about and protest over the exploitation of the gas reserves in the north of the Netherlands. Following years of increased seismic activities and resulting property damage, and following a prolonged political debate, the production of Groningen gas was halted in October 2023. The government's slow and inadequate response to citizens' concerns about the earthquakes has damaged public confidence in the Dutch government.

Lastly, opposition emerges when citizens feel excluded from decision-making. Research indicates that many citizens want to be involved, in limited or more extensive ways, in shaping climate policy (van der Werf & de Kleijn, 2022, pp. 12, 18). Citizens want clearer information about energy-transition measures, and to have a voice in the decisions about its implementation, in particular decisions that directly impact their living environment. In response, the government made local ownership a key requirement for solar and onshore wind parks, hoping this results in higher levels of public acceptance (Ministerie van AZ, 2019, p. 164). Moreover, the government made participation mandatory with the 2024 Act on Environment and Planning. Political support for public involvement remains mixed. On the one hand, the government launched a National Citizens' Climate Assembly, from January 2024 until the summer of 2025 (*Nationaal Burgerberaad Klimaat*, n.d.). On the other, parliament adopted a motion to explore the possibility to withdraw from the Aarhus Convention, which grants citizens the rights to be involved into decision-making on environment-related matters (Motie van het lid Wijen-Nass, 2025).

C. DEBATES ABOUT REALISM AND DISTRIBUTIVE JUSTICE

An important issue in the societal and political debate is the government's ability to implement the transition and to do so fairly. Various societal groups have raised concerns. We illustrate this debate from the perspective of citizens and NGOs on one hand, and companies on the other.

Most Dutch citizens worry about climate change, yet about 40% distrust the state's ability to address it effectively (Klösters et al., 2022, p. 3). This skepticism is reflected in legal challenges by environmental NGOs, who have successfully sued the Dutch state for failing to take sufficient action on climate change (ECLI:NL:HR:2019:2007, Hoge Raad, 19/00135, 2019). Rising energy prices further heighten public concern, as many households already struggle to pay higher bills and energy poverty remains an issue. Beyond effectiveness, citizens also question the fairness of the energy transition. The government has not yet clarified how it will distribute support packages for households and businesses. Decisions such as scrapping the net-metering scheme have made residential solar PV less profitable and primarily affect homeowners, who previously benefited most from the subsidy (Klösters et al., 2022, p. 10).

Firms have also expressed doubts about the government's ability to drive the energy transition. 87% percent of energy-intensive firms report that the slow construction of energy infrastructure and network congestion, poses serious challenges to meeting their 2030 and 2050 sustainability targets. SMEs similarly identify this as a major issue (Meekes et al., 2025, pp. 14–15; VNO-NCW, 2024, pp. 7–9). Some businesses even consider leaving the Netherlands due to the resulting deterioration of the economic climate and rising energy prices (Meekes et al., 2025, pp. 14–15). Beyond effectiveness, firms raise concerns about the fairness of the energy transition. They debate the costs of greening the industrial energy supply and the appropriate role of the government in covering or regulating these costs. As social and local environmental impacts are also part of the discussion, firms question the distribution of these burdens.

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NORWAY

Teknologirådet
Norwegian Board of Technology

I. ENERGY MIX AND THE CARBON NEUTRALITY OBJECTIVE (2050)

A. RECENT EVOLUTION OF THE ENERGY DEMAND STRUCTURE

Norway's final energy demand has remained broadly stable at around 215 TWh over the past decade.[1] Per-capita demand is well above the European average, reflecting cold winters and an energy-intensive industrial base. This stability, however, masks a clear shift in energy demand: electricity use has grown while fossil fuel use has declined. Today, electricity accounts for roughly half of demand, compared to around one-fifth in Europe.[2]

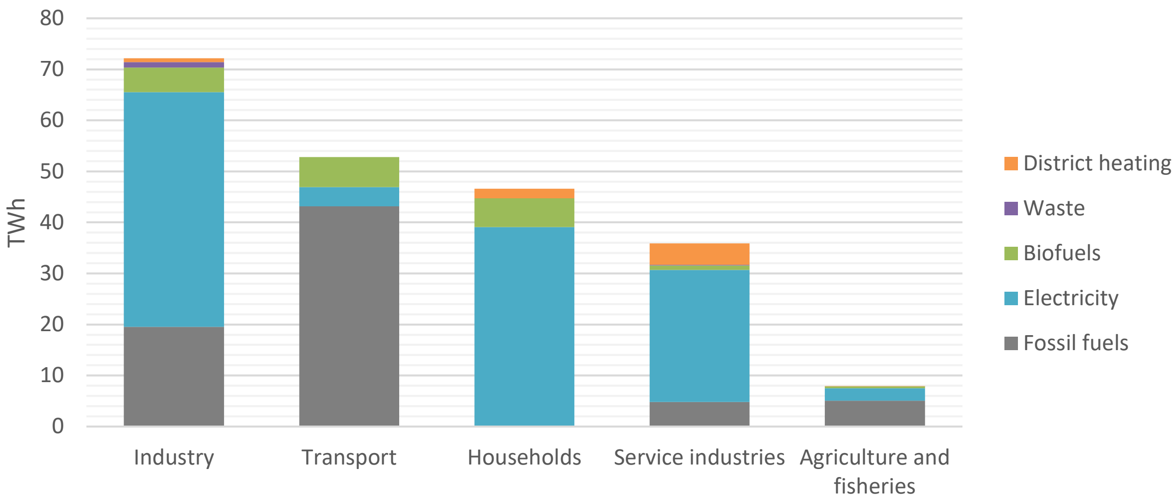
Industry is the largest energy user, contributing about one-third of energy demand. Energy-intensive sectors such as aluminium, ferroalloys and chemicals dominate. Aluminium smelting constitutes an especially large share, almost entirely powered by hydropower.[3] Additional electricity demand is also emerging from data centres and the electrification of oil and gas platforms. Fossil fuel use continues in processes that are harder to electrify.

In households, over three-quarters of energy demand is for heating, largely electrified through panel ovens, floor heating and, increasingly, heat pumps. This makes electricity demand strongly dependent on winter temperatures.

Transport is the sector that has electrified most quickly. Norway now has the world's highest share of electric vehicles (EVs), which have accounted for 95% of new passenger-car sales so far in 2025.[4] Ferries and coastal shipping are starting to electrify as well. Since electric motors are more efficient than combustion engines, this shift reduces overall energy demand.

[1] *Energifakta Norge (2025) Norsk energibruk.*
[2] *IEA (2025) Norway, Europe.*
[3] *Ministry of Energy (2023) NOU 2023:3 Mer av alt – raskere.*
[4] *OFV (2025) To nye elbilrekorder i september.*

Figure 1. Net domestic energy use in Norway by sector and energy carrier, 2024.[1]



B. COMPOSITION OF THE ENERGY MIX, KEY POLICY OBJECTIVES AND PROJECTIONS FOR 2050

Norway's energy mix is unusual in Europe. Almost all electricity comes from renewable sources: hydropower provides about 90% of annual generation and onshore wind about 10%, while solar and thermal generation remains marginal.[2] Large reservoirs give Norway exceptional flexibility compared to most countries. Beyond electricity, however, roughly half of final energy use is still provided by fossil fuels, reflecting continued reliance on oil and gas in industry, transport, and offshore operations.

Norway aims to cut emissions by 90-95% in 2050, with interim targets of 55% by 2030 and 70-75% by 2035 (relative to 1990).[3] Electrification is the central strategy, underpinned by specific policy goals. Notably, all new passenger cars, light vans and city buses should be zero-emission by 2025; half of new trucks and three-quarters of new long-distance buses should be zero-emission by 2030; and emissions from domestic shipping and fisheries should be halved by 2030 (vs. 2005).[4] On the supply side, the most notable ambition is to develop 30 GW of offshore wind capacity by 2040.[5] Norway neither has, nor plans to develop nuclear power capacity.

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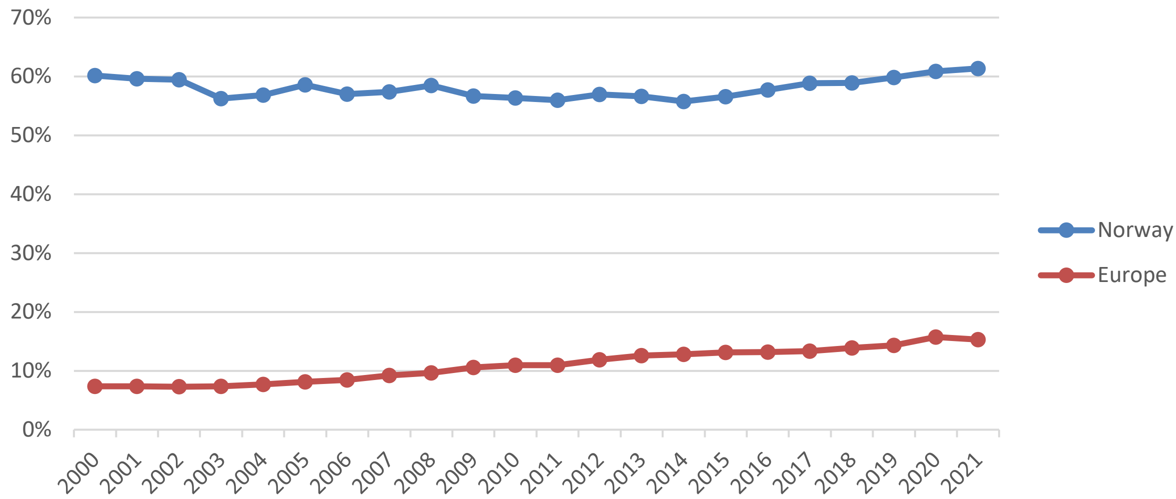
[1] *SSB via Energifakta Norge (2025) Energibruk i ulike sektorer.*
[2] *Energifakta Norge (2025) Kraftproduksjonhttps://energifaktanorge.no/norsk-energibruk/energibruken-i-ulike-sektorer/.*
[3] *Lovdata (2025) Act relating to Norway's climate targets (Climate Change Act).*
4 *Ministry of Climate and Environment (2025) Klimamelding 2035 – på vei mot lavutslippssamfunnet.*
[5] *Government of Norway (2022) Ambitious offshore wind initiative.*

Official outlooks project that electricity demand will rise to 180-260 TWh by 2050, driven by EVs, offshore electrification, hydrogen production and new industry. Hydropower remains the backbone of the electricity system, but capacity is expected to be tight as current scenarios suggest offshore wind ambitions are unlikely to be met without stronger measures.[1]

Figure 2. Share of final energy use that comes from renewable sources, 2000 to 2021[2]



C. TRANSFORMATION PATHWAYS TO ACHIEVE DECARBONISATION GOALS

Norway's decarbonisation strategy combines multiple pathways, with carbon pricing as the central policy instrument: most major sources fall under the EU ETS or a steadily rising national CO_2 tax. Because carbon pricing is unlikely to drive the necessary structural transformations on its own, it is complemented by several targeted measures.

The first pathway is broad electrification, which is far along in road transport and ferries, and gradually expanding in industry and offshore oil and gas operations. A successful transition will require faster grid build-out and renewable expansion.

The second pathway is expansion of renewable energy supply, especially offshore wind. While the government has set a target of 30 GW by 2040, NVE projections show that realisation will require additional incentives, faster permitting and grid investments.[3]

[1] *The 2050 Climate Change Committee (2023) NOU 2023:25 The transition to low emissions – Climate policy choices towards 2050.*
[2] *IEA, IRENA & UNSD via Our World in Data (2024) Share of final energy use that comes from renewable sources.*
[3] *NVE (2025) Langsiktig kraftmarkedsanalyse 2025-2050.*

A third pathway is CCS and clean hydrogen for hard-to-abate sectors. CCS is described in official plans as indispensable for industries such as cement, chemicals and waste incineration. Longship and Northern Lights are flagship projects designed to demonstrate the viability of the technology and, eventually, serve as large-scale CO_2 storage for the European carbon market.[1] Hydrogen and ammonia are being piloted in shipping with public support, while sustainable fuels are promoted in aviation and heavy transport under EU mandates.

The final pathway is energy efficiency, particularly in buildings and industry. Much of the low-hanging fruit has been picked, but some potential remains.[2] However, current incentives often fail to compensate consumers for the high upfront costs and risks of the remaining efficiency measures.

II. CONSEQUENCES OF TECHNOLOGICAL CHOICES

A. TECHNICAL OR OPERATIONAL CHALLENGES ASSOCIATED WITH MANAGING A MORE DIVERSIFIED ENERGY MIX

Norway's many hydropower reservoirs provide adequate and secure electricity supply (especially in wet years) and a strong starting point for balancing electricity generation from wind and solar. Because most hydro sites have already been developed, dispatchable capacity is expected to remain largely stable while future generation will be increasingly variable.[3] Moreover, electrification and new loads from large consumers such as data centres will cause faster and less predictable growth in demand peaks. Thus, the main technical and operational challenge is not to ensure an annual electricity surplus, but to integrate new variable sources in a way that allows supply and demand to be matched at all times.

The grid is the most critical constraint. Grid transmission is congested in many areas, and new lines take about a decade to be built.[4] Norway's long and mountainous geography creates persistent north-south bottlenecks, leaving surpluses in the north unable to reach demand centres in the south. This causes lasting regional price differences, delays in connecting new industry and inefficient use of hydropower's flexibility.

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[1] *Ministry of Climate and Environment (2025) Klimamelding 2035 – på vei mot lavutslippssamfunnet.*
[2] *Ministry of Energy (2023) NOU 2023:3 Mer av alt – raskere: Estimates up to 13 TWh savings potential in buildings and 5-10 TWh in industry by 2030, notably through retrofits, smarter energy management, and increased use of residual heat.*
[3] *Statnett (2025) Langsiktig markedsanalyse 2024-2050.*
[4] *Riksrevisjonen (2025) Dokument 3:7 (2024-2025) Kapasiteten i strømnettet.*

Rising shares of wind and solar also reduce inertia in the Nordic system, as neighbouring countries retire conventional power plants that previously provided stabilising rotating mass.[1] With less inherent stability, the frequency fluctuates more quickly after disturbances, increasing the need for fast-responding balancing resources.

B. MEASURES TO ENHANCE DEMAND-SIDE FLEXIBILITY

Norway has until recently had some of the strongest conditions for demand-side flexibility in Europe. Smart meters are universal, and over 90% of households and small businesses had contracts linked to hourly spot prices.[2] During the 2021-22 energy price crisis, many electricity consumers reduced demand when prices spiked, but subsidies were introduced and partly dampened the price signal. Starting autumn 2025, the new *Norway Price* subsidy scheme further reduces wholesale price exposure,[3] meaning that flexibility will have to depend less on manual behaviour and more on automated systems. Heating (already largely electrified) and EV charging are significant potential sources of flexibility: EVs make up ~30% of the passenger fleet,[4] and their batteries could provide up to 100 GWh of flexibility by 2030 if effectively integrated.[5]

New industry is drawn in through conditional grid connections, where factories or data centres agree to curtail demand at times of high prices in exchange for faster grid access. Pilots such as NorFlex and eFleks test local flexibility markets that pay consumers to reduce load during congestion.[6] Several market reforms are underway, such as the Nordic imbalance settlement period moving from 60 to 15 minutes, which will lower entry barriers for flexible resources like EVs and batteries. Still, Norway lags in opening balancing markets to aggregators. Thus, regulation – not technology – constitutes the main barrier to wider demand-side participation.

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[1] *Statnett (2025) Nordic Grid Development Perspective 2025.*
[2] *NVE/RME (2023) Norway's smart meter journey completes as 99% of Norwegians now have a smart meter; Nordic Energy Research (2024) Evaluation of Nordic Electricity Retail Markets.*
[3] *Government of Norway (2025), "Norway Price" for Electricity and District Heating. The scheme sets a fixed maximum price per kWh, with the state covering costs above this treshold.*
[4] *SSB 2025 Elbilstatistikk for Norge.*
[5] *NVE (2020) NVE Fakta Nr. 7/2020.*
[6] *Statnett (2023) Fleksibilitet som kilde til verdiskaping og forretningsutvikling.*

C. HOW THE EVOLUTION OF THE ENERGY MIX IS AFFECTING ELECTRICITY AND GAS INFRASTRUCTURE

Electrification of transport, industry and offshore operations is adding large loads to the grid, which is already near capacity in many regions. Statnett (the TSO) faces long grid connection queues, while major grid upgrades typically take close to a decade to complete.[1] Grid development is challenging, because electricity must be moved over long distances and difficult terrain, from often-remote hydropower plants and wind farm sites to coastal industrial areas and the populous southeast. Permitting issues, including conflicts related to nature protection and reindeer herding, often prolong construction timelines significantly.

Norway has deep integration into European electricity markets through cross-border interconnectors. The interconnectors enable exports in wet/surplus periods and imports in dry/cold periods when neighbouring prices are lower, but have become politically contentious. Thus, refurbishment of existing links, as well as grid design for offshore wind projects (radial vs hybrid connections), attract public scrutiny.

Regarding molecules, Norway is currently Europe's largest natural gas supplier, and pipeline infrastructure is expected to stay important into the 2030s even as volumes decline.[2] Plans for a hydrogen pipeline to Germany have been halted due to costs and market risk. New infrastructure for CCS is being developed: Longship/Northern Lights provide ship-based CO_2 transport and storage for industry emissions, with cross-border shipments scheduled from 2026 and a scope for CO_2 pipeline infrastructure in the future.

D. ANTICIPATED IMPACTS ON INDUSTRIAL VALUE CHAINS

The energy transition may reshape Norway's industrial base. Oil and gas production is expected to remain significant into the 2030s, sustaining the supplier industry (subsea, drilling, marine) while adding low-carbon services such as platform electrification, CCS and hydrogen.[3] This preserves skills and revenues, but also ties up labour, infrastructure and capital needed for new, green sectors.

In offshore wind, Norwegian firms are well positioned in floating foundations and moorings, subsea cables, installation and operations, port logistics, and grid connection/HVDC systems. Key components such as turbines, blades, nacelles, large bearings, generators and HVDC converters are mainly imported from foreign OEMs. Localisation depends on a predictable auction pipeline, port upgrades and timely grid capacity; otherwise, value chain growth will rely on serving projects abroad.

[1] *Riksrevisjonen (2025) Dokument 3:7 (2024-2025) Kapasiteten i strømnettet.*

[2] *DNV (2023) Energy Transition Outlook Norway 2024*

[3] *Government of Norway (2022) Roadmap – The Green Industrial Initiative*

In CCS, Norway's strengths are CO_2 shipping, terminals, wells and subsurface storage, while capture equipment is supplied by a mix of international and Norwegian vendors. Electrolysers are largely imported globally, with notable exceptions such as Nel.

Onshore, energy-intensive industries such as aluminium, ferroalloys and silicon can benefit from rising European demand for low-carbon materials. However, expansion is constrained by grid capacity and competitiveness depends on retaining affordable long-term PPAs.[1] Future industrial value chains will require access to increasingly scarce skilled labour and risk capital.

III. SOCIAL ACCEPTABILITY OF THE ENERGY TRANSITION

A. PUBLIC ACCEPTANCE OF THE ENERGY TRANSITION IN NORWAY

Surveys show relatively high and stable support for national climate goals. A large majority of Norwegians accept that human activity affects climate change (~70%), and a substantial share (~40%) reports a personal responsibility to support policy that cuts emissions.[2] However, public priorities have shifted: more voters now prioritise economic development ahead of environmental issues, and public acceptance increasingly hinges on expected impacts on jobs, power prices and local value creation.[3]

Several distinctly Norwegian features shape public attitudes towards the energy transition. Decades of cheap, renewable hydropower and widespread electric heating mean most households already "live electric"; EVs, heat pumps and efficiency therefore face relatively low resistance. Acceptance is highly place-sensitive: projects that affect valued landscapes, outdoor life (hiking, recreational fishing) or Sámi reindeer-herding areas face close scrutiny and strong expectations for consultation and mitigation, as the Fosen wind farm developments (and subsequent court case) underscored.[4] Because most generation capacity is publicly owned, communities also expect clear local benefits (dividends to municipal owners, local tax revenues, concession power and fees, and voluntary community funds).

[1] *The EU's NZIA, CRMA and CBAM tilt EU demand toward lower-carbon materials made in Europe.*
[2] *CICERO (2024) CICEROs klimaundersøkelse 2024.*
[3] *Norsk medborgerpanel (2025) Klima og miljø.*
[4] *NIM (2023) About the wind farms on Fosen and the Supreme Court judgment.*

Compared to citizens in other Nordic countries, Norwegians are less likely to believe that climate action will boost the domestic economy and more likely to worry about job losses[1] – reflecting the weight of the petroleum sector in employment and public finances. The political framing "develop, not dismantle" has become mainstream since 2018,[2] and the 2020 temporary petroleum tax package, estimated to equal a 40% investment subsidy,[3] illustrates policymakers' preference for a transition pace that preserves investment and jobs in the sector.

B. THE INFLUENCE OF THE ENERGY PRICE CRISIS ON PERCEPTIONS OF ENERGY POLICIES AND CLIMATE COMMITMENTS

Access to abundant hydropower and an integrated Nordic power market has historically kept electricity prices low and stable. However, the energy price crisis saw electricity prices increase manifold and ignited a fierce public debate about affordability, market design, and integration with Europe. Norway's annual average electricity prices increased six-fold from 2020 to 2022.[4] Norwegian households are uniquely dependent on electricity, especially for winter heating, and until recently, almost all of them purchased electricity based on market-based, hourly set "spot prices."

In response to public pressure, the government quickly introduced a support scheme that covered most of the electricity price for households above 0.70 NOK/kWh (ex. VAT), partly financed by an increase in the ground-rent tax on hydropower.[5] In 2025, the *Norway Price* subsidy scheme went even further, offering a state-subsidised, fixed electricity price of 0.40 NOK/kWh for households and holiday homes.[6] Thus, households now face significantly weaker incentives to adjust their behaviour based on fundamental market signals.

Cross-border interconnectors were also seen as an important contributor to the high electricity costs. The government consequently rejected the proposed NorthConnect cable to the UK, instructed the TSO not to plan additional interconnectors before 2029, and required early offshore wind auctions to have radial (domestic) grid links, rather than hybrid links that enable exports.

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[1] *Nordregio (2023) In all fairness: perceptions of climate policies and the green transition in the Nordic region.*
[2] *Energi og Klima (2025) Hvor kom uttrykket "utvikle, ikke avvikle" fra?*
[3] *Vista Analyse (2024) From Fossil Subsidies to International Climate Finance (report 2024/10).*
[4] *https://www.regjeringen.no/no/tema/energi/regjeringens-stromtiltak/id2900232/?expand=factbox2900261; https://www.ssb.no/energi-og-industri/energi/statistikk/elektrisitetspriser/artikler/rekordhoy-strompris-i-2022--dempet-av-stromstotte*
[5] *Ministry of Finance (2022) Increased resource rent tax on hydropower.*
[6] *Government of Norway (2025) Regjeringens strømtiltak.*

So far, the public debate has not evolved into a broader debate about Norway's climate commitments – perhaps due to the government's quick intervention in the retail market. However, the crisis amplified political tensions related to EU energy market integration, which contributed to the Centre Party's decision to withdraw from government in January 2025. Public debates on energy policy have been recalibrated towards price protection, sovereignty and energy security.

C. TECHNOLOGIES THAT RAISE SIGNIFICANT CONTROVERSY OR PUBLIC RESISTANCE

Onshore wind has become the most controversial source of new energy generation. A decade ago, wind energy was considered the main source of new capacity, but development has largely stalled due to public opposition, which tripled from 2015 to 2020.[1] Public concerns about impacts on landscape, nature and Sámi reindeer-herding rights caused the government to pause new licences in 2019. Licensing has since resumed, but now requires municipal consent and zoning, effectively requiring strong local backing.

By contrast, nuclear power has become markedly more popular in recent years. While only 18% of Norwegians were positive to it in 2016, recent surveys show that a majority (57%) now support nuclear power plants in Norway.[2] Many see nuclear energy as an alternative to investing in (subsidised and/or land-intensive) renewable energy sources.

D. ONGOING PUBLIC OR PARLIAMENTARY DEBATE REGARDING THE REALISM, COST, OR SOCIAL EQUITY OF THE ENERGY TRANSITION

Since the energy price crisis, the energy transition debate has shifted towards a stronger focus on pace, prioritisation and fair burden-sharing. Climate targets still have broad political support, but several political parties acknowledge that there is less appetite for new climate measures than a few years ago.[3] In the run-up to the 2025 parliamentary election, climate and environmental issues were largely absent from campaigns, even though they remained a top concern for about one in five voters.[4]

In the debate on cost and equity, electricity prices dominate. All parties support some form of household relief but diverge on level/design and how much to dampen market signals.

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[1] *https://www.domstol.no/en/supremecourt/rulings/2021/supreme-court-civil-cases/hr-2021-1975-s/*
[2] *European Perceptions of Climate Change Project (EPCC) Topline findings; Norsk medborgerpanel (2025) Hva mener folk i Norge om kjernekraft?*
[3] *NTRANS (2025) Energi- og klimaomstilling under press – Stortingspartienes politikk og mulige konsekvenser fram mot 2050 (rapport 02/25).*
[4] *Aftenposten (2025) En ny sak seiler opp som viktigst hos velgerne.*

Meanwhile, the impact of government subsidies on public finances has become a growing flashpoint. Public opposition to (subsidy-dependent) offshore wind projects nearly tripled since 2022.[1] The legitimacy of state support for the transition has also been eroded by controversies over high executive pay at subsidised "green" ventures and publicly owned utilities during the energy price crisis.[2]

The public increasingly questions whether new large power users – such as data centres, hydrogen, and battery manufacturing – deliver sufficient societal value to justify the pressure they put on grid capacity and regional power balances. Electrification of large petroleum sites is contested for similar reasons. The plan to electrify Equinor's Melkøya LNG facility – framed by the government as Norway's single most significant climate measure[3] – has met strong regional opposition centred on power prices, required grid upgrades, potential crowding-out of other industry, and the distribution of benefits.[4] Critics also question the global emissions effect.

Regarding realism, the Norwegian Environment Agency has concluded that Norway is not on track for meeting its 2030 climate target.[5] The gap between ambition and actual progress is occasionally raised in public debate, but other issues such as specific technologies, projects and policy initiatives feature more prominently.

Finally, European market integration remains contentious: cross-border interconnectors split parties and act as proxies for concerns about price control and national self-determination. The parties' positions range from strengthening interconnection to outright opposition to new grid capacity, reflecting a broader debate about Norway's relationship with the EU and its climate and energy policy.

[1] *Norsk medborgerpanel (2025) Klima og miljø.*
[2] *DN (2025) Freyr-topp fikk lønn på 27 millioner – men snart er det over; Aftenposten (2025) Strømprisene har gått i taket. Det har også kraftsjefenes lønn.*
[3] *NRK (2023) Regjeringen om elektrifiseringen: -Det største, enkeltstående klimatiltaket noensinne.*
[4] *EnergiWatch (2024) 72 prosent av befolkningen i Finnmark er mot elektrifisering av Melkøya*
[5] *Norwegian Environment Agency (2024) Klimatiltak i Norge: Kunnskapsgrunnlag 2024*

POLAND

Bureau of Research, Chancellery of the Sejm
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I. ENERGY MIX AND THE CARBON NEUTRALITY OBJECTIVE (2050)

A. HOW HAS THE STRUCTURE OF ENERGY DEMAND EVOLVED IN YOUR COUNTRY IN RECENT YEARS?

Between 2013 and 2023, the structure of final energy consumption in Poland underwent significant changes. Despite an overall increase in total consumption from 63.5 to 70.0 Mtoe (an average of 1.0% per year), a clear trend has emerged towards electrification and a gradual shift away from fossil fuels, particularly coal. In 2023, the industrial and household sectors remained the largest final energy consumers. However, both – alongside the services sector – recorded a decline in consumption compared to previous years. An increase was observed in the transport sector, while energy use in agriculture remained stable.

In the industrial sector, a notable reduction was registered in the consumption of industrial gases (–38.2%), solid fossil fuels (–34.8%), and electricity (–11.0%). These declines were accompanied by increased use of liquid fuels (+29.0%), district heat (+16.9%), natural gas (+13.3%), renewable energy sources (RES) and biofuels (+23.5%), and non-renewable waste (+69.2%). In the household sector, natural gas – mainly used for heating purposes —remained the dominant and growing energy carrier (21.1%), followed by coal-based fuels (20.6%) and district heating (17.5%), both of which declined in share[1]. Electricity consumption rose by 12.5%, driven primarily by the electrification of heating systems, including a sharp increase in the number of heat pumps (over 124,000 units sold in 2023). Biomass use, particularly firewood, also increased, contributing to the gradual displacement of coal in individual heating systems. In the transport sector, electricity consumption recorded the highest rate of growth – rising by 8.2% year-on-year and by 48.5% compared to 2015 – accounting for 3.8% of final energy use in the sector. This was largely attributable to the expanding fleet of electric vehicles.

[1] *Efektywność wykorzystania energii w latach 2013-2023 [Energy efficiency in 2013–2023] https://stat.gov.pl/obszary-tematyczne/srodowisko-energia/energia/efektywnosc-wykorzystania-energii-w-latach-2013-2023,9,8.html; https://www.are.waw.pl/en.*

B. WHAT IS THE CURRENT COMPOSITION OF THE ENERGY MIX, AND WHAT ARE THE KEY POLICY OBJECTIVES OR PROJECTIONS BY 2050 (E.G. SHARE OF FOSSIL FUELS, NUCLEAR, RENEWABLES)?

Poland’s energy mix is undergoing a significant transformation, reflecting the ongoing transition from fossil fuels to RES. In 2024, hard coal and lignite remained the primary source of electricity, accounting for generation of 86.4 TWh (56.2% of gross electricity production – the highest proportion in the EU). However, coal’s share in the Polish energy mix declined substantially in recent years. Natural gas, considered a transitional fuel in the decarbonisation pathway, contributed around 10–11.6%, driven primarily by the increasing utilisation of combined cycle gas turbine (CCGT) units. The share of RES in electricity generation reached a record high of 29.4% (45.2 TWh), with wind energy (14.5%; 23.5 TWh) and solar photovoltaic (9.1%; 17.3 TWh) technologies playing a leading role, followed by biomass and hydropower with more limited contributions[1]. A landmark development occurred in June 2025, when, for the first time, the monthly share of electricity generated from renewable sources (44.1%) exceeded that from coal (43.7%).

The energy transition, as outlined in the 2025 draft update of the National Energy and Climate Plan (NECP) for 2030 with a 2040 outlook, foresees a 53.9% reduction in CO_2 emissions, a renewable energy share in electricity generation of 51.8% by 2030, and 79.8% by 2040[2]. Poland has committed to achieving climate neutrality by 2050, which will require the near-complete phase-out of coal and natural gas in electricity generation. Offshore wind energy is expected to serve as a key pillar of the future energy system, supported by the development of nuclear power. In addition, the advancement of energy storage technologies, the modernization of grid infrastructure, the use of renewable hydrogen, and improvements in energy efficiency across all sectors of the economy are envisaged.

C. WHAT TRANSFORMATION PATHWAYS ARE CURRENTLY UNDER DISCUSSION OR IMPLEMENTATION TO ACHIEVE DECARBONISATION GOALS?

In Poland, several parallel energy transition pathways are currently being discussed or implemented. These include, in particular:

(a) *the dynamic expansion of RES* – especially solar photovoltaics (with an estimated installed capacity increase to ~26.8 GW by the end of 2025) and wind energy, both onshore (capacity expected to reach up to 41 GW by 2040

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[1] *Energy Transition in Poland. Edition 2025, Forum Energii, 2025, report available on the website: https://www.forum-energii.eu/en/transformacja-energetyczna-polski-edycja-2025.*
[2] *Poland approves draft revised NECP with 2030–2040 outlook – https://www.enerdata.net/publications/daily-energy-news/poland-approves-draft-revised-necp-2030-2040-outlook.html.*

following the easing of spatial planning restrictions) and offshore (with a target of 18 GW in the Baltic Sea by 2040);

(b) the deployment of nuclear energy – the first nuclear reactor (AP1000 technology) is planned to begin supplying electricity to the grid in 2036, with a total of 6–9 GW of nuclear capacity expected to be in place by 2040; in parallel, small modular reactor (SMR) projects are also under development, including two BWRX-300 reactors comissioned by ORLEN Synthos Green Energy, scheduled to start operation by 2035;

(c) *the treatment of natural gas as a transitional fuel* – alongside the development of renewable hydrogen (in line with the Hydrogen Strategy 2030 with a 2040 outlook), biogas and biomethane, and major infrastructure investments (such as the LNG terminal and the Baltic Pipe);

(d) *the modernisation of grid infrastructure*, integration with the European energy market, and the enhancement of system flexibility – through the deployment of battery energy storage systems (BESS), Demand Side Response (DSR) solutions, and grid digitalisation;

(e) *the decarbonisation of the building and heating sectors* – by electrifying heating (including the rollout of heat pumps), expanding high-efficiency cogeneration from RES, and deploying low-emission district heating systems (based on geothermal energy and biogas).

D. HAS YOUR ORGANISATION CONDUCTED ANY RECENT ASSESSMENT OF THESE EVOLUTIONS (E.G. SCENARIO MODELLING, SYSTEM-LEVEL IMPACT STUDIES)? IF SO, COULD YOU BRIEFLY DESCRIBE THE FINDINGS?

BEOS has not been involved in scenario modelling or system-level assessments of energy transition policy. However, the progress of the energy transition in Poland is evaluated by both independent expert organisations and public institutions. Among these is the Centre for Climate and Energy Analyses (CAKE), a specialised analytical body operating under the Institute of Environmental Protection, a state research institute.

In connection with the requirement to update the National Energy and Climate Plan, analyses have been carried out based on two scenarios: the WEM (With Existing Measures) and the WAM (With Additional Measures). The WAM scenario foresees, among other things, a 50.4% reduction in greenhouse gas emissions by 2030, an increase in the share of RES to 32.6% of gross final energy consumption, and to 56.1% in the electricity sector, with a complete coal phase-out around 2035[1].

[1] *Roadmap to EU climate neutrality – Scrutiny of Member States. Poland's climate action strategy, EP Briefing, 2024, p. 6, https://www.europarl.europa.eu/RegData/etudes/BRIE/2024/767168/EPRS_BRI%282024%29767168_EN.pdf?*

Analyses conducted by the Forum Energii and the Clean Air Task Force (CATF) indicate that only the WAM scenario provides a pathway to align with the EU's 2050 climate neutrality target. However, its implementation requires strengthened financial, legislative and infrastructure-related instruments, as well as the inclusion of social acceptance and just transition considerations[1]. CATF further recommends the development of additional scenarios that account for potential delays and implementation risks. In parallel, a 2023 report by the Polish District Heating Association (*Polskie Towarzystwo Energetyki Cieplnej*) assessed the impact of the Fit for 55 package on the district heating sector, identifying necessary technologies and estimating the costs of transformation[2]. The 2025 edition of the "Energy Transition in Poland" report by Forum Energii documents recent progress while highlighting gaps in sectoral coordination, RES deployment, final fuel mix structure, and the pace of emissions reduction[3].

II. CONSEQUENCES OF TECHNOLOGICAL CHOICES

A. WHAT ARE THE MAIN TECHNICAL OR OPERATIONAL CHALLENGES ASSOCIATED WITH MANAGING A MORE DIVERSIFIED ENERGY MIX IN YOUR COUNTRY?

Managing Poland's increasingly diversified energy mix presents significant technical and operational challenges, primarily stemming from an inadequately adapted electricity infrastructure. A substantial share of the transmission and distribution networks is obsolete, with more than one-third of grid lines exceeding 40 years of age[4]. This legacy infrastructure limits the system's capacity to integrate variable RES. Grid congestion and transmission constraints are already leading to curtailment of RES generation[5].

Furthermore, the high variability of RES output complicates system forecasting and balancing. In 2024, system imbalances exceeded 1,000 MW in 20% of settlement periods, and in 3.3% of cases – 2,000 MW[6]. The insufficient

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[1] *What the Public Consultation reveals about Poland's Updated National Energy and Climate Plan – https://www.catf.us/resource/what-public-consultation-reveals-about-polands-updated-national-energy-climate-plan/.*
[2] *Assessment of the impact of the EU „Fit for 55" package on the transformation of the district heating sector in Poland, Report by Polish Association of Professional Combined Heat and Power Plants available on the website: https://ptec.org.pl/wp-content/uploads/2023/06/20230530-Assessment-of-the-impact-of-the-EU-Fit-for-55-package-on-th-transformation-of-the-district-heating-sector-in-Poland.pdf.*
[3] *Energy Transition in Poland. Edition 2025, Forum Energii, 2025.*
[4] *How to modernize Poland's outdated electric grid – https://energytransition.org/2023/04/how-to-modernize-polands-outdated-electric-grid/.*
[5] *Grid Congestion in the Polish Power Grid – https://www.dnv.com/article/grid-congestion-in-the-polish-power-grid/.*
[6] *Poland exceeds 22 GW in solar capacity and secures 10.8 GW in wind: System stability under pressure – https://strategicenergy.eu/poland-system-stability-under-pressure/.*

development of energy storage technologies and grid flexibility remains a persistent issue. There is a lack of long-duration storage facilities, while the investment costs remain prohibitive[1]. Despite the introduction of registers and administrative facilitations, coherent tariff structures and financing models for storage assets and DSR schemes are still lacking.

Simultaneously, the progressive phase-out of conventional power plants is resulting in a loss of natural system inertia, further compromising frequency and voltage stability. Reactive power management and ensuring cybersecurity – particularly in light of the growing number of distributed energy resources (DERs) – are becoming increasingly problematic.

B. WHAT MEASURES ARE BEING IMPLEMENTED OR CONSIDERED TO ENHANCE DEMAND-SIDE FLEXIBILITY (E.G. TIME-OF-USE TARIFFS, DEMAND RESPONSE)?

Poland is advancing measures to strengthen demand-side flexibility in line with EU and national regulations. Since August 2024, electricity suppliers with over 200,000 customers are required to offer the dynamic pricing contractbased on, for example, day-ahead market prices[2], encouraging consumers to shift demand to low-cost hours and support system stability amid growing renewable generation.

The roll-out of dynamic pricing is supported by funding the smart meters – as well as the implementation of the Central Energy Market Information System (CSIRE). Time-of-Use (ToU) tariffs are particularly promoted in the industrial sector as a cost-optimisation tool. For instance, several companies in the food industry are already shifting refrigeration and sanitation processes to off-peak hours without disrupting production.

The Transmission System Operator (TSO) offers DSR programmes in which participating companies and aggregators commit to reducing electricity consumption during specific time windows, receiving remuneration regardless of whether the reduction is activated. Further development of local flexibility markets is planned to enable both Distribution System Operators (DSOs) and the TSO to procure services from aggregators, prosumers, and storage facilities to manage local congestion and grid constraints.

The 2021 amendment to the Energy Law supports the deployment of energy storage systems: battery systems of above 50 kW are subject to mandatory registration, while those above 10 MW require licensing.

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[1] *See e.g.: Energy storage: Key to the effective use of renewables? – https://www.euractiv.pl/section/energia-i-srodowisko/news/energy-storage-renewable-poland-gaz-nuclear-eu-climate-transformation-fit-for-55-coal-exit/.*

[2] *Electricity bills: starting from 24 August, households can enter into contracts with dynamic energy pricing. What should consumers know before signing up? – https://www.ure.gov.pl/en/communication/news/399%2CElectricity-bills-starting-from-24-August-households-can-enter-into-contracts-wi.html.*

These installations benefit from a 50% grid connection fee reduction and can access available support schemes[1]. By 2026, Poland is expected to adopt a formal system flexibility target, integrating DSR and dynamic pricing mechanisms into the capacity market framework and national climate policy. Preparatory work is also underway to leverage electrolysers as flexible industrial loads capable of responding to market signals and grid needs.

C. HOW IS THE EVOLUTION OF THE ENERGY MIX AFFECTING ELECTRICITY AND GAS INFRASTRUCTURE (E.G. GRID CAPACITY, RELIABILITY, CROSS-BORDER FLOWS)?

The transformation of Poland's energy mix – driven by the expansion of RES, gas-fired generation, and the planned introduction of nuclear power – is having a profound impact on both electricity and gas infrastructure. The variability of generation, particularly from distributed RES, necessitates the modernisation of networks originally designed for centralised coal-based power. The geographical shift of generation assets (e.g. to the northern regions) and increasing RES curtailment further intensify the need for transmission grid expansion[2]. TSO plans to invest over PLN 64 billion by 2034, including the construction of 4,850 km of 400 kV lines, substation modernisation, and the deployment of High Voltage Direct Current (HVDC) technology[3]. While power quality indicators such as ENS (Energy Not Supplied) and AIT (Average Interruption Time) remain relatively good, their upward trend highlights the need for urgent upgrades to distribution networks. Cross-border interconnections – such as the existing LitPol Link and the planned Harmony Link—are being developed to enhance market integration. However, current interconnection capacity (approx. 5%) falls short of the EU target of 15% by 2030[4]. The planned increase in gas-fired generation capacity to 9–12 GW by 2034 requires secure gas supply. Key infrastructure investments include the expansion of the Baltic Pipe, the LNG terminal in Świnoujście, and interconnectors with Lithuania and Slovakia. Gas storage capacity is also being expanded, with a target of 4.1 bcm by 2027. The gradual shift away from coal in favour of gas, renewables, and nuclear will continue to demand comprehensive infrastructure adaptation – both technically and from a regulatory perspective.

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[1] *Poland Electricity Security Policy – https://www.iea.org/articles/poland-electricity-security-policy.*

[2] *Poland's power grid needs €25 billion upgrade for renewables: report – https://www.euractiv.com/section/eet/news/polands-power-grid-needs-e25-billion-upgrade-for-renewables-report/.*

[3] *Poland to spend $16 billion on power grid by 2034 – https://www.reuters.com/business/energy/poland-spend-16-billion-power-grid-by-2034-2024-03-15/.*

[4] *Options for integration of the Polish energy market within the European Union – https://www.forum-energii.eu/en/options-for-integration-of-the-polish-energy-market-within-the-european-union.*

D. WHAT ARE THE ANTICIPATED IMPACTS ON INDUSTRIAL VALUE CHAINS (E.G. MANUFACTURING CAPACITY, LOCALISATION, STRATEGIC DEPENDENCIES)?

The energy transition in Poland is triggering significant shifts across industrial value chains, affecting production capacities, investment locations, and strategic dependencies. Rising energy prices are undermining the competitiveness of energy-intensive sectors such as chemicals and metallurgy, prompting investments in production modernisation and energy efficiency. However, macroeconomic models[1] suggest that decarbonisation could generate increased value added and net job creation in a longer term. The industrial geography is also evolving: investments are moving from the south of the country – traditionally located near coal resources – towards the north, closer to renewable energy infrastructure (e.g. offshore wind), facilitating the emergence of new industrial clusters, such as a wind turbine components factory in Szczecin[2]. At the same time, dependence on imported critical raw materials (e.g. lithium, cobalt) is growing, exposing Poland to geopolitical risks. Projects such as the Baltic Pipe and the LNG terminal in Świnoujście are strengthening energy independence, but emerging technologies – such as batteries—remain vulnerable to global trade disruptions. Moreover, evolving EU regulatory frameworks, including the planned methodology for calculating the carbon footprint of batteries based on the energy mix of the country of of manufacture, may negatively impact the competitiveness of domestic investments, such as Poland's growing battery sector. A key challenge remains public acceptance of the transition, particularly in coal-dependent regions. The experience of the 1990s has shown that uncoordinated mine closures led to job losses, social degradation, and persistent poverty. At the same time, digitalisation and technological innovation – including small modular reactors (SMRs), hydrogen, and e-mobility – have the potential to position Poland as a major industrial hub within the EU.

[1] *Decarbonisation of energy-intensive industries in context – https://instrat.pl/en/industry-decarbonisation/.*
[2] *Poland as a strategic hub for logistics and industrial investment – https://bpcc.org.pl/pl/poland-as-a-strategic-hub-for-logistics-and-industrial-investment/?.*

III. SOCIAL ACCEPTABILITY OF THE ENERGY TRANSITION

A. HOW WOULD YOU CHARACTERISE THE LEVEL OF PUBLIC ACCEPTANCE OF THE ENERGY TRANSITION IN YOUR COUNTRY?

Public acceptance of the energy transition in Poland is moderately positive but marked by significant societal divisions and concerns. According to a 2024 study by UCE Research and DGA S.A., 45.9% of Poles view the transition favourably, 29.9% negatively, while 24.2% remain undecided[1]. However, according to a 2024 survey by the Public Opinion Research Center, only 25% of the population supports achieving climate neutrality by 2050 (support is highest among residents of large cities, people with higher socioeconomic status, and young people), while 68% would prefer to delay this target . This indicates general agreement with the direction of the transition, but widespread anxiety about its pace. There is strong support for specific technologies – e.g. 64% of respondents are in favour of nuclear energy, and 67% of supporters would accept the construction of a nuclear power plant in their own region – demonstrating growing public trust in nuclear power as part of the future energy mix [2]. An increasing number of citizens also perceive renewable energy sources as a means to lower energy costs and address energy poverty[3]. Nevertheless, the transition is still subject to disinformation and public scepticism, primarily due to limited awareness and a lack of trust in public institutions.

B. TO WHAT EXTENT HAS THE ENERGY PRICE CRISIS OF 2022 INFLUENCED PERCEPTIONS OF ENERGY POLICIES AND CLIMATE COMMITMENTS?

The 2022 energy price crisis – triggered by Russia's invasion of Ukraine and the ensuing EU sanctions – significantly influenced public perceptions of energy and climate policy in Poland. According to the EIB Climate Survey from 2022, 65% of Polish citizens believed that the war and energy prices should accelerate the green transition, while 83% recognised the risk of climate crisis if consumption was not curbed[4]. At the same time, a 2023 report by the Institute of Public Affairs indicated that Poles saw renewables,

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[1] *https://www.kierunekenergetyka.pl/artykul%2C105617%2Cpolacy-zadowoleni-z-transformacji-energetycznej-blisko-co-drugi-badany-potwierdza-taka-opinie.html?*

[2] *Public Opinion on Energy Policy, Public Opinion Research Center, Report no. 56/2024 – the full version of the report: https://www.cbos.pl/SPISKOM.POL/2024/K_056_24.PDF?, English summary of the report: https://www.cbos.pl/EN/publications/reports_text.php?id=6827&utm.*

[3] *Wysokie ceny energii powodem oporu konsumentów wobec transformacji sektora [High energy prices cause consumer resistance to sector transformation], https://www.ey.com/pl_pl/newsroom/2024/04/ecci-konsumenci-energetyka-ey. *

[4] *See information on the results of the fifth edition of the EIB Climate Survey on the website: https://www.eib.org/en/press/all/2022-438-two-thirds-of-poles-say-the-war-in-ukraine-and-high-energy-prices-should-accelerate-the-green-transition?.*

energy efficiency, and diversification of energy sources as appropriate responses to the crisis, although a growing division between large urban areas and smaller towns regarding the support received from the state to offset the costs of the energy crisis was also observed[1]. Businesses – particularly SMEs – were strongly affected by soaring energy costs, with 70% expressing concern about supply disruptions during the heating season. Interest in investing in RES increased, but government support was widely viewed as insufficient[2]. Public attitudes towards energy technologies also shifted: opposition to nuclear power dropped to 13% (2022) [3], and acceptance of RES rose – marking a departure from previous trends. However, data from 2023–2024 suggest that the initial wave of public mobilisation is weakening. The share of respondents who consider climate change a very serious issue for our planet declined from 51% to 41%, and support for prioritising RES fell from 55% to 41%[4]. While the 2022 crisis served as a catalyst for change, issue fatigue and the lack of sustained strategic communication may undermine long-term public support for the energy transition

C. ARE THERE SPECIFIC TECHNOLOGIES (E.G. WIND POWER, NUCLEAR ENERGY) THAT RAISE SIGNIFICANT CONTROVERSY OR PUBLIC RESISTANCE?

In Poland, the most socially contested energy technologies are nuclear power and onshore wind. Despite growing overall support for nuclear energy, a 2024 CBOS survey shows that 22% of respondents still oppose the construction of nuclear power plants, and general support has declined to 64% – down from 75% in 2022[5]. Public concerns are mainly related to safety, the risk of accidents, radiation exposure, and long-term waste management. At the local level, however, support is significantly higher: for instance, in the area surrounding the planned Lubiatowo-Kopalino nuclear power plant, 67% of residents are in favour of the project, with overall acceptance of nuclear

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[1] *The larger the city, the more often residents declared lower levels of support from the state – P. Sobiesiak Penszko, K. Banul-Wójcikowska, Kryzys energetyczny. Postawy, opinie i oczekiwania Polek i Polaków [The energy crisis. Attitudes, opinions, and expectations of Polish women and men], Institute of Public Affairs 2023, report available on the website: https://www.isp.org.pl/pl/publikacje/kryzys-energetyczny-postawy-opinie-i-oczekiwania-polakow-i-polek?.*

[2] *Reakcja polskiego biznesu na szok energetyczny 2022 - podwyżki cen, cięcia kosztów i zielone inwestycje [The response of Polish businesses to the 2022 energy shock – price increases, cost cuts, and green investments]. Raport ING Bank Śląski z wykorzystaniem badania ilościowego GfK Polonia, 2022, report available on the website: https://ekonomiczny.ing.pl/publikacja/773031*

[3] *The highest level of opposition to nuclear energy was recorded in Poland in 2006, when as many as 58% of Poles were against this technology – https://www.blue-europe.eu/analysis-en/short-analysis/polands-energy-transition-overcoming-the-coal-myth-and-embracing-nuclear-power/.*

[4] *Global Public Confidence Study 2023. Report on Climate Confidence, IRIS Network, https://www.irisnetwork.org/IRIS---2023-Climate-Confidence-Report---July-14-v2-2023.pdf; Global Public Confidence Study 2024. Report on Climate Confidence, IRIS Network, https://www.irisnetwork.org/IRIS---2024-Climate-Confidence-Report---October-2024_v02.pdf.*

[5] *Public Opinion on Energy Policy, Public Opinion Research Center, Report no. 56/2024.*

energy in the region exceeding 70%[1]. This suggests that opposition is stronger at the national level, while locally there is a stronger perception of economic and social benefits, such as lower energy prices and CSR-driven investments. As for onshore wind energy, the technology continues to enjoy majority support. According to a 2023 survey by the Energy Regulatory Office (URE), 66% of Poles support state funding for wind energy development, and 71% do not consider turbines visually disruptive to the landscape[2]. However, data from 2024 show a rise in "local opposition": the share of respondents opposing wind farms in their vicinity increased to 32% (from 22% in 2023), while support for building wind farms nearby declined to 55% (from 68% in 2023) [3]. This reflects a growing prevalence of NIMBY (Not In My Backyard) attitudes, particularly in smaller towns and rural areas.

D. IS THERE AN ONGOING PUBLIC OR PARLIAMENTARY DEBATE REGARDING THE REALISM, COST, OR SOCIAL EQUITY OF THE ENERGY TRANSITION?

In Poland, an active public and parliamentary debate is ongoing regarding the feasibility, cost, and social fairness of the energy transition. Coal regions remain at the heart of the controversy. Protests by coal miners (January 2025) and appeals from trade unions have raised concerns about potential job losses and the lack of systemic support mechanisms[4]. Local governments and energy companies – such as PGE – are calling for increased allocations from the Just Transition Fund, arguing that current funding levels are insufficient to meet the scale of the challenge.

At the parliamentary level, the ongoing revision of the NECP has faced criticism from NGOs, who view the updated climate targets as lacking ambition, as well as from opposition parties[5]. In the Senate[6] and at sectoral

[1] *Public support for the construction of a nuclear power plant in Pomerania remains high – https://pej.pl/en/press-center/news/public-support-for-the-construction-of-a-nuclear-power-plant-in-pomerania-remains-high/.*
[2] *Badanie opinii konsumentów energii – „Energia UREgulowana" [Energy consumer opinion survey – "Regulated Energy"], 2023, report available on the website: https://www.ure.gov.pl/pl/urzad/informacje-ogolne/aktualnosci/11436%2CEnergia-UREgulowana-regulator-zapytal-konsumentow-o-opinie-na-temat-wybranych-as.html.*
[3] *Public Opinion on Energy Policy, Public Opinion Research Center, Report no. 56/2024.*
[4] *Thousands join miners protest in Warsaw against coal power plant closures – https://notesfrompoland.com/2025/01/10/thousands-join-miners-protest-in-warsaw-against-coal-power-plant-closures.*
[5] *CLEW Guide – Poland's govt yet to deliver on energy transition promises – https://www.cleanenergywire.org/factsheets/clew-guide-upcoming-election-will-shape-direction-and-pace-polands-energy-transition.*
[6] *See e.g. information on the meeting of chairs of parliamentary climate and environment committees within the presidency of the Council of the European Union, held by the Senate: "Zero-emission energy versus EU's competitiveness and security" – parliamentary dimension of the Polish presidency – https://parleu2025.pl/en/news/14-april/.*

events – such as the 2025 Polish Climate Congress[1] – key topics of discussion include the economic costs of the transition, its impact on industrial competitiveness, and the need to build public acceptance for emerging technologies such as renewables, SMRs, and hydrogen. The pace of the transition is also a central point of contention: should Poland align fully with EU targets, or adjust its trajectory to reflect national socio-economic circumstances?

[1] *See e.g. information on the Climate Congress of Poland: https://www.polskikongresklimatyczny.pl/en/rada-programowa.*

PORTUGAL

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I. ENERGY MIX AND THE CARBON NEUTRALITY OBJECTIVE (2050)

A. HOW HAS THE STRUCTURE OF ENERGY DEMAND EVOLVED IN YOUR COUNTRY IN RECENT YEARS?

Over the past five years, Portugal has experienced a structural decline in primary energy demand, reflecting efficiency measures and the progressive replacement of fossil fuels with renewables. Between 2019 and 2023, primary energy consumption decreased by 8%, including reductions of 28% in natural gas and 10% in oil, while renewable energy use grew by 20% (DGEG, 2024).

In 2024, total electricity demand reached 51.4 TWh, the second-highest level ever recorded, just 2% below the 2010 peak (REN, 2025). By contrast, natural gas consumption fell to 40.5 TWh, its lowest level since 2003. This resulted mainly from a 56% decline in gas use for power generation, although conventional gas demand (industry, services, residential) grew slightly by 2%.

Gas supplies came almost entirely through the Sines LNG terminal, with negligible pipeline imports from Spain. Nigeria (53%) and the United States (41%) were the dominant LNG suppliers (DGEG, 2024).

B. WHAT IS THE CURRENT COMPOSITION OF THE ENERGY MIX, AND WHAT ARE THE KEY POLICY OBJECTIVES OR PROJECTIONS BY 2050 (E.G. SHARE OF FOSSIL FUELS, NUCLEAR, RENEWABLES)?

In 2023, Portugal's electricity generation mix was dominated by hydropower (30%) and wind power (27%), with solar and biomass power making up the remaining renewable share. In 2024, renewable electricity generation reached an all-time high of 36.7 TWh, covering 71% of national demand (REN, 2025).

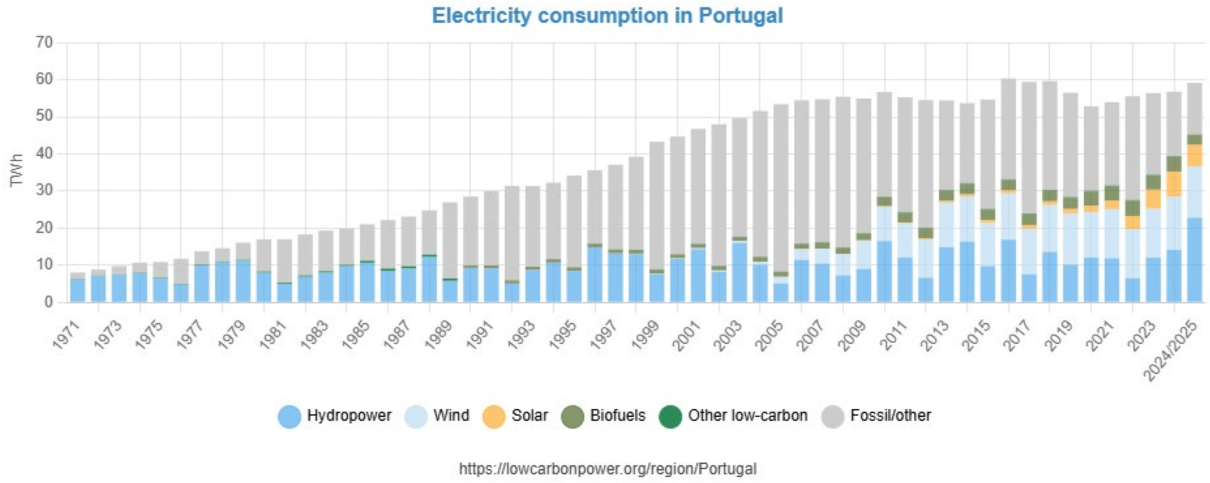

Chart 1: Electricity comsumption in Portugal (source: lowcarbonpower.org)

Breakdown for 2024:

- Hydropower: 28% of demand, productivity index 1.16 (above historical average).
- Wind power: 27%, productivity index 1.06 (above historical average).
- Solar PV (photovoltaic): ~10%, a record share, with 37% growth compared to 2023.
- Biomass: ~6%.
- Fossil-based generation: 5.1 TWh (10% of consumption), the lowest since 1979.
- Net electricity imports: 10.5 TWh, covering 20% of national demand.

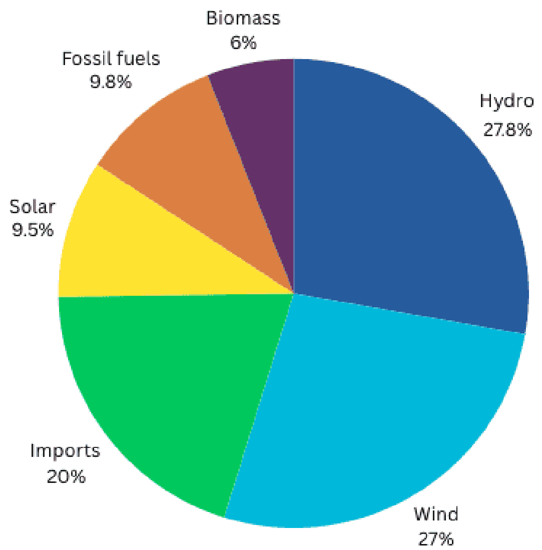

Chart 2: Portugal's electricity mix in 2024 (source: theprogressplaybook.com).

According to APREN (Portuguese Renewable Energy Association), the production of electricity based on renewable energy reached almost 77% (APREN, 2025). Continuous investment in hydro and wind powe generation (APE, 2023)has significantly reduced the carbon intensity of the Public Service Electricity Network (RESP), as underlined by Maia et al. (2024).

Portugal has adopted the goal of carbon neutrality by 2045 and aims for a 93% renewable share in electricity by 2030. The country is at the forefront of decarbonization, but it also demonstrates a national commitment to a more sustainable future, regardless of political cycles or short-term strategies (Pereira, 2025).

C. WHAT TRANSFORMATION PATHWAYS ARE CURRENTLY UNDER DISCUSSION OR IMPLEMENTATION TO ACHIEVE DECARBONISATION GOALS?

Portugal's decarbonisation pathways are anchored on several pillars, such as:

- Coal phase-out: Portugal closed its last coal power plant in 2021, becoming one of the first EU members to do so (APA, RNC2050, 2019).
- Expansion of renewable generation: large-scale deployment of solar PV (including floating systems), and the development of floating offshore wind projects (MAAC, 2023).
- Energy storage and grid flexibility: the Tâmega pumped-storage hydro complex and pilot battery storage projects are being developed to stabilise the system (REN, 2022).
- Electrification of mobility and efficiency: accelerated adoption of electric vehicles and building renovation programs supported by the Environmental Fund (Fundo Ambiental, 2024).
- Green hydrogen: the National Hydrogen Strategy (2020) identifies large-scale projects in Sines and Aveiro as strategic for decarbonising heavy industry and exports.

D. HAS YOUR ORGANISATION CONDUCTED ANY RECENT ASSESSMENT OF THESE EVOLUTIONS (E.G. SCENARIO MODELLING, SYSTEM-LEVEL IMPACT STUDIES)? IF SO, COULD YOU BRIEFLY DESCRIBE THE FINDINGS?

According to the IEA (2023) Energy Policy Review, Portugal reduced fossil-based electricity generation by 59% between 2023 and 2024, largely due to coal phase-out and increased renewable penetration. The National Roadmap for Carbon Neutrality 2050 (RNC2050) confirms that Portugal is broadly aligned with its neutrality targets, though challenges remain regarding security of supply, system flexibility, and interconnection with the rest of Europe.

In addition to national-level assessments, sector-specific roadmaps have been developed. A prominent example is the CarbonFree_Guide4Metal Project, (carbonfreemetalportugal.pt), led by AIMMAP and CATIM, with the support of Portugal's Recovery and Resilience Plan (PRR). This initiative established a technical-operational roadmap for the metalworking and metallurgical sector (METAL Portugal), one of the country's most energy-intensive and export-oriented industries.

This roadmap, aligned with both the National Energy and Climate Plan 2030 (PNEC 2030) and the RNC2050, applies the SBTi Net Zero Standard as its methodological reference. It quantified greenhouse gas emissions for Scopes 1, 2 and 3, estimating 2022 emissions at 4.77 $MtCO_2e$, of which Scope 3 accounted for 92.9%. Intermediate reduction targets were set: -50% by 2030 and -72% by 2050, compared to 2005 levels. Two digital tools were also created:

- "Pegada Metal": enables companies to calculate their carbon footprint under the GHG Protocol (Scopes 1 and 2).

- "Roteiro Metal": supports companies in generating customised decarbonisation pathways, integrating measures such as energy efficiency, electrification, renewable self-production, circular economy, and carbon capture.

The strategy emphasises short-term measures (efficiency and waste heat recovery), while long-term measures depend on electrification of industrial processes, renewable hydrogen, green fuels, and carbon capture. This roadmap illustrates how industrial value chains can operationalise national climate targets, while safeguarding competitiveness and export capacity.

II. CONSEQUENCES OF TECHNOLOGICAL CHOICES

A. WHAT ARE THE MAIN TECHNICAL OR OPERATIONAL CHALLENGES ASSOCIATED WITH MANAGING A MORE DIVERSIFIED ENERGY MIX IN YOUR COUNTRY?

The rapid increase of variable renewables (solar and wind, nearly 40% of generation) creates major challenges for system operation. Droughts reduce hydro output, requiring balancing through imports and gas plants. Portugal's relatively low interconnection capacity with Spain and France further limits system resilience. Recent analyses highlight that Portugal and Spain remain among the most vulnerable EU countries to blackouts due to their low interconnection capacity and dependence on Iberian cross-border flows (Euronews, 2025).

The ENTSO-E Ten-Year Network Development Plan (ENTSO-E, 2022) highlights Portugal's need to reinforce cross-border capacity to reach the EU's 15% electricity interconnection target by 2030.

B. WHAT MEASURES ARE BEING IMPLEMENTED OR CONSIDERED TO ENHANCE DEMAND-SIDE FLEXIBILITY (E.G. TIME-OF-USE TARIFFS, DEMAND RESPONSE)?

Portugal is advancing demand-side management mechanisms, including:

- Time-of-use and dynamic tariffs to shift consumption to periods of renewable surplus.
- Deployment of smart meters, which already cover over 80% of households (E-REDES, 2024; ERSE, 2024).
- Energy communities and collective self-consumption, regulated by Decree-Law 162/2019, enabling local prosumers and aggregators to participate actively in flexibility markets.

C. HOW IS THE EVOLUTION OF THE ENERGY MIX AFFECTING ELECTRICITY AND GAS INFRASTRUCTURE (E.G. GRID CAPACITY, RELIABILITY, CROSS-BORDER FLOWS)?

The transitioning energy mix is significantly affecting electricity and gas infrastructure, requiring profound adjustments:

- Electricity networks: expansion of transmission capacity, digitalisation, and large-scale storage solutions are essential to integrate higher shares of renewables.
- Cross-border electricity flows: in 2024, net imports covered 20% of national demand, underlining reliance on the Iberian and French markets (Euronews, 2025).
- Gas networks: the role of Sines LNG terminal remains strategic, though Portugal faces vulnerability to global LNG price volatility and geopolitical risks.

D. WHAT ARE THE ANTICIPATED IMPACTS ON INDUSTRIAL VALUE CHAINS (E.G. MANUFACTURING CAPACITY, LOCALISATION, STRATEGIC DEPENDENCIES)?

The transition generates both opportunities and dependencies:

- Electro-intensive industries (e.g., "green steel", data centres) are increasingly attracted by competitive renewable electricity.

- Green hydrogen is expected to build new industrial clusters, especially around ports and heavy transport, as shown by the Hydrogen Valleys projects in Sines and Northern Portugal (EcoNews, 2021; Chemical Processing, 2023).
- Portugal holds significant lithium reserves, relevant for EU battery value chains, but mining projects (Barroso region) face strong opposition due to environmental and social concerns.
- The ports of Viana do Castelo and Setúbal are positioned to become hubs for floating offshore wind assembly and maintenance, linking local supply chains with European industrial policy.

III. SOCIAL ACCEPTABILITY OF THE ENERGY TRANSITION

In Portugal, public support for the energy transition is generally strong, particularly regarding renewable energies, which are associated with sustainability, independence, and lower exposure to international fossil fuel markets (REN, 2025; APREN, 2025).

Still, technology acceptability remains a sensitive issue. Nuclear energy is politically excluded but often reappears in European debates on energy security (IEA, 2023). Wind power, though central to Portugal's electricity mix, faces increasing local resistance, mainly related to landscape transformation, biodiversity impacts, and noise (Pereira, 2025). Offshore wind projects have also raised concerns about marine ecosystems and their interaction with fishing and tourism (MAAC, 2023).

At the same time, local engagement is emerging as a key factor of social legitimacy. Energy communities and municipal-led initiatives allow citizens and local authorities to take part directly in renewable generation and self-consumption, reinforcing trust and ownership of the transition (Decree-Law 162/2019). These experiences suggest that transparent dialogue, fair distribution of costs and benefits, and genuine participation of communities are as important as technical feasibility in ensuring long-term public support (APA, RNC2050, 2019).

A. HOW WOULD YOU CHARACTERISE THE LEVEL OF PUBLIC ACCEPTANCE OF THE ENERGY TRANSITION IN YOUR COUNTRY?

Public opinion is broadly supportive of decarbonisation and renewable expansion. The record 71% renewable share in 2024 has strengthened confidence in the transition (REN, 2025).

In fact, there was an effectiveness of SIFAR policy (Photovoltaic Integration System for Self-Consumption and Grid) in reducing CO_2 emissions to the atmosphere, although this policy has not achieved its purpose (Maia et al., 2024).

B. TO WHAT EXTENT HAS THE ENERGY PRICE CRISIS OF 2022 INFLUENCED PERCEPTIONS OF ENERGY POLICIES AND CLIMATE COMMITMENTS?

The 2022 gas crisis raised awareness of energy dependency and reinforced calls for diversification and local renewable sources. However, it also revealed vulnerabilities: Portugal has one of the highest rates of energy poverty in the EU, with around 20.8% of the population unable to keep their homes adequately warm in 2023 (AMAN Alliance, 2023). In response, Portugal approved its National Energy Poverty Strategy in 2024, which aims to eradicate energy poverty by 2050 (European Energy Poverty Observatory, 2024).

The crisis highlighted the need to reconcile climate goals with affordability and equity, themes also emphasised in the REPowerEU Plan.

C. ARE THERE SPECIFIC TECHNOLOGIES (E.G. WIND POWER, NUCLEAR ENERGY) THAT RAISE SIGNIFICANT CONTROVERSY OR PUBLIC RESISTANCE?

Onshore wind is generally accepted at the national level, but local opposition persists due to landscape transformation, biodiversity impacts, and limited procedural justice in licensing processes (Oliveira et al., 2025).

Nuclear energy is politically excluded in Portugal, with government officials and renewable associations reaffirming that it is neither sustainable nor desirable, even if it remains part of EU-level debates on security of supply (The Portugal News, 2021; PV Magazine, 2022).

Lithium mining, although not an energy source itself but rather a critical raw material for battery storage technologies, has become highly contested in northern Portugal (Barroso region). Licensing processes have triggered public protests, municipal opposition, and legal challenges, with international scrutiny highlighting lack of transparency and risks to local communities and ecosystems (Reuters, 2025; The Guardian, 2025; Dehesas Vivas, 2024).

D. IS THERE AN ONGOING PUBLIC OR PARLIAMENTARY DEBATE REGARDING THE REALISM, COST, OR SOCIAL EQUITY OF THE ENERGY TRANSITION?

There is broad political consensus on achieving carbon neutrality, but disputes remain over:

- The costs of the transition for households and SMEs.
- The distribution of benefits and burdens across regions, especially gas-dependent industries.

- The pace of implementation of hydrogen, offshore wind, and digitalisation initiatives.

Ongoing debates reference the revision of PNEC 2030 and the National Strategy for Climate Change Adaptation (ENAAC), as well as the creation of the Interministerial Commission for Climate Action (Resolução do Conselho de Ministros nº 19/2025).

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SPAIN

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I. RECONFIGURING THE ENERGY MIX FOR CLIMATE NEUTRALITY

A. HOW HAS THE STRUCTURE OF ENERGY DEMAND EVOLVED IN YOUR COUNTRY IN RECENT YEARS?

In Spain, data from 2023 indicates that the distribution of energy consumption is led by the transport sector (39%), followed by the industrial and residential sectors (23% and 17%, respectively). The consumption of other sectors was: 12% in commercial and public services; 6% in non-energy use; 3% in agriculture. This trend has remained stable in recent years, even in 2020, when there was a drastic decrease in transport due to the pandemic[1].

Spain has successfully reduced its overall energy demand over recent years, achieving a 35% reduction in the energy intensity of its economy since 2000. This progress reflects greater efficiency and a shift from high-consumption industries to a more prominent service sector. Electricity demand grew 1% in 2024, reaching 248,811 GWh. This increase follows two years of decline, but demand still remains below pre-COVID levels[2].

B. WHAT IS THE CURRENT COMPOSITION OF THE ENERGY MIX, AND WHAT ARE THE KEY POLICY OBJECTIVES OR PROJECTIONS BY 2050 (E.G. SHARE OF FOSSIL FUELS, NUCLEAR, RENEWABLES)?

In 2023, Spain's **total energy mix** remained dominated by non-renewable sources, which accounted for 68% of the total supply. Oil made up the largest share at 43%, followed by natural gas (23%) and with a much smaller share from coal (2%). Renewable sources contributed 19% to the mix. The leading renewable technologies were wind and solar, which together made up 10%, followed by biofuels and waste (7%), and hydropower (2%). Additionally, nuclear power accounted for 13% of the total supply[1].

It is important to distinguish between the total energy mix, which reflects all energy used across economic sectors such as transport, heating, and heavy industry, and the electricity mix, which refers only to the power sector and excludes the use of fuels.

The most recent data from *Red Eléctrica Española (REE, the Spanish electricity grid operator)* (2024) show that renewable energies make up the largest share of Spain's **electricity mix**, accounting for 57% of total generation. This is followed by nuclear energy at 20%, and combined cycle plants at 14%. Within the renewable segment, wind power is the leading source at 23%, followed by solar photovoltaic (17%), hydroelectric power (13%), and solar thermal (2%). In 2024, Spain's total installed capacity was 132 GW, of which 85 GW corresponded to renewable sources[2].

By 2050, Spain aims to achieve climate neutrality, as established in the *The Law on Climate Change and Energy Transition adopted* in May 2021[3]. That implies a 100% renewable electric sector and reducing greenhouse gas emissions by 90% compared to 1990[4]. This law designates the National Integrated Energy and Climate Plan[4] and the Long-Term Decarbonization Strategy[5] as the planning instruments for addressing the energy transition. These plans address objectives by 2030, which include cutting emissions by 32% from 1990 levels, reaching a 48% share of renewables in final energy use, ensuring that 81% of electricity comes from renewables, improving energy efficiency by 43%, and reducing energy dependence to 50%[5]. In addition, Spain's official plan foresees the gradual closure of all nuclear power plants between 2027 and 2035[4,6]. However, political debate continues, with different stakeholders disagreeing on nuclear energy's role in supply security, climate goals, and the costs of the energy transition (See social acceptability section).

The decarbonisation pathways under implementation[4,5] focus on the electrification of most energy uses. By 2030, **35% of Spain's economy should be electrified.** Today, electricity already covers **around 24% of final energy demand**, reflecting steady progress and underlining the opportunity to further advance the transition in the coming years). Spain is also reforming its carbon pricing and taxation to align with the EU Emissions Trading System, implementing new taxes on high-carbon sectors and products like diesel, and reforming existing energy taxes to promote lower electricity prices while increasing diesel and coal costs[7]. Green hydrogen produced from water electrolysis is another energy transition solution promoted by Spain's Recovery, Transformation and Resilience Plan. The Spanish Hydrogen Roadmap[8] establishes the objective to install at least 40 GW of electrolysers by 2030 and Spain will contribute to produce up to 10 million tons of renewable hydrogen in the EU.

C. HAS YOUR ORGANISATION CONDUCTED ANY RECENT ASSESSMENT OF THESE EVOLUTIONS (E.G. SCENARIO MODELLING, SYSTEM-LEVEL IMPACT STUDIES)? IF SO, COULD YOU BRIEFLY DESCRIBE THE FINDINGS?

Oficina C has not conducted recent assessments on this specific topic. However, it has published other energy-related policy briefs, expressly commissioned by the Congress of Deputies, such as *"Green hydrogen as a fuel"*[9] and *"Critical raw materials in the energy transition"*[10].

II. TECHNOLOGICAL CONSEQUENCES OF THE TRANSITION

A. WHAT ARE THE MAIN TECHNICAL OR OPERATIONAL CHALLENGES ASSOCIATED WITH MANAGING A MORE DIVERSIFIED ENERGY MIX IN YOUR COUNTRY?

A more diversified energy mix enhances the system's security, but it also brings several challenges. High shares of renewable energy, particularly solar and wind, introduce variability and intermittency into the system[11]. Managing these fluctuations requires advanced forecasting, flexible backup generation, and robust grid management[12]. Large-scale, long-duration storage, including batteries, pumped hydro, and hydrogen are critical to balance these fluctuations[13,14]. The connection of new renewable power plants to the grid, together with the electrification of transport, heating, and other sectors by 2030 raises electricity demand. These changes require network upgrades, grid digitalization and modernization, operational flexibility, and careful planning to maintain supply security[15,16]. Reliance on imported renewable technologies increases technological dependence, highlighting the need for sector coupling and coordinated planning across electricity and gas networks[13,17].

B. WHAT MEASURES ARE BEING IMPLEMENTED OR CONSIDERED TO ENHANCE DEMAND-SIDE FLEXIBILITY (E.G. TIME-OF-USE TARIFFS, DEMAND RESPONSE)?

Spain has advanced in demand-side flexibility with monetary incentives. Time of Use (ToU) tariff programme, launched in June 2021, under which around 50% of the electricity bill is linked to system and network charges[18]. Complementing ToU, the Voluntary Price for Small Consumers (PVPC) allows households with less than 10 kW to view hourly wholesale market prices published the day before and adjust their usage[18,19].

Regulatory measures include Royal Decree-law 17/2022, which established an active demand response service[20]. The National Commission on Markets and Competition (CNMC) also adopted Circular 1/2024, introducing flexible access capacity[21]. In parallel, the Draft Royal Decree on the General Regulation on Supply and Contracting introduces independent aggregators[22]. Nevertheless, collective self-consumption (regulated by Royal Decree 244/2019) enables neighbours within 2 km to share surplus solar generation[23,24].

In addition, Spain is piloting local flexibility markets through the IREMEL project[25], allowing distributed resources (like rooftop solar, batteries, or demand-side response) to provide flexibility services directly to local grid operators to solve congestion problems[23,24].

These measures provide a framework to influence consumption, but more efforts are needed to promote consumer awareness and adapt lifestyle changes to couple demand with renewable generation[26]. In this sense, technological innovation is needed to provide accessible real-time information to the consumer.

C. HOW IS THE EVOLUTION OF THE ENERGY MIX AFFECTING ELECTRICITY AND GAS INFRASTRUCTURE (E.G. GRID CAPACITY, RELIABILITY, CROSS-BORDER FLOWS)?

The rapid expansion of solar and wind generation challenges Spain's electricity and gas infrastructure, which must be coupled to manage increasing renewable capacity, ensure system reliability, and make the most of limited cross-border flows[27]. Electricity infrastructure needs further investment to connect new renewable power plants and adapt to the changing system (including storage systems, digitalization and flexibility solutions). Regarding gas infrastructure, declining demand will require adapting existing networks from supply-oriented, unidirectional systems to bidirectional networks with integrated storage and flexibility[28,29]. It also needs long term planning to include the deployment of infrastructure related to other renewable options, such as hydrogen and its derivatives. Expanding interconnections with France and Portugal is key to strengthening security of supply and facilitating cross-border electricity flows, thereby contributing to the EU objective of achieving at least 15% interconnection capacity by 2030[30].

D. WHAT ARE THE ANTICIPATED IMPACTS ON INDUSTRIAL VALUE CHAINS (E.G. MANUFACTURING CAPACITY, LOCALISATION, STRATEGIC DEPENDENCIES)?

Energy-intensive sectors such as steel, cement, chemicals and glass face major shifts as decarbonisation requires electrification or the use of renewable fuels, such as electrolytic hydrogen[31]. Spain is positioning itself as a green hydrogen hub through initiatives such as H2Med[32,32]. At the same time, new industrial ecosystems are emerging in renewables: Spain's wind has a growing domestic industrial base[33], while solar PV supply chains remain import-dependent, notably on China[34].

The expansion of renewables is increasing the demand for critical minerals for solar, wind, and batteries for stationary use and transport. Transport electrification will drive demand for lithium, cobalt and rare earths through 2050, representing 54–92% of total use, while only 23–68% could be met domestically through recycling[35]. Therefore, there is potential for a growing industrial sector in the recycling of raw materials and renewable technologies. It is worth noting that the European Union has selected 47 projects to strengthen its strategic raw materials capacities under the Critical Raw Materials Act, which sets the targets of extracting 10%, processing 40%, and recycling 25% of the EU's annual consumption of strategic raw materials by 2030. Among these projects, seven are based in Spain, six mining initiatives and one recycling plant, mostly located in Extremadura and Andalusia. The acceptance of domestic mining varies among regions, where areas with an established mining culture are more prone to have a positive attitude towards mining activities. Meanwhile, Spain´s automotive sector, Europe's second-largest producer, is undergoing rapid restructuring as value shifts from traditional components to batteries and electric systems[36].

Although net job creation is expected in renewables, hydrogen and related sectors, traditional industries risk contraction, making workforce reskilling critical[37,38].

III. SOCIAL ACCEPTABILITY AND POLITICAL SUSTAINABILITY

A. HOW WOULD YOU CHARACTERISE THE LEVEL OF PUBLIC ACCEPTANCE OF THE ENERGY TRANSITION IN YOUR COUNTRY? ARE THERE SPECIFIC TECHNOLOGIES (E.G. WIND POWER, NUCLEAR ENERGY) THAT RAISE SIGNIFICANT CONTROVERSY OR PUBLIC RESISTANCE?

Public acceptance of Spain's energy transition is generally high, with Eurobarometer surveys[39] and national polls[40] consistently showing strong citizen support for renewable energy sources[41,42] and climate and energy legislation[40,43,44]. While some studies[45–47], reports[48–50] and news[51–54] reflect that local opposition exists around large-scale wind and solar projects, some national surveys suggest their general acceptance[40,55]. Main barriers to the adoption of these renewable energies include concerns related to environmental impact, fisheries, and landscape preservation[48,56]. Regarding nuclear energy, opposition still outweighs support in Spain[57], in contrast to trends in other EU countries[58]. Nevertheless, the current debate centres on whether to close or maintain existing nuclear plants and recent studies indicate rising public support towards nuclear energy[59], from 24% in 2019 to 43% in 2023[40]. Attitudes towards promising nuclear options such as fusion energy are currently considered moderately positive[60].

B. TO WHAT EXTENT HAS THE ENERGY PRICE CRISIS OF 2022 INFLUENCED PERCEPTIONS OF ENERGY POLICIES AND CLIMATE COMMITMENTS?

Available literature does not suggest significant shifts in public perceptions of environmental policies or climate commitments in Spain following the 2022 energy price crisis. Recent surveys indicate consistently high levels of support for climate action and related policies[40,61,62]. Likewise, in Spain 64% of responders agreed that renewable energy deployment should be accelerated, energy efficiency improved, and the transition to a green economy speed up[63]. Nonetheless, energy prices are a matter of concern for Spaniards, with priority giving to helping consumers access more affordable energy prices[62].

General public perceptions may be linked to the national measures[46-48] adopted during the crisis. The “Iberian exception,” which capped gas prices in electricity generation, helped decouple electricity costs from international markets, contributing to lower inflation and significantly reducing household bills, particularly for vulnerable consumers[64–66]. According to official estimates, these measures cut the average regulated household electricity bill by 30% in average (up to 64% in the case of vulnerable consumers)[47,48]. Still, as the authors point out with reference to Bank of Spain calculations, only 15-20% of the measures qualify as targeted[48].

C. IS THERE AN ONGOING PUBLIC OR PARLIAMENTARY DEBATE REGARDING THE REALISM, COST, OR SOCIAL EQUITY OF THE ENERGY TRANSITION?

In April 2025, a major blackout reignited concerns about the country’s power system. Although no official final studies have yet been published, the incident is matter of debate in the Spanish Congress[67] and may have influenced public opinion and deepened political divides. In any case, a survey conducted by Spain’s CIS after the blackout found that 44.2% of respondents believed the key to preventing another such blackout is modernizing the electricity grid.

Parliamentary groups have put forward a number of non-legislative proposals. At more specific level, the Republican Group suggested expanding distance criteria for energy communities in rural areas. SUMAR group emphasised the need to work on organization and social acceptance of renewables installations. VOX group highlighted the protection of agricultural land from energy installations. The Popular group proposed maintaining nuclear operations to support supply security.

Government (a coalition led by the Socialist Party, PSOE) initiatives also reflect these concerns. In February 2025, the Spanish Senate debated the social cost of the transition, announcing a new energy poverty strategy and a Social Climate Plan. Likewise, the Government has recently launched the **Electricity Transmission Network Plan with a 2030 horizon**, outlining an investment of €13.59 billion by the end of the decade. The proposal is designed to meet the country's needs and to align with the objectives of the Integrated National Energy and Climate Plan 2023–2030 (PNIEC), giving priority to industrial projects. The draft Royal Decree, currently under public consultation, seeks to regulate investment plans for electricity transmission and distribution networks.

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SWEDEN

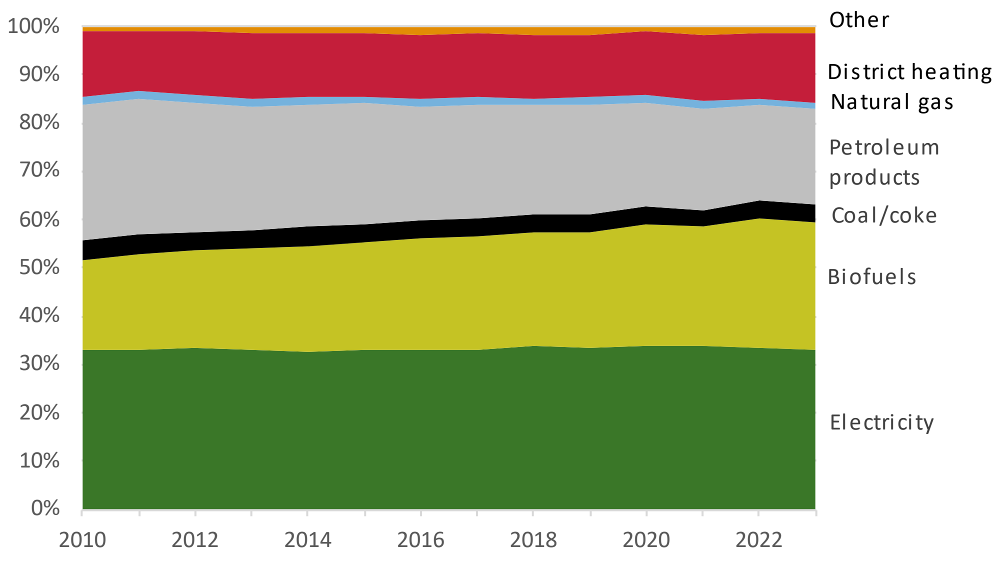
Evaluation and Research Secretariat (ERS) of the Swedish Riksdag

I. ENERGY MIX AND THE CARBON NEUTRALITY OBJECTIVE

A. ENERGY CONSUMPTION AND ENERGY MIX

Between 2010 and 2023, total energy consumption decreased by 10 per cent, from 395 TWh to 353 TWh[1]. When adjusted for population size, the decrease is even larger (20 per cent). This decreasing trend applies to all major sectors (industry, transport and housing/services). The energy sources that decreased the most are natural gas[2] (40 per cent) and petroleum products (35 per cent), while biofuel increased by 25 per cent. In total, fossil fuels decreased by one third. This development is also evident in the energy mix, where biofuels increased their share from 19 to 26 per cent, and petroleum products decreased from 28 to 20 per cent (fig 1). Natural gas was a marginal source of energy during the entire time frame. The share of energy from all fossil fuels combined decreased from 34 to 25 per cent.

Figure 1 Energy mix 2010–2023, based on consumption



Source: Swedish Energy Agency

About one third of all energy consumed comes from electricity, which is 98 per cent fossil-free. Electricity production consists chiefly of hydroelectric (about 40 per cent) and nuclear power (30 per cent, down from around

[1] *Source: Swedish Energy Agency.*
[2] *Includes town gas.*

40 per cent prior to 2020). Wind power has steadily increased to around one fifth of electricity production, while solar power still has a marginal share of all production (2 per cent). CHP (Combined heat and power), of which 80 per cent is renewable, makes up the remaining part (8 per cent).

B. POLICY OBJECTIVES AND PROJECTIONS

The overarching objective regarding Sweden's energy mix is 100 per cent fossil-free electricity production by 2040, and achieving net zero emissions of greenhouse gases by 2045. According to the Swedish Energy Agency's (SEA) scenario analysis, fossil fuel use could decrease by between 79 and 93 per cent by 2050 compared to 2023, depending on policy choices and external factors (SEA 2025a). Combined with measures to capture and store CO_2, net zero would be achieved by 2045 at the latest. All scenarios are based on nuclear power being stable or increasing, increasing wind power, continuing electrification and a reduction of fossil fuels.

C. PATHWAYS TO GOAL ACHIEVEMENT

According to the Government's action plan for climate, submitted to the Riksdag in December 2023 (communication 2023/24:59), the key conditions for achieving net zero by 2045 are ensuring access to fossil-free electricity through investment in infrastructure, making environmental permit procedures more efficient, ensuring key competencies and critical material for electrification and renewables, increasing recycling and reuse, pricing greenhouse gas emissions and incentivising negative emissions, supporting effective capital provision, and fostering public engagement and acceptance of climate policy instruments. The opposition has criticised the action plan on a number of points (committee report 2023/24:MJU15). The areas where there is most conflict concern the methods for achieving fossil-free energy, stage goals and the pace of change towards net zero, and how Sweden should act in the EU and globally.

- In the Budget Bill for 2025 (Govt. bill 2024/25:1), the Government is investing heavily in efforts to strengthen the resilience of the energy system, by developing regional and local power grids. To motivate local councils to permit new wind power plants, the Government has proposed a mechanism by which property tax paid by power companies is funnelled back to municipalities. In the spring of 2025, the Riksdag decided on a model of government loans and two-way CfD agreements which guarantee a certain minimum electricity price, for the expansion of new nuclear power (Govt. bill 2024/25:150, committee report 2024/25:NU20). An area that will receive less funding in the coming years is energy efficiency. According to the Government, there is a risk that existing objectives regarding energy efficiency may conflict with achieving net zero, as the industry's transition to fossil-free energy may entail less efficient energy use than is the case at present.

D. PREVIOUS REPORTS FROM THE RIKSDAG

The Committee on Transport and Communications has commissioned two studies pertaining to this subject area. The first aimed to identify alternatives to fossil fuels in the transport sector, and concluded that electrification of the vehicle fleet, combined with biofuels in aviation and shipping, was the preferred alternative (2017/18:RFR13). The latest report was a review of methods to develop the charging infrastructure (2023/24:RFR7). In order to create the conditions for expansion, the report points for example to increased collaboration between actors at different levels, with the state as a coordinator. Government grants have been important, but should be expanded to charging infrastructure for heavy vehicles. The Riksdag Research Service has conducted a number of reports in recent years that have been made public (see the "RUT" reports, that is reports from the Research Service, in the reference list). Some findings from these studies are that previous projections regarding electricity demand have almost always been overestimates, that Sweden consumes 16 per cent of the global production of HVO[1], and that Sweden is dependent on net imports of electricity during a normal winter.

II. CONSEQUENCES OF TECHNOLOGICAL CHOICES

A. IDENTIFIED CHALLENGES

An increase in intermittent (weather-dependent) energy sources places higher requirements on the flexibility of the power system, both in the long and short term and in real time. Flexibility on the supply side can be enhanced through measures such as developing hydroelectric power to its full potential, load-following production in nuclear plants, and solar/wind hybrid plants (SEA, 2025b). This needs to be complemented with increased capacity for energy storage. Moreover, the national grid has to be updated and developed to eliminate bottlenecks and support increased production and consumption. According to a recent report by the Swedish Energy Markets Inspectorate (SEMI), nine out of ten network companies report an increased need for transmission capacity (SEMI, 2025).

Another challenge concerns the phasing out of fossil fuels in the transport sector. The increase in electrical vehicles (EVs) has tapered off due to the difficult economic situation for households, but the SEA still projects that the proportion of EVs among passenger cars will increase from ten per cent in 2023 to 85–90 per cent in 2045 (SEA, 2024a). As of 2024, rechargeable cars (EVs and hybrids) tend to be registered mainly in urban municipalities, with a considerably older vehicle fleet in rural areas (Transport Analysis, 2024a). In northern Sweden, battery capacity may be an obstacle to higher

[1] *Hydrogenerated vegetable oil, a biofuel.*

take-up, because of cold weather and long driving distances. Among heavier vehicles, EVs are still rare, with the exception of electric city buses and light lorries. In recent years, the public charging infrastructure for passenger cars has been expanded, while charging infrastructure for heavy road vehicles, maritime transport and aviation is lagging behind (Transport analysis, 2024b).

Due to a lowering of the reduction obligation level[1], the proportion of renewables in fuel decreased from 26 per cent in 2023 to 13 per cent in 2024, with predominantly diesel filling its place (SEA, 2024b). The motivation behind these changes was primarily to alleviate the historically high consumer prices (Govt. bill 2023/24:28). The use of the reduction obligation scheme as a mean of reducing emissions has also been criticised by the Swedish National Audit Office (SNAO) as being unfeasible, not cost-effective and having regressive effects on households, with unknown societal economic consequences (SNAO, 2023:13).

B. DEMAND FLEXIBILITY

On the demand side, flexibility can be achieved through improved information to consumers and more precise pricing, supported by automation and real-time monitoring (SEMI, 2023). From October 2025, quarter-hourly electricity prices will be introduced on the Nordic spot market, and from 2027, all network companies must implement flexible fees, meaning that grid tariffs may be dependent on the timing of consumption. New solutions for consumers to automatically control their energy consumption have been developed and this is being implemented in parts of Sweden (Göteborg Energi, 2025). There is also an unrealised potential in energy-heavy industries to contribute to flexibility, which would require limited investment but might entail increased production costs (SEA, 2025b).

C. IMPACT ON INFRASTRUCTURE

Electrification places higher demands on existing infrastructure. Around 60 per cent of network companies describe current or expected limitations in grid capacity, and over two thirds of companies state that they are currently investing in physical infrastructure (SEMI, 2025). Grid bottlenecks between the north and the south contribute to price differences between bidding zones (Energiforsk, 2024). In October 2024, a new flow-based method for capacity calculation was introduced in the Nordic electricity grid (Energinet et al, 2025). Its purpose was to ensure more efficient use of the grid and increase capacity, while levelling out price differentials. However, available capacity has decreased since the new method was introduced. Tests are now being conducted with new settings and increased relaxation to investigate whether additional capacity can be made available.

[1] *From 7.8 per cent (petrol) and 30. 5 per cent (diesel) to 6 per cent in 2024, and 10 per cent from 2025.*

Overall, Sweden is a net exporter of electricity, but also imports electricity (primarily from Norway) during the winter months (Svenska kraftnät, 2025). Although Sweden has good transmission capacity to neighbouring countries, import opportunities may be limited if these countries are also experiencing strain.

D. IMPACT ON INDUSTRY

Both the expansion of electricity production and grid infrastructure are necessary to further electrify industry (SEA, 2023a). Swedish industry is a heterogeneous sector where production processes and conditions differ widely, and the development towards fossil-free production has reached different stages in different subsectors (SEA, 2024c). Changing conditions due to an economic downturn and increased protectionism, as well as uncertainties regarding the regulatory framework concerning long-term climate targets, are some of the main reasons mentioned for cancelling large-scale investments in innovative fossil-free technologies. There are also many technological challenges to be overcome. A clear obstacle to flexibility of electricity use in industry is process limitations, i.e. long start-up times and other technical limitations, as well as the need for investments to adapt processes to enable more flexibility (SEA, 2023a). There is also a risk that product quality or delivery reliability will be affected.

III. SOCIAL ACCEPTABILITY OF THE ENERGY TRANSITION

A. PUBLIC ACCEPTANCE AND PERCEPTIONS

The SOM Institute at the University of Gothenburg has been collecting survey data on the population's opinions regarding environmental issues since 1999. The survey shows downward trends in the proportion affirming that Sweden should invest more in all power sources (including wind, biofuels and fossil fuels), with the exception of nuclear power, which has increased to about 35 per cent, up from ten per cent (SOM Institute, 2025). However, a majority (60 per cent) are still in favour of investing more in wind power, and solar power has a steady approval rate at around 75–80 per cent[1]. Most policy measures listed to decrease emissions are assessed more positively than negatively[2]. Another long-term survey regarding climate change and policy has been conducted by the Swedish Environmental Protection Agency since 2002. In the latest study, between 72 and 79 per cent were positive towards measures such as allocating resources to fossil-free electricity

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[1] *A sudden drop to 49 per cent (wind) and 66 per cent (solar) in 2024 could be due to changes in the wording and ordering of questions (SOM Institute, 2025).*

[2] *For example, expanding public transport, prohibiting subsidies of fossil fuels, removing obstacles for establishing wind turbines, and mandatory solar panels on new constructions.*

production, renewable fuels, electricity infrastructure and public transportation (New Republic, 2025). Almost 70 per cent said that climate concerns affected their choice of transportation.

B. EFFECTS OF THE ENERGY PRICE CRISIS ON PUBLIC OPINION

As can be seen in the surveys reported above, there has been a long-term decline in support for larger investments in both wind, solar, biofuel and hydroelectric power sources, but no clear drop between 2022 and 2023. It is possible that the temporary economic support to households with high electricity costs that was in effect in 2022–2023 may have alleviated the impact. However, the upsurge of nuclear energy as an alternative is most likely an effect of the energy price crisis. One clear effect has been efforts to save energy, with 85 per cent of respondents in a survey in 2024 stating that they had decreased their energy consumption, compared to 74 per cent in 2021 (ibid.). Consumption data also shows a decrease in emissions of five per cent in 2023 compared to 2021 (seven per cent for housing/ services)[1]. The price crisis due to high inflation in 2022–2023 may also have impacted the support for other policy measures such as the carbon tax on fossil fuels (Axelsson, Matti & Rönnerstrand, 2025).

C. CONTROVERSY AND PUBLIC RESISTANCE

As the surveys above show, a majority are positive towards investing more in wind power. However, only a third are positive towards establishing wind power plants in their local area. Local opinion tends to be unfavourable, often due to concerns regarding noise pollution, blocked views, and house value depreciation. Half of all wind power plants are declined by local county councils (Axelsson, Marzelius & Pakkala, 2025). The new government grant to compensate municipalities with wind power plants may be one way to impact local opinion. Other proposals include that part of the proceeds will be allocated to the local community (SOU 2023:18). These measures have broad political support (parliamentary record 2004/25:49). However, the SEA has cautioned that economic incentives are more likely to be effective in poorer municipalities in the north, while electricity production needs to increase primarily in the south (SEA, 2021, 2023b).

Nuclear power is the most controversial energy source, and it has been one of the most debated political issues for many decades. Between 2016 and 2019, a majority in the Riksdag had agreed on a common platform, the Energy Agreement, with a goal of 100 per cent renewables in electricity production in 2040. After two years, it collapsed when the Moderates and the Christian Democrats left the agreement due to conflicts over the role of nuclear power. They wanted a reformulation of the goal as 100 per cent fossil-free.

[1] *Source: Swedish Energy Agency.*

Since then, the Social Democrats and the Centre party have shifted their position, and there is a large majority in favour of accepting nuclear energy as part of the energy mix also in the future (parliamentary records 2024/25:49 and 2024/25:111). There are still major political differences regarding both the weight of nuclear energy in the energy mix, and how new plants should be financed, with the Government advocating state support, while opposition parties are either completely against nuclear energy, or critical to risk-sharing by the state with market actors (Prot. 2024/25:120).

D. ONGOING DEBATE

Regarding realism, both sides of the debate are more optimistic about their own solutions when it comes to technical feasibility, cost, and time frame, and accuse the other side of being unrealistic (parliamentary record 2024/25:49). Both sides also use "market logic" to justify their own position, but are willing to intervene in the market to bring about the desired changes (parliamentary record 2024/25:111). This is true for nuclear power, as well as wind power and novel technologies for energy storage. There is a marked difference in how the cost of nuclear power is framed: as a necessary investment, or as an economic risk which will block other alternatives (parliamentary record 2024/25:120).

- Another ongoing political controversy concerns the importance of increasing energy efficiency. Energy efficiency is a much higher priority for the opposition than for the Government, both in rhetoric and budget proposals, while the Government is primarily focused on production and electricity infrastructure (committee report 2024/25:NU19).
- Equity aspects are discussed primarily with regard to electricity costs for households, which periodically differ markedly between bidding zones. Apart from the impact on households, low electricity prices and adequate energy production are seen as paramount for industry (parliamentary record 2024/25:49). On this question, there is more or less political unity. The Left Party and the Green Party also want more targeted measures directed at poorer households while the Sweden Democrats emphasise the higher economic burden in rural communities of fuel costs (parliamentary record 2024/25:111).

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SWITZERLAND

Swiss Foundation for Technology Assessment (TA-SWISS)

I. ENERGY MIX AND THE CARBON NEUTRALITY OBJECTIVE (2050)

A. HOW HAS THE STRUCTURE OF ENERGY DEMAND EVOLVED IN YOUR COUNTRY IN RECENT YEARS?

The energy consumption in Switzerland has been increasing until about the first decade of the millennium. However, since about 2010 the overall energy demand shows a decreasing trend of about minus 10% per decade (see figure 1), while at the same time the economy has grown by about 30%[1].

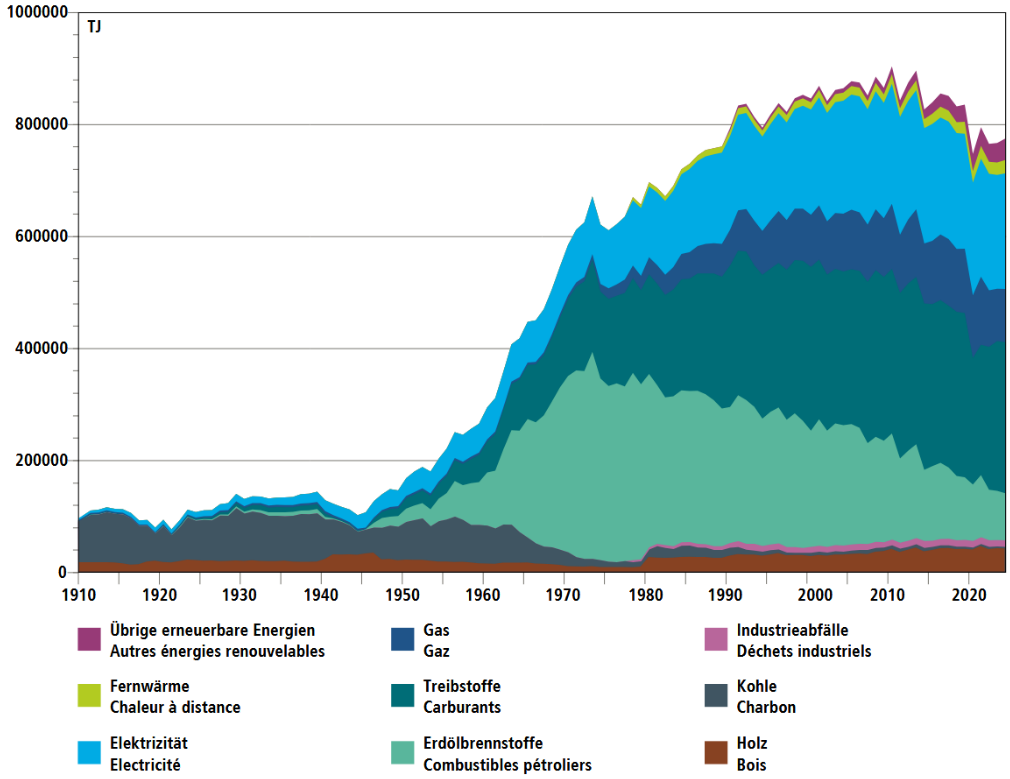

Figure 1: *Final energy consumption (terajoule) 1910–2024 by energy source for other renewable energies, gaz, industrial waste, district heating, transport fuels, coal, electricity, oil fuel and wood.* (*Swiss Overall Energy Statistics 2024, p. 3, Swiss Federal Office of Energy*[1])

[1] *Schweizerische Gesamtenergiestatistik, BFE 2024.*

The use of oil products has decreased significantly, mainly in heating and industry, while transport fuels have seen only a modest decline. Electricity demand, in contrast, has hardly changed over the last decade, and thus until now the increasing efficiency of electrical equipment seems to more or less neutralize the rising number of electric cars and heat pumps[1].

B. WHAT IS THE CURRENT COMPOSITION OF THE ENERGY MIX, AND WHAT ARE THE KEY POLICY OBJECTIVES OR PROJECTIONS BY 2050 (E.G. SHARE OF FOSSIL FUELS, NUCLEAR, RENEWABLES)?

Electricity production in Switzerland has long relied on hydropower and nuclear energy, which explains its comparatively low carbon emissions. However, the share of electricity covers only about a fourth of the total energy demand, while almost 60% of energy consumption still comes from fossil fuels (see figure 2). Transport remains by far the largest energy-consuming sector and continues to depend heavily on fossil fuels.

One of the key policy objectives on the path to carbon neutrality is to replace oil and gas for heating, transport and industry with electricity, for example by the use of electric vehicles and heat pumps. At the same time, it remains crucial to preserve the low-CO_2-emission profile of Swiss electricity generation[1].

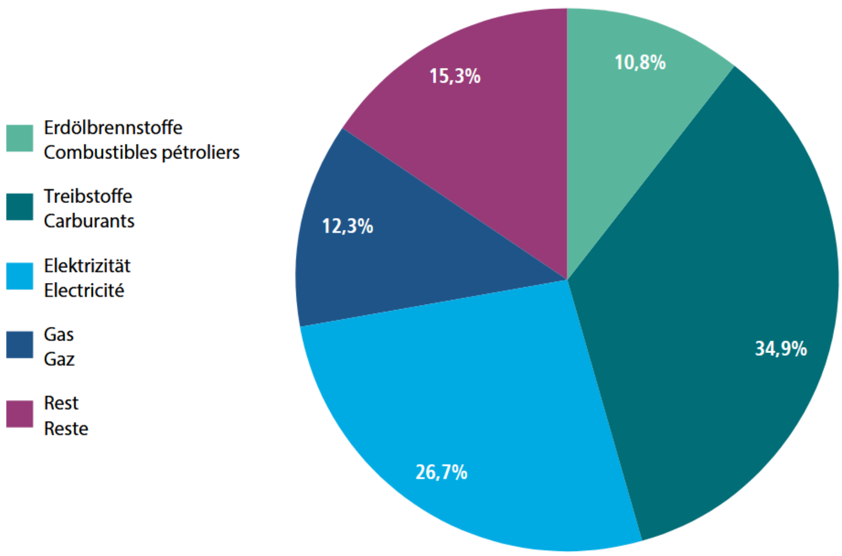

Figure 2: *Breakdown of final consumption by energy source 2024: oil fuels, transport fuels, electricity, gaz, other energy sources (Swiss Overall Energy Statistics 2024, p. 4, Swiss Federal Office of Energy[1])*

[1] *Swiss Energy System 2050: Pathways to Net Zero* CO_2 *and Security of Supply.*

C. WHAT TRANSFORMATION PATHWAYS ARE CURRENTLY UNDER DISCUSSION OR IMPLEMENTATION TO ACHIEVE DECARBONISATION GOALS?

In a national vote in 2017, the Swiss population approved a long-term energy strategy[1] aiming at reaching carbon neutrality. The concept relies above all on an expansion of solar power, complemented by wind and hydropower, to meet the growing electricity demand driven by the electrification of transport and heating as well as increasingly energy-demanding data centres. At the same time, under the impression of the nuclear accident at Fukushima, Switzerland decided to ban the construction of new nuclear power plants, but to continue using the existing nuclear power plants as long as they are rated as safe. The new Federal act on secure electricity supply[2], approved by the Swiss population in 2024, provides the basis for the rapid expansion of renewable energy production, including funding instruments like subsidies and a set of regulations for electricity production, transport, storage and consumption. Since the rollout of renewable energy production advances slower than planned, in the recent years nuclear power is becoming an issue in politics and society again and there are popular and political initiatives to lift the ban of building new nuclear power plants (see also chapter 3).

D. HAS YOUR ORGANISATION CONDUCTED ANY RECENT ASSESSMENT OF THESE EVOLUTIONS (E.G. SCENARIO MODELLING, SYSTEM-LEVEL IMPACT STUDIES)?

TA-SWISS has not yet conducted a study on the transformation of the energy mix in Switzerland. However, in the past, a study on negative emission technologies has been carried out, and currently, a project investigating the chances and risks of new nuclear technologies in Switzerland is in progress. The latter includes the modelling of different scenarios of energy systems comprising new nuclear technologies – with a mid- and long-term time frame – and examines possible advantages and challenges from a technical, societal, political, economic and legal perspective. The study report is expected to be published in mid-2026.

[1] *Schweizerische Energiestrategie 2050, Swiss Federal Office of Energy.*
[2] *Federal act on a secure electricity supply, Swiss Federal Office of Energy.*

II. CONSEQUENCES OF TECHNOLOGICAL CHOICES

A. WHAT ARE THE MAIN TECHNICAL OR OPERATIONAL CHALLENGES ASSOCIATED WITH MANAGING A MORE DIVERSIFIED ENERGY MIX IN YOUR COUNTRY?

The Swiss energy strategy 2050 is intended to contribute to reducing Switzerland's energy-related environmental impact[1]. In recent years also the security of energy supply has emerged as a key challenge in the political debate. In this context the option of a future new construction of nuclear power in Switzerland is increasingly becoming an issue on the political level. The two larger of the currently running ~1 Gigawatt reactors nuclear plants in Switzerland will reach 60 years of operation in 2039 and 2044 and it remains open if or how long they will be continued to be operated beyond that. The two smaller of the currently running Swiss nuclear plants are scheduled to shut down in 2032 and 2033 resulting in a significant loss (~600 Megawatt) of production capacity. At the same time, the expansion of renewables entails a number of challenges for Switzerland's energy transition. Photovoltaics and wind are both weather dependent. Since wind power is not well supported by the Swiss population, the expansion mainly happens in solar. This leads to the situation that electricity production is rather unevenly distributed, with an overproduction during daytime on the daily scale and during summer on the seasonal scale[2]. On the daily scale, peak photovoltaic production in summer can largely be absorbed through local battery storage at the site of production (mostly on buildings), through demand-side management within households or neighbourhoods, or by briefly curtailing production. In turn, short-term weather fluctuations can be balanced by the large pump-hydro plants in the Alps. The main challenge is seasonal storage of photovoltaics overproduction in summer to the wintertime. There is quite some storage potential from hydro dams in the Alps, but they will not be sufficient to solve the problem. There are many other possibilities to store energy (e.g. heat storage, production of storable synthetic fuels like hydrogen, methane or methanol), but except of storage of heat, which can be used for heating in winter, most possibilities are less inefficient, for example a lot of the energy is lost during conversion of electricity into the storable substance and back (like hydrogen), and they involve high costs[3]. A possible supplement for photovoltaics would be wind power, because wind delivers most of its energy production in winter and during bad weather. Other alternatives for more winter production would be alpine photovoltaics, which is often a technical, environmental[4] and economic challenge, or nuclear energy, but there is currently no legal basis for the new construction of the latter.

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[1] *Schweizerische Energiestrategie 2050.*
[2] *Swiss Energy System 2050: Pathways to Net Zero CO_2 and Security of Supply.*
[3] *Overview of seasonal energy storage - interrelationships, significance and prospects in the Swiss context, to be published in October 2025.*
[4] *Ausbau erneuerbarer Energien biodiversitäts- und landschaftsverträglich planen.*

B. WHAT MEASURES ARE BEING IMPLEMENTED OR CONSIDERED TO ENHANCE DEMAND-SIDE FLEXIBILITY (E.G. TIME-OF-USE TARIFFS, DEMAND RESPONSE)?

Demand-side flexibility will be a key to manage the imbalance of electricity production peaks in summer and electricity consumption peaks. A certain grid expansion will be necessary, also due to a widespread need of renewal of older sections, but demand-side management could lower the requirements and corresponding costs considerably[6]. To support demand flexibility, the new 'Federal Act on a secure electricity supply'[1] includes the possibility of combining flats, neighbouring houses or even neighbourhoods that are connected to the same distribution centre into consumer communities in order to increase local self-consumption. However, the time-of-use-tariffs are currently still in political discussion.

C. HOW IS THE EVOLUTION OF THE ENERGY MIX AFFECTING ELECTRICITY AND GAS INFRASTRUCTURE (E.G. GRID CAPACITY, RELIABILITY, CROSS-BORDER FLOWS)?

Currently the Swiss electricity grid is currently being renewed and expanded. The local power distribution centres are adapted to be able not only to distribute electricity coming from the high voltage level to a large number of consumers, but also collect electricity from local 'prosumers', i.e. households that both produce and consume electricity, to the higher level grids[2].

At the end of December 2024, the Swiss Federal Council took note of the material conclusion of the negotiations of a new electricity agreement with the European Union[3]. Such an agreement could help Switzerland to strengthen security of supply and grid stability, as well as to simplify electricity trading. Currently, the Swiss parliament is debating on this issue. The final decision will be made by a public vote sometime in the next few years.

[1] *Swiss Federal Act on a secure electricity supply, Swiss Federal Office of Energy.*
[2] *New framework conditions for developing the network, Swiss Federal Office of Energy.*
[3] *Electricity agreement Switzerland – EU, Press Release, 13.06.25, Swiss Federal Office of Energy.*

III. SOCIAL ACCEPTABILITY OF THE ENERGY TRANSITION

A. HOW WOULD YOU CHARACTERISE THE LEVEL OF PUBLIC ACCEPTANCE OF THE ENERGY TRANSITION IN YOUR COUNTRY AND IS THERE CONTROVERSY ABOUT SPECIFIC TECHNOLOGIES?

In the Swiss system of direct democracy, the population plays a important role in shaping the energy infrastructure. The participatory process offers many opportunities for taking influence. However, in general, energy technologies require broad public acceptance[1] in order for projects to prevail in the political process. A recent study on public opinion toward energy sources shows that rooftop solar and large-scale hydropower enjoy the highest levels of acceptance among the Swiss public[2]. A further survey, published in 2025, reveals that people consider security of supply the top priority, closely followed by affordable electricity and climate neutrality[3]. And more than two-thirds of respondents believe that all climate-friendly technologies – including nuclear power – should be used. If no additional solar, wind or hydropower plants could be built, the Swiss population would clearly prefer new nuclear power plants (49 percent) over gas-fired plants (26 percent) as sources of additional electricity[13]. The survey also reveals that a majority (56 percent) of the public would like to see the debate on nuclear energy reopened.

B. TO WHAT EXTENT HAS THE ENERGY PRICE CRISIS OF 2022 INFLUENCED PERCEPTIONS OF ENERGY POLICIES AND CLIMATE COMMITMENTS?

Energy policy and strategies are currently a much and controversially debated issue in the Swiss politics and society. With the geopolitical changes over the last years, security of supply is becoming an increasingly important political and societal issue. Public attitudes towards nuclear energy have shifted repeatedly over the past decades, and surveys continue to reveal a broad spectrum of views . After the Fukushima accident in 2011 and the subsequent decisions of the Federal Council and Parliament, the Swiss population voted in 2017 to phase out nuclear power and to prohibit the construction of new plants. Yet, with regard to political and social uncertainties in relation of the possible electricity shortages, as in 2022, as well as concerns regarding future import options a debate is currently unfolding in politics and the public about the continued operation or new construction of nuclear power plants. At the same time, considering the growing e-mobility, the rising use of heat pumps and increasingly energy-intensive AI systems, it can be expected that the electricity demand will increase significantly more than was assumed a few years ago.

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[1] *Bringing the policy making perspective in: A political approach to social acceptance. Dermont C, Ingold K, Kammermann L, Stadelmann . Energy Policy, 108, 359-368, 2017.*

[2] *Renewable Energy Outlook 2, ETH Zurich, 2025.*

[3] *VSE Umfrage bestätigt: Versorgungssicherheit hat für Schweizer Bevölkerung oberste Priorität, 2025.*

C. ARE THERE SPECIFIC TECHNOLOGIES (E.G. WIND POWER, NUCLEAR ENERGY) THAT RAISE SIGNIFICANT CONTROVERSY OR PUBLIC RESISTANCE?

See 3.1.

D. IS THERE AN ONGOING PUBLIC OR PARLIAMENTARY DEBATE REGARDING THE REALISM, COST, OR SOCIAL EQUITY OF THE ENERGY TRANSITION?

In the coming years, Switzerland will see an intense political and societal debate on energy issues – particularly on nuclear power. The discussion about a possible continuation of nuclear energy was launched in the Swiss Parliament in 2022, and since then, several related parliamentary requests and proposals have been submitted[1]. Notably, in March 2024 the Council of States approved a parliamentary request to allow the continued operation of existing nuclear plants. The Federal Council now has two years either to implement the mandate or to propose its dismissal[2]. In addition, a popular initiative was submitted in February 2024 calling for the lifting of the ban on constructing new nuclear power plants[3]. On 13 August 2025, the Swiss Federal Council adopted its message on an indirect counterproposal to this initiative. While rejecting the initiative itself, the counterproposal foresees amending the Nuclear Energy Act to again approve new nuclear power plants in Switzerland. This would keep nuclear energy open as an option for ensuring Switzerland's long-term energy security[4]. At the same time, Switzerland is revising its long-term energy perspectives. These scenarios, which include a time frame as of 2060, are expected to be completed by the end of 2027 and will serve as the basis for future energy policy[5].

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[1] *Postulat Hess 22.3621 "Rahmenbedingungen für den Bau neuer Kernkraftwerke schaffen" (am 11.06.24 vom NR abgelehnt); Motion Knecht 22.3067 "Aufhebung des Verbots, Rahmenbewilligungen für Kernkraftwerke zu erteilen" (abgelehnt), Interpellation Schilliger 22.3663 "Wie würde sich der Einbezug des Landschaftsbildes auf die Wirtschaftlichkeit der Kernenergie auswirken?" (erledigt); Motion Egger 21.3916 "Für eine Umweltpolitik mit Anreizen statt Abgaben" (abgelehnt); Motion Hess 21.3901 "CO_2-arme Stromproduktion mit Kernenergie" (abgelehnt); Postulat 22.4021 FDP-Liberale Fraktion "Erhalt der bestehenden Kernkraftwerke als langfristige Option gegen eine Stromlücke" (angenommen).*
[2] *Postulat Burkart 23.4152 "Weiterbetrieb der bestehenden Kernkraftwerke ermöglichen".*
[3] *Eidgenössische Volksinitiative "Jederzeit Strom für alle (Blackout stoppen)": https://blackout-stoppen.ch/#worum-es-geht.*
[4] *Medienmitteilung des Schweizerischen Bundesrates "Initiative «Blackout stoppen» – Bundesrat verabschiedet Botschaft zum indirekten Gegenvorschlag", 13.08.2025.*
[5] *Energy perspectives 2060, Swiss Federal Office of Energy.*

UNITED KINGDOM

Parliamentary Office of Science and Technology – UK Parliament

I. ENERGY MIX AND THE CARBON NEUTRALITY OBJECTIVE (2050)

A. HOW HAS THE STRUCTURE OF ENERGY DEMAND EVOLVED IN YOUR COUNTRY IN RECENT YEARS?

Total final energy consumption has decreased since the start of the decade from 172 mtoe in 2000[1] to 150 mtoe in 2013[2] to 133 mtoe in 2024.[3] In 2024 industrial electricity use was down 28%, commercial down 10% and domestic down 16% when compared to 2000 levels. See Table 1 for 2024 sector specific energy demands.[3]

Demand for petroleum products decreased to 61 million tonnes in 2024 from 77 million tonnes in 2000, with a significant drop during the pandemic due to decreased transport usage.[3]

UK natural gas demand peaked in 2004 and was 36% below this level in 2024. This cut was driven by a combination of less demand for gas for electricity generation and more electricity imports.[3]

There has been a long phase out of coal with the last coal fired power station closing in 2024. The demand for coal is currently at 4% of 2000 levels.[3]

Net imports have grown. In 2000 the UK was a net exporter. In 2004 the UK became a net importer and in 2024 there was a 43% import dependency with over 90% of imports comprising of oil and gas, predominantly from the US and Norway respectively.[3]

Energy intensity has decreased as appliances become more efficient, and air and rail travel return to higher levels of occupation post pandemic.[4]

Table 1: Final energy consumption per sector 2024[3]

Sector	Transport	Domestic	Commercial/ Public Administration	Industry	Other
Final energy consumption (mtoe)	54.0	34.0	20.6	19.5	4.5
Final energy consumption (% of total)	41.3	26.0	15.8	14.9	1.9

B. WHAT IS THE CURRENT COMPOSITION OF THE ENERGY MIX, AND WHAT ARE THE KEY POLICY OBJECTIVES OR PROJECTIONS BY 2050 (E.G. SHARE OF FOSSIL FUELS, NUCLEAR, RENEWABLES)?

Fossil fuels meet ~75% of the UK energy demand and are split between natural gas (29%) for heating and electricity, and petroleum (45%) for transport.[3,5]

Electricity makes up 18% of final energy consumption, see Table 2. for the breakdown of the different energy sources in 2024.[3] In 2024 low carbon sources made up 64% of electricity generation with the largest percentage of this coming from wind, onshore and offshore (45%), and nuclear (22%), see Table 3.[6]

Table 2: Final energy consumption sources in 2024[3]

Energy type	Petroleum	Natural gas	Electricity	Bioenergy & waste	Heat sold	Coal	Coke and breeze	Other solid fuels
Percentage of total	45.40%	29.00%	18.30%	5.70%	1.00%	0.40%	0.10%	0.10%

Table 3: UK generation from low-carbon sources in 2024[6]

Technology	TWh
Offshore wind	48.5
Nuclear	40.6
Onshore wind	34.7
Plant biomass	26.6
Solar	14.4
Hydro	5.8
Energy from waste	5.5
Anaerobic digestion	3.5
Landfill gas	2.9
Sewage sludge digestion	1.0
Other	0.8
Total	184.3

The UK has committed to Net Zero by 2050 (Scotland by 2045), which equates to a 30% emissions reduction by 2030.[7] The Clean Power 2030 Action Plan aims to reduce the carbon intensity of electricity generation to 50gCO_2eq/kWh and have 95% of generation be from clean sources, alongside shifting the country to be a net exporter of electricity by 2030. The Department for Energy Security and Net Zero (DESNZ) projections for the electricity generation mix for 2030 are shown in Table 4.[6]

Table 4: Current (2023) and expected installed capacity of electricity generation by 2030[6]

Generation type	Current installed capacity (GW)	DESNZ '2030 Clean Power Capacity Range' (GW)
Offshore wind	14.8	43-50
Onshore wind	14.2	27-29
Solar	16.6	45-47
Nuclear	5.9	3-4
Low carbon dispatchable power	4.3	2-7
Unabated gas	35.6	35

C. WHAT TRANSFORMATION PATHWAYS ARE CURRENTLY UNDER DISCUSSION OR IMPLEMENTATION TO ACHIEVE DECARBONISATION GOALS?

The UK's main climate policy document is the 2021 Net Zero Strategy (Build Back Greener), which outlines decarbonisation strategies for all sectors to reach net zero emissions by 2050. There is a specific focus on energy security and the British Energy Security Strategy aims to accelerate the growth of low carbon technologies. This includes support for the transport and storage of CO_2 and hydrogen, heat pump installation, offshore wind and low carbon fuels for transport, among others.[7,8] Additionally, the UK Government have created Great British Energy, a publicly owned energy company, to co-invest with industry into energy infrastructure, alongside additional nuclear support through Great British Energy - Nuclear.[9]

The creation of a Future System Operator to oversee energy planning[8], alongside a Transmission Acceleration Plan, and an effort to improve grid connections is part of government's mission to solve major infrastructure challenges.[10] The Planning and Infrastructure bill, which is currently being debated, sets out reforms to Nationally Significant Infrastructure Projects, electricity network connections, planning consent in Scotland, long duration energy storage, community benefits, land use and offshore transmission.[11]

Government has also published the Warm Homes Plan which aims to improve energy efficiency and provide grants for domestic solar panels, insulation, and storage. In April, government recommitted to a phase-out date for petrol/diesel vehicles of 2030 for cars and 2035 for vans through a trading scheme and continues to provide grants for consumer purchase of EV's.[12]

D. HAS YOUR ORGANISATION CONDUCTED ANY RECENT ASSESSMENT OF THESE EVOLUTIONS (E.G. SCENARIO MODELLING, SYSTEM-LEVEL IMPACT STUDIES)? IF SO, COULD YOU BRIEFLY DESCRIBE THE FINDINGS?

In the last 12 months the Parliamentary Office of Science and Technology (POST), alongside the House of Commons and Lords Libraries, has conducted research into an array of energy transition topics, including: planning, energy security, energy prices, storage, transport (road, aviation and maritime), renewable generation, clean power targets and energy efficiency.[13,14]

Parliament scrutinise government plans on the energy and wider net zero transition, while the Climate Change Committee give advice and report on plans and progress.[15]

Several select committees have published research or have current inquiries into energy topics, these include infrastructure planning, retrofitting homes, the circular economy, community energy, nuclear, skills and workforce, industrial decarbonisation strategies, energy prices and Great British Energy.[16–18]

II. CONSEQUENCES OF TECHNOLOGICAL CHOICES

A. WHAT ARE THE MAIN TECHNICAL OR OPERATIONAL CHALLENGES ASSOCIATED WITH MANAGING A MORE DIVERSIFIED ENERGY MIX IN YOUR COUNTRY?

One major challenge in the UK's more diversified grid is energy storage, as wind and solar rely on weather conditions, ensuring the UK energy supply remains stable, flexible, and resilient to weather effects. Co-locating storage alongside wind plants could also help to manage the impact of constraints on the system as the yearly cost of constraints grew from £170 million in 2010 to £1.3 billion in 2022.[19]

Planning needs to be clear and strategic. According to the Energy Security and Net Zero Committee's recommendations, there are concerns that the government's National Policy Statements, alongside the upcoming National Energy Systems Operator's Centralised and Spatial Strategic Network Plans need clarification in terms of grid connections, public engagement/community benefits, ecological and landscape mitigations, land type and usage and how these different plans and policy statements will work together.[20]

Key decarbonisation sectors including energy, home heating and steel have found that a lot of their workforce is approaching retirement, at a time when they are growing, which presents risk when a wide range of green skills are needed.[21]

There are ongoing debates about the affordability of electricity; the price of electricity is usually set by gas as the most expensive generator.[22] This means that the cheaper electricity price of wind and solar is not necessarily reflected in customer's bills.[9]

B. WHAT MEASURES ARE BEING IMPLEMENTED OR CONSIDERED TO ENHANCE DEMAND-SIDE FLEXIBILITY (E.G. TIME-OF-USE TARIFFS, DEMAND RESPONSE)?

The government's Clean Flexibility Roadmap aims to: increase consumer awareness and engagement in flexibility, support network planning and operation by improving asset visibility, and explore secure data sharing.[23]

The Market-Wide Half Hourly Settlement programme alongside the Review of Electricity Market Arrangements (REMA) aim to incentivise customer off-peak usage through smart tariffs, with some companies offering more granular time-of-use tariffs already. Government has said it will support the rollout of energy smart appliances and aims to increase awareness and engagement with flexibility while ensuring data security through the Smart Secure Electricity Systems Programme.[23] The 2021 Electric Vehicle (Smart Charge Points) regulations require domestic EV chargers to have smart functionality, and the government has committed to requiring the same for heat pumps.[24]

A cap and floor mechanism will be introduced for long duration energy storage in 2025 to support non-domestic flexibility.[23] REMA is also looking into reforming the transmission charges to try and boost deployment of non-domestic short-duration flexibility.[25]

In terms of digitalisation, the government has introduced a National Digital Twin Programme in part to explore the use of AI in the energy sector; some studies suggest that it could boost GDP by up to 4.4%.[26] Digitalisation of the energy system could reduce costs by £10 billion annually by 2050 although this presents some cybersecurity concerns.[26]

C. HOW IS THE EVOLUTION OF THE ENERGY MIX AFFECTING ELECTRICITY AND GAS INFRASTRUCTURE (E.G. GRID CAPACITY, RELIABILITY, CROSS-BORDER FLOWS)?

In terms of electricity infrastructure, wind farms are often located in remote areas, therefore transmission across long distances is needed.[27] Current constraint payments are over £1 billion and could rise to £2 billion due to a lack of transmission network investment.[28] The Eastern Green Link projects aim to increase the cross-border electricity flows between Scotland and England thus better connecting areas of renewable generation with demand.[29]

35% of electricity generation is distribution-connected, which is an increase of 20% from 2011.[30] The volume of distribution-connected generation is expected to increase from ~30 GW to 80-140 GW in 2050, which means the UK will need to build four times more distribution network in the next 7 years than it built in the last 30.[31]

There is also difficulty in accessing grid connections, the queue to the national transmission network is one of the main obstacles with over 700 GW of projects waiting to connect.[28]

The amount of imported electricity has increased recently due to the price difference between domestic fossil fuel-based generation and international renewables (French nuclear and European solar). This is mainly caused by the decommissioning of several domestic baseload generators (coal, gas and nuclear) alongside the growth of cheap European renewables, which decreases competition and increases price.[32]

As electrification increases, the gas network will become less necessary for the transport of domestic gas for heating and cooking. It is therefore being considered for other uses such as hydrogen transport for industry use. Hydrogen's potential use in domestic heating is thought to be limited, and alternative uses for gas network infrastructure include water transport or electricity cables.[31]

D. WHAT ARE THE ANTICIPATED IMPACTS ON INDUSTRIAL VALUE CHAINS (E.G. MANUFACTURING CAPACITY, LOCALISATION, STRATEGIC DEPENDENCIES)?

The British Geological Survey outlined potential concerns around increased demand for critical minerals, these include lithium for electric vehicles and battery storage, and rare earth elements for use in wind turbines. The last UK coal power station has now closed and there is an additional concern around supply of coal power byproducts such as sulphur and gypsum. The report stated that the UK is reliant on many imported raw and processed materials and waste is often exported; it clarified the importance of domestic supply chains and circular economies in reducing criticality of certain minerals.[33]

The upcoming UK Critical Minerals Strategy aims to reduce reliance on overseas critical minerals and optimise domestic resources, for example: lithium mining in Cornwall, nickel in Wales, and recycling rare earth magnets in Birmingham and Belfast. A taskforce is currently researching a Circular Economy Strategy which will aim to support recycling to reduce dependence on international supply chains.[34]

The Clean Energy Industries Sector Plan has 2035 ambitions that include securing more resilient and robust supply chains and creating hundreds of thousands of green industry jobs countrywide.[34]

To support this, the government has committed to aiding regional industrial clusters focussing on CCUS, hydrogen for industry, freeports and offshore wind. According to the government, the UK geography allows storage of up to 78 billion tonnes of CO_2 for potential international use and the export market of CCUS and hydrogen could range from £5.8 – £9.8 billion by 2050. There is an industry ambition of 50% local content for CCUS projects and a new Market Demand Guarantee is being considered to stimulate domestic production of network infrastructure, while UK Export Finance is helping to create good international contracts. The National Wealth Fund have committed £5.8 billion to these clusters, alongside a £1 billion Clean Energy Supply Chain Fund from Great British Energy.[34]

III. SOCIAL ACCEPTABILITY OF THE ENERGY TRANSITION

A. HOW WOULD YOU CHARACTERISE THE LEVEL OF PUBLIC ACCEPTANCE OF THE ENERGY TRANSITION IN YOUR COUNTRY?

According to polling by the Tony Blair Institute, the majority of the public support Net Zero, but it is not considered the highest priority, sitting below the cost of living, healthcare, the economy and immigration.[35]

However, there is some opposition to Net Zero, and the topic has become more politicised with concerns around the cost of living and the fairness of the transition.[36] Only 19% of the UK public believe the 2050 Net Zero goals will be reached, and 45% do not think bold action is worth it if China is not seen to be making clear efforts.[35]

More people are concerned about the short-term impacts of energy transition plans, but more positive about the longer term. 65% expect living expenses to rise, but a large majority (84%) still supported the use of renewable energy to provide electricity, fuel and heat. [37]

B. TO WHAT EXTENT HAS THE ENERGY PRICE CRISIS OF 2022 INFLUENCED PERCEPTIONS OF ENERGY POLICIES AND CLIMATE COMMITMENTS?

The average annual gas and electricity bill rose from ~£1,216 in winter 2021/22 to £2,380 in winter 2022/23. Prices have not returned to pre-energy crisis levels and remained at £1,849 in summer 2025.[38] In June 2022 37% of people were struggling to pay their energy bills and there is evidence that customers were rationing their usage.

As a result of this 83% of people are concerned with the "UK not being too dependent on energy from other countries".[37] This has increased discussions about energy security.[39]

The Energy Crisis Commission recommended a transition away from gas towards renewables, to reform the market to lessen the impact of gas prices on energy bills, incentivise domestic demand-side response, and improve energy efficiency while increasing support for vulnerable households.[40]

C. ARE THERE SPECIFIC TECHNOLOGIES (E.G. WIND POWER, NUCLEAR ENERGY) THAT RAISE SIGNIFICANT CONTROVERSY OR PUBLIC RESISTANCE?

A large majority (80%) of people support renewable energy as a general concept but this varies for specific technologies. In spring 2025, support for onshore wind farms was 73%, but only 37% when it was to be built in the local area, due to concerns about the visual and ecological impact. Similarly, support for solar farms drops from 88% to 47% when people are asked about a local solar farm.[41]

In 2024, a Nuclear Industry Association poll found that people are broadly in support of nuclear energy (65%), but fewer think that more reactors should be built (45%). Net support of 14% is much lower than that of other renewable generation and is closer to that of gas with carbon capture (13%). The reasons given for the lower support are issues with nuclear waste management, and uncertainty around the actual emissions associated with nuclear electricity generation.[42]

In terms of domestic flexibility, 52% were comfortable with their energy supplier collecting more data, although 40% were not comfortable with it.[37]

There is some wariness around heat pumps, primarily due to the cost and feasibility, whether they work better than traditional boilers, and who will fix and install them.[36,43] Only 15% of people would consider replacing their current heating system while it was still working.[43]

D. IS THERE AN ONGOING PUBLIC OR PARLIAMENTARY DEBATE REGARDING THE REALISM, COST, OR SOCIAL EQUITY OF THE ENERGY TRANSITION?

The leader of the Conservative party recently announced that they no longer supported the 2050 Net Zero target saying it was unfeasible, citing consumer energy costs as one the main reasons. Former Conservative Prime Minister Theresa May, who originally announced the target, was critical of this policy change.[44]

The Energy Security and Net Zero Committee has ongoing inquiries around building support for the energy transition,[36] and the cost of energy.[45]

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UNITED STATES OF AMERICA

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Achieving carbon neutrality by 2050 requires a profound and accelerated transformation of energy systems. This transition involves not only a reconfiguration of the energy mix, but also far-reaching technological consequences stemming from the choices made, as well as the crucial issue of social acceptability.

RECONFIGURING THE ENERGY MIX FOR CLIMATE NEUTRALITY

Meeting the 2050 carbon neutrality target calls for deep structural shifts in national energy systems, many of which are already underway. These changes affect both the demand for energy and the composition of energy supply, with electricity systems at the forefront of the transition.

The evolution of energy demand reflects major trends: increased electrification of end-uses, the development of new applications (notably electric mobility and heat pumps), and the implementation of efficiency measures. Simultaneously, the energy mix itself is undergoing diversification. While fossil fuels (coal, oil, gas) still represent a significant share in many national mixes, their gradual replacement by low-carbon sources – nuclear energy and renewables (solar, wind, hydro, biomass) – is central to decarbonisation strategies.

The transition pathway varies across countries depending on political choices, resource availability, and industrial capabilities. Its evaluation involves the assessment of past and projected trends, the coherence of decarbonisation roadmaps with climate targets, and the robustness of strategies under different geopolitical and economic scenarios.

TECHNOLOGICAL CONSEQUENCES OF THE TRANSITION

The transformation of the energy mix carries significant downstream implications, both technical and industrial.

The management of a more heterogeneous and decentralised energy system poses new challenges, particularly in terms of grid operation and balancing intermittent sources such as wind and solar. The shift to a low-carbon system necessitates greater flexibility on the demand side, through time-of-use tariffs and intelligent energy management systems.

These changes also impact infrastructure: transmission and distribution networks must be adapted to accommodate variable flows and bidirectional exchanges. On the industrial front, choices regarding technologies (e.g., small modular reactors, green hydrogen, carbon capture) determine the reorganisation of supply chains and the development of new manufacturing capacities.

SOCIAL ACCEPTABILITY AND POLITICAL SUSTAINABILITY

The success of the energy transition does not depend solely on technical feasibility or economic viability; it also hinges on public acceptance and the capacity of societies to manage the social costs and benefits of the transition.

While climate commitments have generally enjoyed broad support, events such as the 2022 gas crisis have heightened awareness of energy vulnerabilities, especially regarding price volatility and dependency on external suppliers. This has reopened debates on the pace and realism of decarbonisation, particularly the rapid shift toward a highly electrified system.

Questions of technology acceptability (notably nuclear and wind power) continue to polarise public opinion. At the same time, the distributional effects of energy policies, such as the cost of climate measures for households and SMEs, are gaining prominence in public discourse. Reconciling ambitious environmental objectives with economic equity and democratic legitimacy remains one of the central challenges of the transition.

I. ENERGY MIX AND THE CARBON NEUTRALITY OBJECTIVE (2050)

A. HOW HAS THE STRUCTURE OF ENERGY DEMAND EVOLVED IN YOUR COUNTRY IN RECENT YEARS?

According to U.S. Energy Administration (EIA) Data, total U.S. primary energy consumption has remained relatively flat from 2000 (97 quadrillion British Thermal Units (Btus)) to 2024 (94 quadrillion BTUs). Average per capita use decreased by 20 percent, from 344 million BTUs in 2000 to 277 million BTUs in 2024.[1]

[1] *U.S. Energy Information Administration - EIA - Independent Statistics and Analysis.*

B. WHAT IS THE CURRENT COMPOSITION OF THE ENERGY MIX, AND WHAT ARE THE KEY POLICY OBJECTIVES OR PROJECTIONS BY 2050 (E.G. SHARE OF FOSSIL FUELS, NUCLEAR, RENEWABLES)?

According to the EIA, in 2024, total primary energy consumption was (by percentage): petroleum 38, natural gas 36, renewable sources 9, nuclear 9, and coal 8. Electricity is a secondary energy source provided by those primary sources.[1]

The federal government supports and intervenes in U.S. energy production and consumption in various ways, such as providing tax incentives, grants, and other support to promote domestic production of energy from various sources, as well as setting standards and requirements. The federal government also plays an important role in contributing to the development of new technologies for a variety of energy sources, such as by funding research or providing incentives.

Energy consumption in the United States is influenced by multiple sectors and levels of government. For example, most electricity customers in the United Sates are served by private companies – investor-owned utilities. The federal government does not direct how much renewable generating capacity private companies should build or how much renewable electricity they should produce. The responsibility for regulating the electricity industry is divided between the states and the federal government. State entities, such as public utility commissions, regulate utility management, operations, electricity rate structures, and capacity acquisition within their state. According to the EIA, over half of states have renewable portfolio standards or clean energy standards.[2]

C. WHAT TRANSFORMATION PATHWAYS ARE CURRENTLY UNDER DISCUSSION OR IMPLEMENTATION TO ACHIEVE DECARBONISATION GOALS?

The U.S. uses a wide variety of pathways that can contribute to the achievement of decarbonization goals. We highlight below a few examples mentioned in our reports although some approaches continue to evolve.

• The federal government has taken several steps to explore or promote energy storage technologies. For example, in 2021 the Infrastructure Investment and Jobs Act appropriated $505 million to the Department of Energy (DOE) for energy storage demonstration projects for fiscal years 2022 to 2025. The act also required DOE to study codes and standards for energy storage systems and establish a grant program to enhance U.S. battery

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[1] *U.S. energy facts explained - consumption and production - U.S. Energy Information Administration (EIA).*

[2] *Renewable energy explained - renewable portfolio and clean energy standards - U.S. Energy Information Administration (EIA).*

manufacturing. Further, the Inflation Reduction Act of 2022 created and expanded tax credits for investment in energy storage technology. Within the executive branch, the Federal Energy Regulatory Commission (FERC) issued orders in 2018 and 2019 to remove barriers to market participation for energy storage technologies.[1]

- In recent years, government and industry have taken steps to reduce CO_2 emissions in the construction sector. In 2024 DOE, with industry input, defined the criteria for a zero-emissions building.[2] Government and industry have also partnered to pilot sustainable building technologies such as more efficient solar panels, windows, insulation, and heating systems. Incentives, including federal, state and local grants and tax rebates, have subsidized some costs.

- Fusion energy companies have received billions of dollars of private investment in addition to federal grants with the goal of commercializing fusion energy.

D. HAS YOUR ORGANISATION CONDUCTED ANY RECENT ASSESSMENT OF THESE EVOLUTIONS (E.G. SCENARIO MODELLING, SYSTEM-LEVEL IMPACT STUDIES)? IF SO, COULD YOU BRIEFLY DESCRIBE THE FINDINGS?

We have issued many technology assessments, Science & Tech Spotlights, and audits related to changing energy systems. These range from work on technologies that are already in widespread use, such as wind energy, to those that require substantial maturation and are relatively uncertain, such as fusion. We include examples below and provide details about some of the related technical and operational challenges under question 2.1.

- **Wind Energy:** Wind energy is one of the fastest growing renewable energy sources globally. Onshore and offshore wind energy can provide an abundant source of electricity without producing pollution from fuel combustion during operation. This provides significant environmental and public health benefits. However, development of wind energy facilities could also change the landscape, affect wildlife, and have other negative environmental effects. We issued a technology assessment that identified technologies and approaches to help address these effects across a wind facility's life cycle and an audit that examined potential impacts and oversight of offshore wind development.[3]

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[1] *Utility-Scale Energy Storage: Technologies and Challenges for an Evolving Grid | U.S. GAO*

[2] *Science & Tech Spotlight: Sustainable Building Technologies | U.S. GAO.*

[3] *Wind Energy: Technologies and Approaches to Help Address Environmental Effects | U.S. GAO and Offshore Wind Energy: Actions Needed to Address Gaps in Interior's Oversight of Development | U.S. GAO.*

- **Carbon Capture, Utilization, and Storage (CCUS):** CCUS refers to a group of technologies for reducing CO_2 emissions or removing CO_2 from the atmosphere. Capture includes technologies that separate and purify CO_2 from a source, which could be an industrial facility such as a power generation or manufacturing facility (point-source capture) or the atmosphere (direct air capture). Both point-source capture and direct air capture result in a concentrated stream of CO_2 that can be compressed and transported – typically via pipeline – either for conversion into economically valuable products (utilization) or for storage in deep underground geologic formations. The U.S. is a global leader in CCUS deployment, with more than 50 percent of the world's capture capacity as of 2021. We examined the status, benefits, and challenges of CCUS technologies.[1]

- **Hydrogen:** Hydrogen has potential uses in many industries, including steel production, vehicle fuel cells, aviation fuel, and power generation. If produced with low-carbon methods, it could play a significant role in reducing greenhouse gas emissions and air pollution. Hydrogen is a versatile fuel and a useful ingredient in certain industries. Its use produces no carbon dioxide, making it potentially useful for decarbonization in some applications. Today, hydrogen is mostly used in certain mature industrial processes, including production of ammonia for fertilizer and removal of sulfur in oil refining.[2]

- **Ocean Energy:** Renewable ocean energy has the potential to reduce global carbon emissions from fossil fuels by 500 million tons by 2050, and could also meet the energy needs of isolated communities, which may not have access to reliable electricity sources.[3]

- **Nuclear microreactors:** Nuclear microreactors are very small reactors usually generating less than 50 megawatts electric (MWe), enough to power a small community. They offer the potential of faster deployment compared to conventional large reactors. Microreactors could be produced more quickly than larger reactors, and within weeks, transported and deployed to locations such as isolated military bases or communities affected by natural disasters. They are designed to provide resilient, non-carbon emitting, and independent power in those environments.[4]

[1] *Decarbonization: Status, Challenges, and Policy Options for Carbon Capture, Utilization, and Storage | U.S. GAO.*
[2] *Science & Tech Spotlight: Hydrogen Uses | U.S. GAO.*
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[4] *Science & Tech Spotlight: Nuclear Microreactors | U.S. GAO.*

- **Fusion:** Nuclear fusion, the process that powers the sun and other stars, could produce electric power without carbon emissions, long-lived nuclear waste, or risk of meltdowns. Researchers and companies are pursuing many different concepts for fusion energy and have reported recent progress, such as the development of high-temperature superconducting magnets that could make fusion devices much more compact.[1]

II. CONSEQUENCES OF TECHNOLOGICAL CHOICES

A. WHAT ARE THE MAIN TECHNICAL OR OPERATIONAL CHALLENGES ASSOCIATED WITH MANAGING A MORE DIVERSIFIED ENERGY MIX IN YOUR COUNTRY?

We have identified a wide range of challenges associated with components of a more diversified energy mix. Some examples include:

- **Wind Energy:** Growing development of wind energy facilities could increase certain potential environmental effects, including greater consumption of resources like critical materials and steel, potential decommissioning and recycling difficulties, and ecological effects such as wildlife harm. In addition, we reported that offshore wind development can have various positive and negative effects, such as on climate and public health, marine life and ecosystems, fishing industry, economic and community, tribal resources, defense and radar systems, and maritime navigation and safety. The extent of effects will vary depending on the location, size, and type of offshore wind infrastructure. Because technology and implementation are still developing, the extent of some effects is unknown.

- **Carbon Capture, Utilization, and Storage (CCUS):** Many technologies for CCUS are ready for wider demonstration or deployment, but multiple challenges limit their use. Applications of capture technologies at point sources are mature in some sectors (e.g., natural gas processing) but require further demonstration in some of the highest-emitting sectors (e.g., power generation). Direct air capture is not as mature, but has been implemented at pilot scale. Lengthy time to deployment and high costs hinder widespread deployment of both types of carbon capture in the near term. Technologies for transporting, storing, and directly using captured CO_2 are mature. Companies are beginning to commercialize utilization technologies that convert captured CO_2 into valuable products such as ethanol, sustainable aviation fuel, and mineral aggregates. However, many CO_2-based products are not cost-competitive with conventional products, may be excluded from the market by industry standards, and lack a standardized method for ensuring they effectively reduce CO_2 emissions.

[1] *Fusion Energy: Potentially Transformative Technology Still Faces Fundamental Challenges | U.S. GAO.*

- **Hydrogen:** There is disagreement about the viability of hydrogen as an energy solution in some uses. Hydrogen uses vary in maturity. For example, hydrogen-fueled vehicles are available in a few markets, while hydrogen's use in long-range aircraft is not mature. Obstacles to using hydrogen more widely include high costs and the need to significantly modify infrastructure for many applications. Additional research and development (R&D) may help address these challenges, and hydrogen "hubs" have been funded to accelerate commercialization.

- **Ocean Energy:** Ocean energy technologies are generally costlier than other renewable energy technologies because of high installation, operation, and maintenance costs. This reinforces a perception that ocean energy is risky, and makes it harder to find investors and insurance. The main environmental risks of ocean energy technologies include collision of marine life with underwater turbines, creation of underwater noise, and habitat changes. More research is needed to assess the long-term effects of ocean energy technologies on the environment and marine wildlife.

- **Nuclear microreactors:** Microreactors are currently in the earliest stages of development, with individual designs ranging in maturity. In the U.S., deploying a reactor requires many years of careful planning and close coordination between reactor designers and regulators. Many of the designs call for the use of fuel enriched up to 20% U-235 (high-assay, low-enriched uranium, or HALEU), which is currently unavailable in the commercial U.S. market, and may also present proliferation and safety risks. Other innovations, such as improved cooling, heat transfer, and different approaches to manage the reaction, are also needed to sustain a nuclear reaction in a much smaller package than that of conventional nuclear reactors.

- **Fusion:** Several challenges must be overcome to achieve commercial fusion, and stakeholders' projections of this timeline range from 10 years to several decades. These include scientific challenges, such as the lack of full understanding of the physics of plasmas, the state of matter needed for fusion. There are also engineering challenges, such as the need to develop materials that can withstand fusion conditions for decades. No facility exists where materials can be fully tested. More generally, the task of extracting energy from fusion to provide an economical source of electric power presents several complex systems engineering problems that have yet to be solved. To date, no fusion energy device has yet produced more energy than it consumes.

B. WHAT MEASURES ARE BEING IMPLEMENTED OR CONSIDERED TO ENHANCE DEMAND-SIDE FLEXIBILITY (E.G. TIME-OF-USE TARIFFS, DEMAND RESPONSE)?

Given the regulatory framework in the U.S., states drive utilities to adopt such programs or companies choose to adopt them without necessarily having external incentives. According to DOE, most utilities offer at least one time-variable pricing program option for any given customer class. These often include simple time-of-use rates, where prices move at set times and amounts through the day. DOE also reports that the majority of U.S. utilities offer their customers some kind of demand response option. With these options, customers receive a rate discount or other incentive to voluntarily reduce their electricity consumption for a short time-period to help address compromised grid reliability or high wholesale market prices.[1]

Given the limited federal role, we have not issued reports specific to these issues. We have, however, examined some technologies to reduce energy demand. For example:

- **Green Building Technology:** Use of sustainable building materials can reduce the CO_2 emissions in building construction and operations. Use of renewable power sources and more energy-efficient construction materials can reduce energy demand and utility costs. The initial cost of buying and installing more sustainable building systems can be high, and different technical skills may be needed to operate and maintain those systems. Estimates of a building's future cost savings and benefits are uncertain, and some future savings and benefits may not accrue to the building's original ownership and investors.[2]

C. HOW IS THE EVOLUTION OF THE ENERGY MIX AFFECTING ELECTRICITY AND GAS INFRASTRUCTURE (E.G. GRID CAPACITY, RELIABILITY, CROSS-BORDER FLOWS)?

The electricity grid is a massive feat of engineering, which one author called "the most complex machine ever made".[3] Grid operators must ensure that electricity supply constantly matches power demand. This balancing act requires them to forecast electricity demand and schedule and operate power plants to meet demand, which varies by time of day and year, since it is difficult to economically store large quantities of electricity. Several factors have made the task of matching electricity supply and demand even more complex. Variable electricity sources, such as wind and solar power, are supplying an increasing share of electricity, but their output varies with the

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[1] *Demand Response and Time-Variable Pricing Programs | Department of Energy.*

[2] *Science & Tech Spotlight: Sustainable Building Technologies | U.S. GAO.*

[3] *Schewe, Phillip F., The grid: a journey through the heart of our electrified world (Washington, DC: Joseph Henry Press, 2007).*

weather and does not always match demand. Further, the increasing use of variable energy resources, interaction of such energy sources with traditional generation sources, and changing role of electricity customers have increased the complexity of matching electricity supply with demand at all times.

Energy storage provides a solution to help achieve flexibility, enhance grid reliability and power quality, and accommodate the scale-up of renewable energy. We examined technologies to store energy at the utility-scale.[1] Storage technologies could promote increased adoption of renewable energy sources such as solar and wind by capturing their excess power and returning it to the grid when these sources are less available. However, energy storage, along with renewable energy generation, may require changes in the way the power system is organized and operated.

D. WHAT ARE THE ANTICIPATED IMPACTS ON INDUSTRIAL VALUE CHAINS (E.G. MANUFACTURING CAPACITY, LOCALISATION, STRATEGIC DEPENDENCIES)?

Industrial value chains in the energy sector can be highly complex. Some of our work has examined strategic dependencies. Critical minerals are essential to some clean energy technologies. For example, rare earth elements are a key component in permanent magnets, which are used in wind turbines and electric vehicle motors. Increasing adoption of these technologies is expected to increase the demand for these minerals in the coming decades. We reported in 2024 that just one mine was producing rare earth elements in the U.S. (in Mountain Pass, California), while about 70 percent of the world's rare earth elements ore supply came from deposits in China.[2] An even greater share of rare earth elements separation and processing occurs in China (around 90 percent). We reported that these minerals are vulnerable to supply-chain disruptions for several reasons, including U.S. reliance on foreign sources, as well as the rapid growth in demand for critical minerals in the U.S. and abroad. We reported that domestic, nontraditional sources of minerals could increase the U.S. manufacturing sector's independence from foreign suppliers, reducing the need to open new mines, among other benefits.

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[1] *Utility-Scale Energy Storage: Technologies and Challenges for an Evolving Grid | U.S. GAO.*

[2] *Critical Minerals: Status, Challenges, and Policy Options for Recovery from Nontraditional Sources | U.S. GAO.*

III. SOCIAL ACCEPTABILITY OF THE ENERGY TRANSITION

A. HOW WOULD YOU CHARACTERISE THE LEVEL OF PUBLIC ACCEPTANCE OF THE ENERGY TRANSITION IN YOUR COUNTRY?

We have not focused any reports specifically on public acceptance of the energy transition in the U.S. However, in multiple reports, we highlighted the importance of effective communication and working closely with communities as plans are developed for new energy projects. For example, we included a chapter in our CCUS report on community acceptance and engagement. CCUS, like many technologies, has faced public opposition and is likely to face more in the future. If CCUS is to achieve widespread deployment in the U.S., it will require acceptance by and effective engagement with communities where CCUS projects and related infrastructure are to be located. We identified common questions communities have, examined some successful and failed efforts to engage communities, and identified lessons from those efforts.

B. TO WHAT EXTENT HAS THE ENERGY PRICE CRISIS OF 2022 INFLUENCED PERCEPTIONS OF ENERGY POLICIES AND CLIMATE COMMITMENTS?

We have not conducted work on this topic.

C. ARE THERE SPECIFIC TECHNOLOGIES (E.G. WIND POWER, NUCLEAR ENERGY) THAT RAISE SIGNIFICANT CONTROVERSY OR PUBLIC RESISTANCE?

Some of our work has addressed facets of public perception. For example, in our fusion energy technology assessment, we noted that little is known about public perception of fusion energy in the U.S. and we conducted focus groups with the public as part of our work. In our critical minerals technology assessment, we stated that because recovery of critical minerals from nontraditional sources is relatively nascent compared to traditional mining, the effects these projects will have on nearby populations is not yet fully understood. In our wind energy technology assessment, we reported that while stakeholders in wind energy have studied public opinions and attitudes toward wind energy projects, there are knowledge gaps in understanding the public’s awareness of environmental effects. As previously mentioned, our CCUS report examined public acceptance of CCUS projects and included lessons for future projects.

D. IS THERE AN ONGOING PUBLIC OR PARLIAMENTARY DEBATE REGARDING THE REALISM, COST, OR SOCIAL EQUITY OF THE ENERGY TRANSITION?

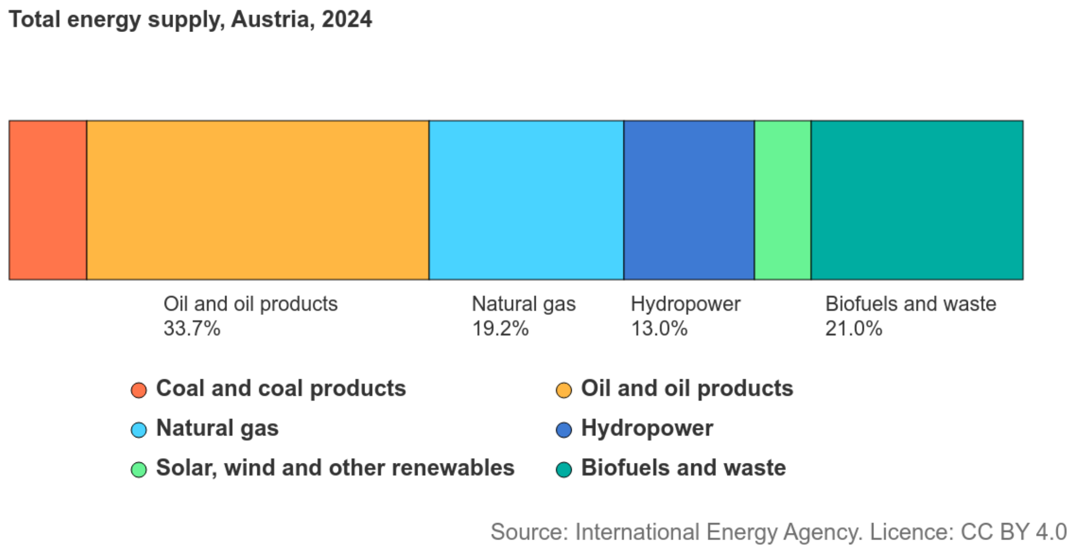
There have been ongoing debates in the U.S. about all of these issues, given that priorities and values can vary widely. Our fact-based, non-partisan work strives to present the U.S. Congress with a range of stakeholder views addressing considerations such as realism/feasibility, cost, and societal considerations. We are currently conducting technology assessments on additional related topics including reducing reliance on critical minerals, housing construction innovations, and hydrogen energy. We also anticipate future related work as interests grow and evolve.

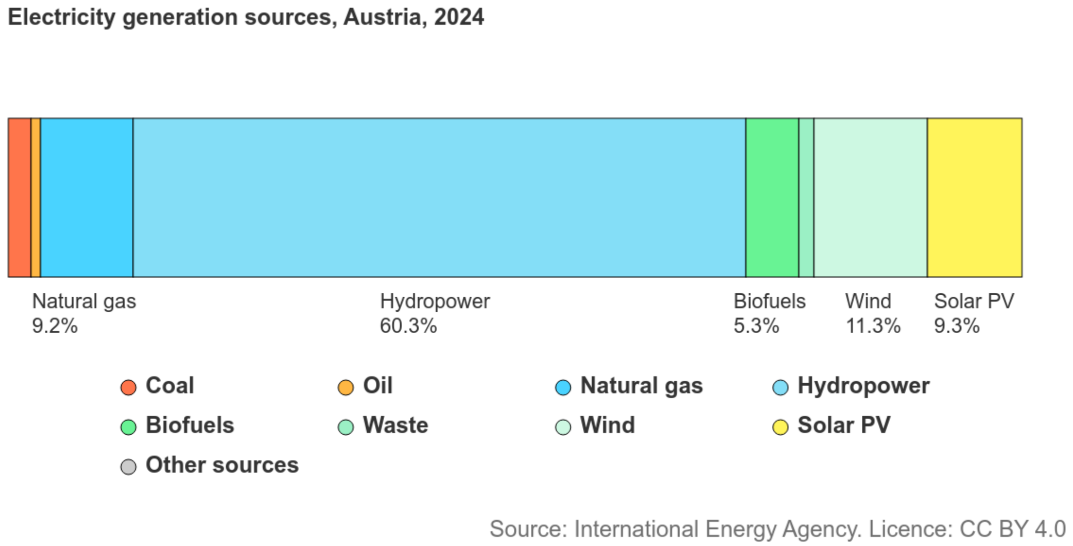
COUNTRY PROFILES

This document compiles for each country the energy mix, the electricity mix, and changes in CO_2 emissions, electricity consumption, and energy intensity of the economy since 2000.

Source: International Energy Agency (IEA)

AUSTRIA

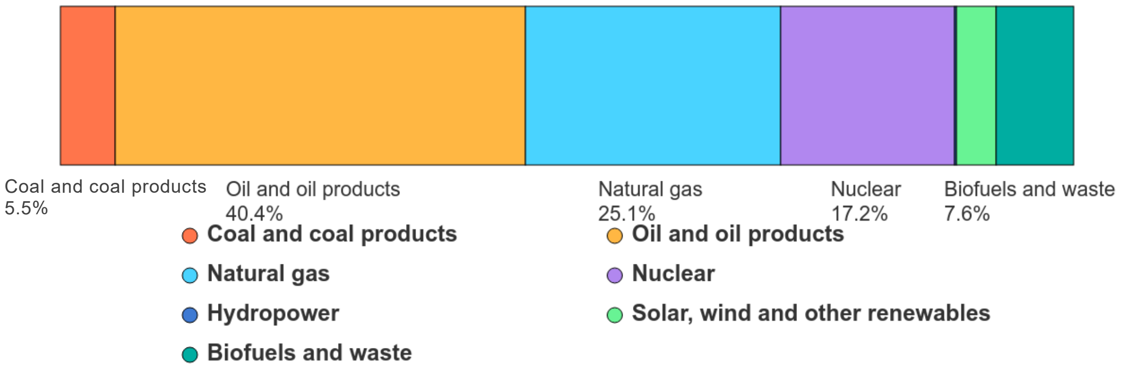




CO_2 emissions (2000-2022)	-8%
Energy-related CO_2 emissions (2022)	57 Mt CO_2
Electricty consumption per capita (2000-2024)	+11%
Energy intensity of the economy (2000-2024)	-23%

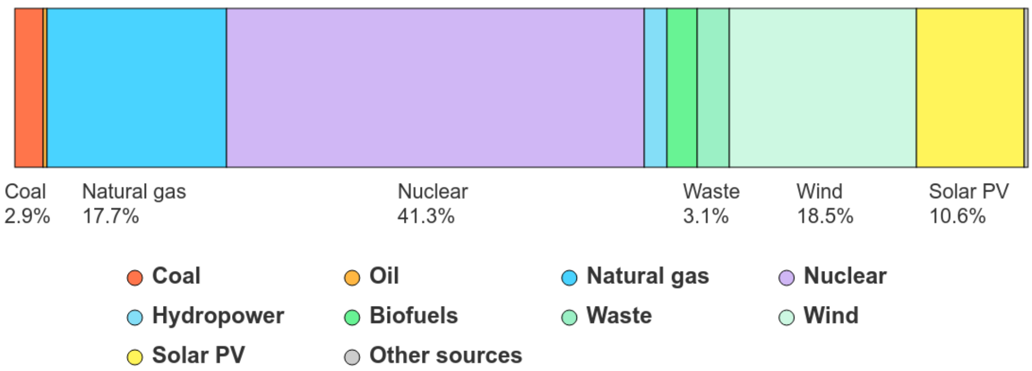
BELGIUM

Total energy supply, Belgium, 2024



Source: International Energy Agency. Licence: CC BY 4.0

Electricity generation sources, Belgium, 2024

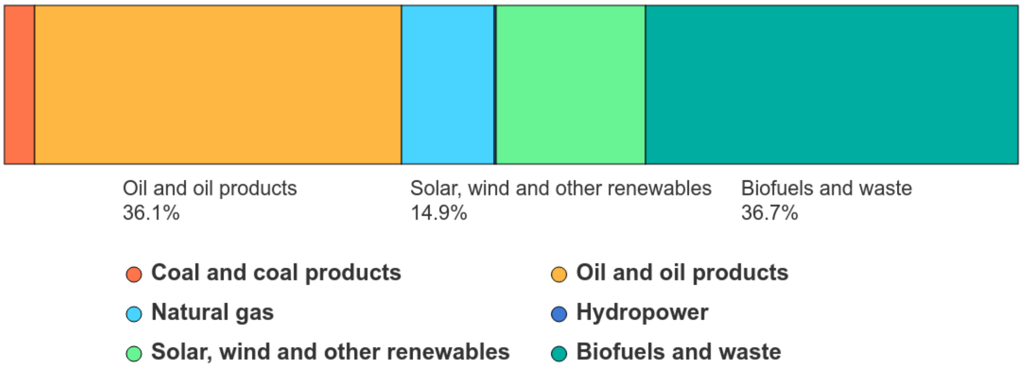


Source: International Energy Agency. Licence: CC BY 4.0

CO_2 emissions (2000-2022)	-28%
Energy-related CO_2 emissions (2022)	79 Mt CO_2
Electricty consumption per capita (2000-2024)	-16%
Energy intensity of the economy (2000-2024)	-43%

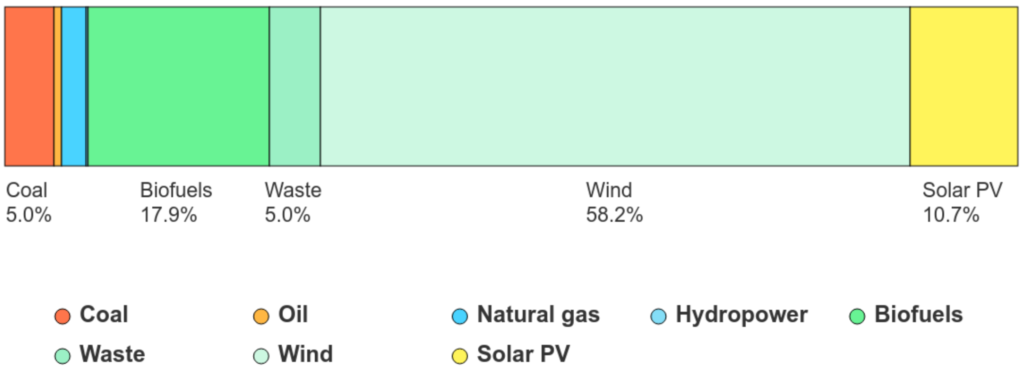
DENMARK

Total energy supply, Denmark, 2024



Source: International Energy Agency. Licence: CC BY 4.0

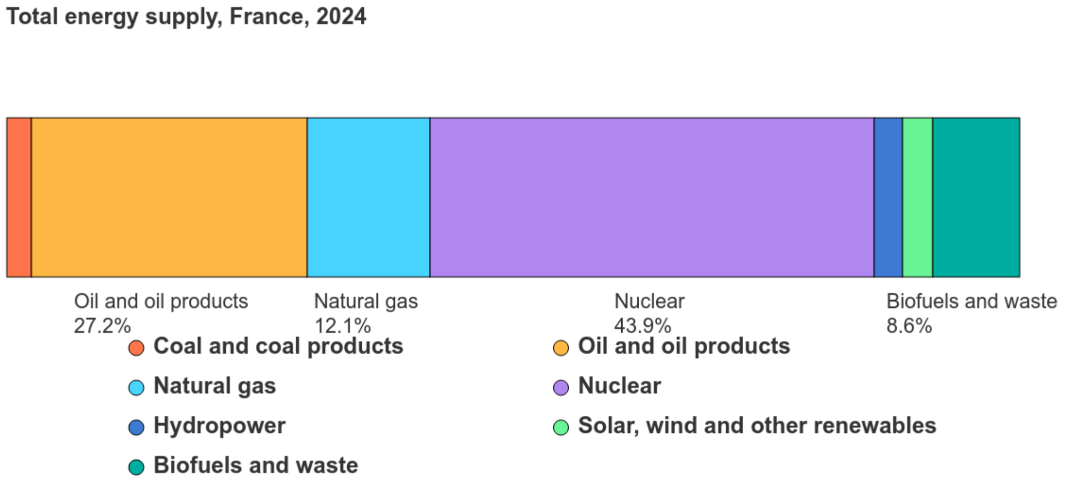
Electricity generation sources, Denmark, 2024



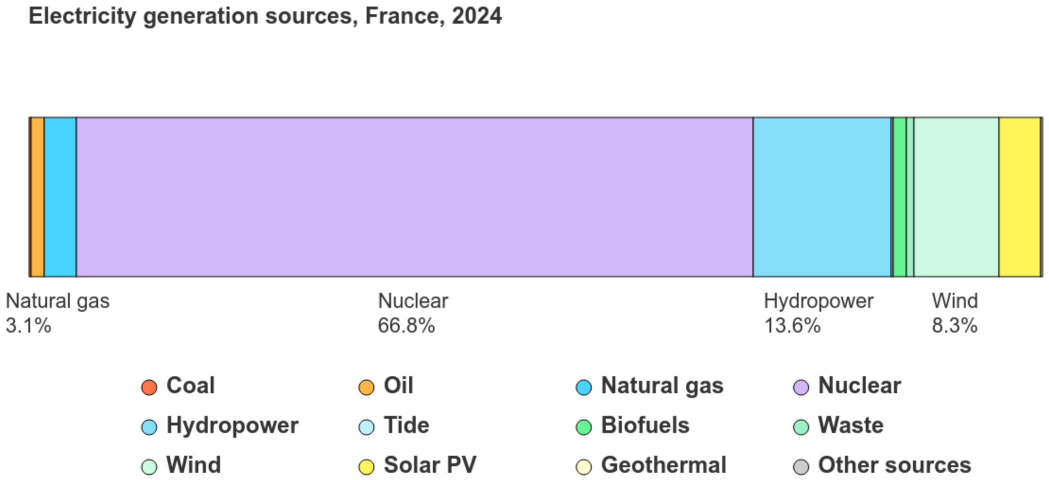
Source: International Energy Agency. Licence: CC BY 4.0

CO_2 emissions (2000-2022)	-47%
Energy-related CO_2 emissions (2022)	27 Mt CO_2
Electricty consumption per capita (2000-2024)	-5%
Energy intensity of the economy (2000-2024)	-44%

FRANCE



Source: International Energy Agency. Licence: CC BY 4.0

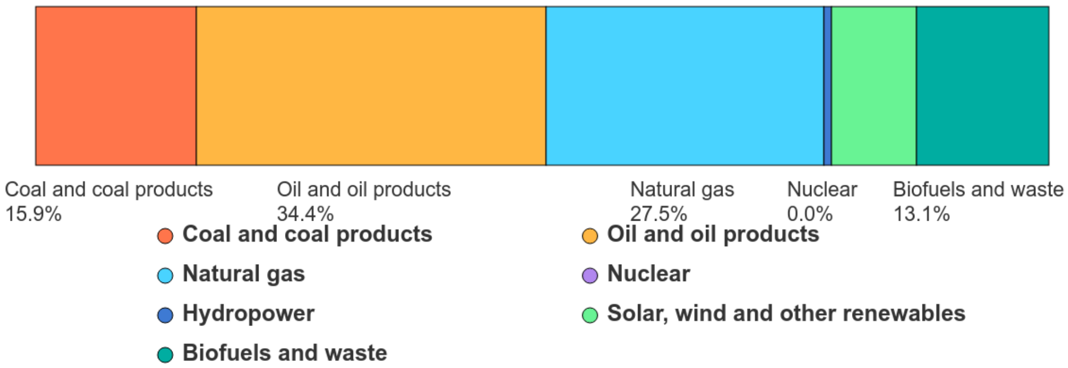


Source: International Energy Agency. Licence: CC BY 4.0

CO_2 emissions (2000-2022)	-22%
Energy-related CO_2 emissions (2022)	283 Mt CO_2
Electricty consumption per capita (2000-2024)	-11%
Energy intensity of the economy (2000-2024)	-35%

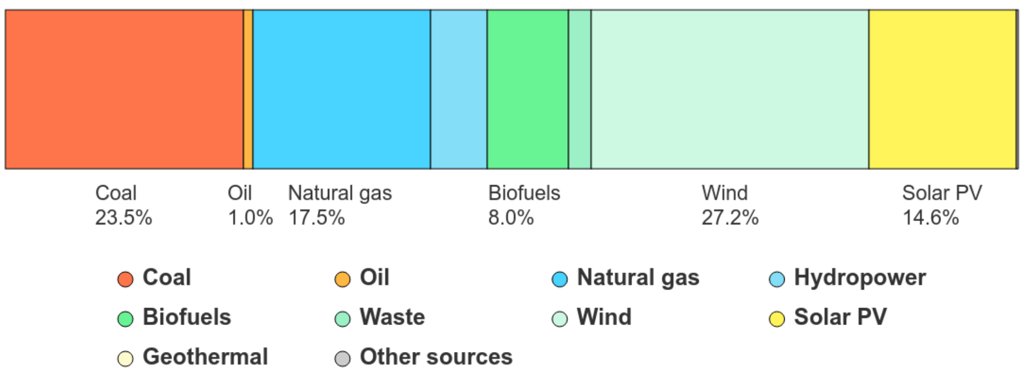
GERMANY

Total energy supply, Germany, 2024



Source: International Energy Agency. Licence: CC BY 4.0

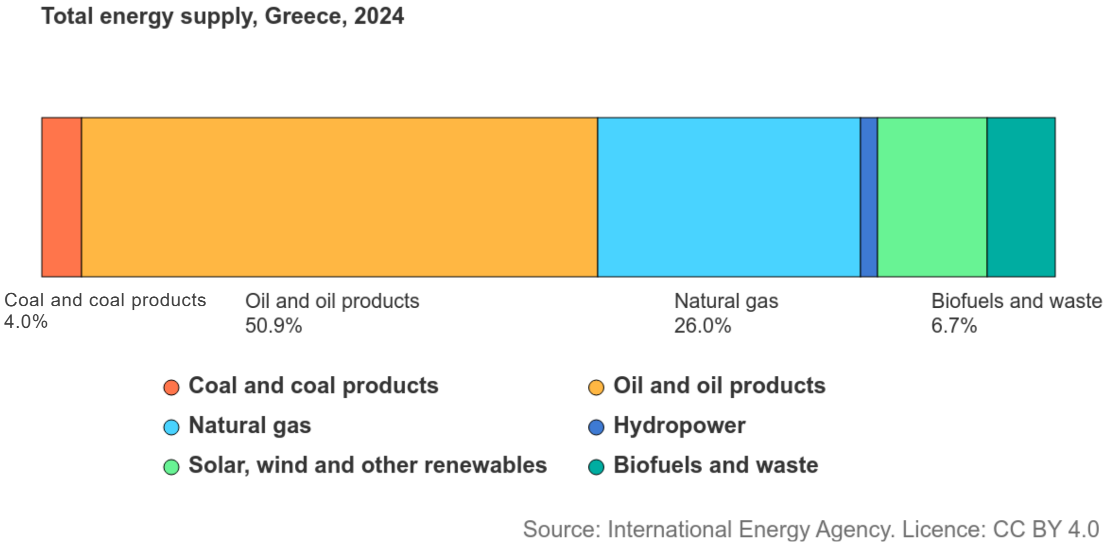
Electricity generation sources, Germany, 2024

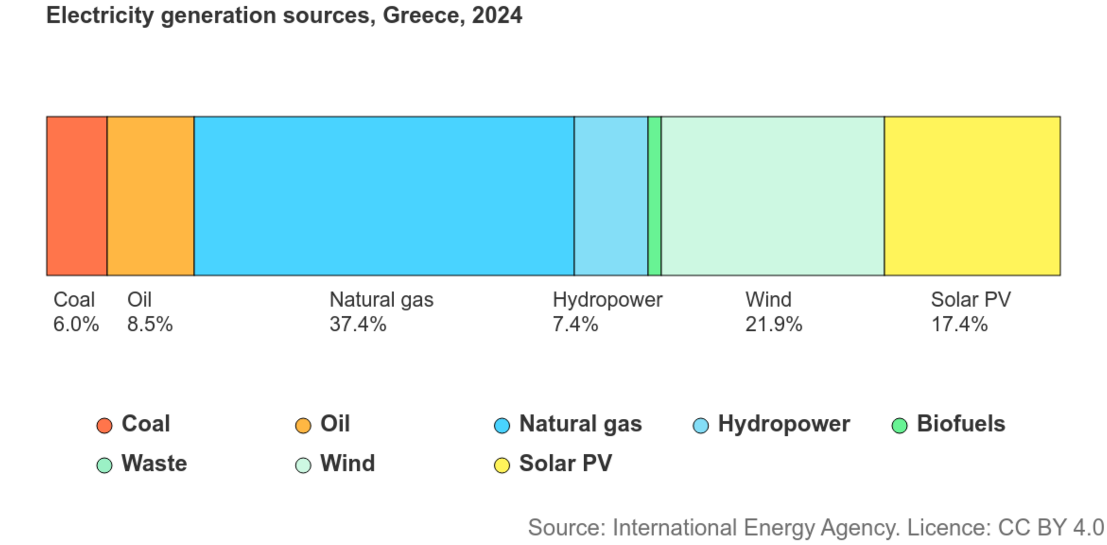


Source: International Energy Agency. Licence: CC BY 4.0

CO_2 emissions (2000-2022)	-25%
Energy-related CO_2 emissions (2022)	612 Mt CO_2
Electricty consumption per capita (2000-2024)	-10%
Energy intensity of the economy (2000-2024)	-45%

GREECE

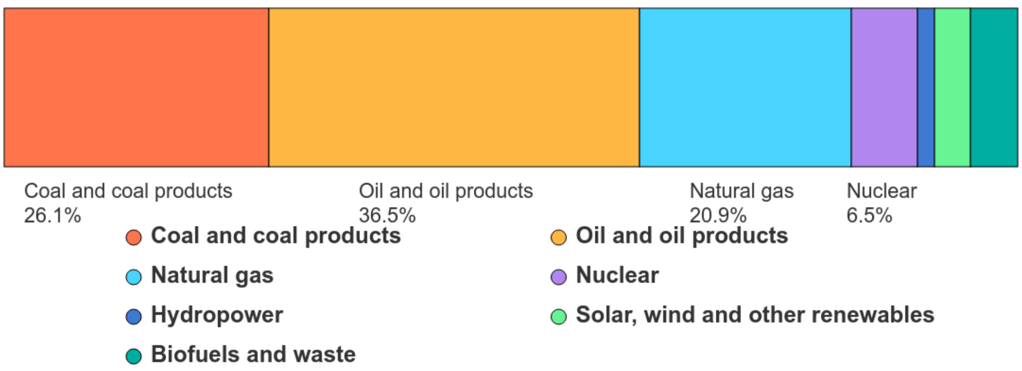




CO_2 emissions (2000-2022)	-42%
Energy-related CO_2 emissions (2022)	51 Mt CO_2
Electricty consumption per capita (2000-2024)	+1%
Energy intensity of the economy (2000-2024)	-36%

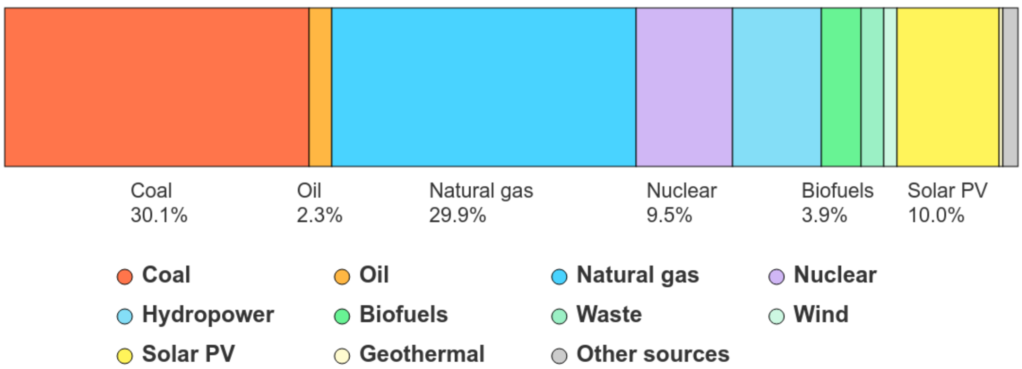
JAPAN

Total energy supply, Japan, 2024



Source: International Energy Agency. Licence: CC BY 4.0

Electricity generation sources, Japan, 2024

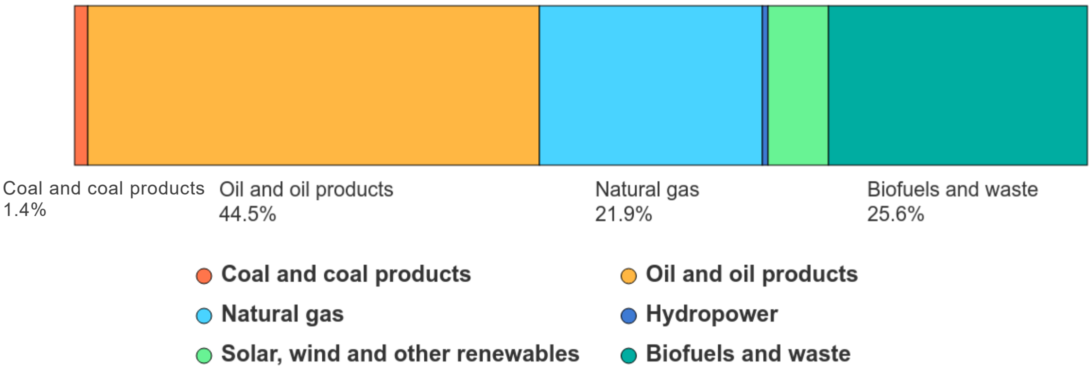


Source: International Energy Agency. Licence: CC BY 4.0

CO_2 emissions (2000-2022)	-15%
Energy-related CO_2 emissions (2022)	974 Mt CO_2
Electricty consumption per capita (2000-2024)	-6%
Energy intensity of the economy (2000-2024)	-38%

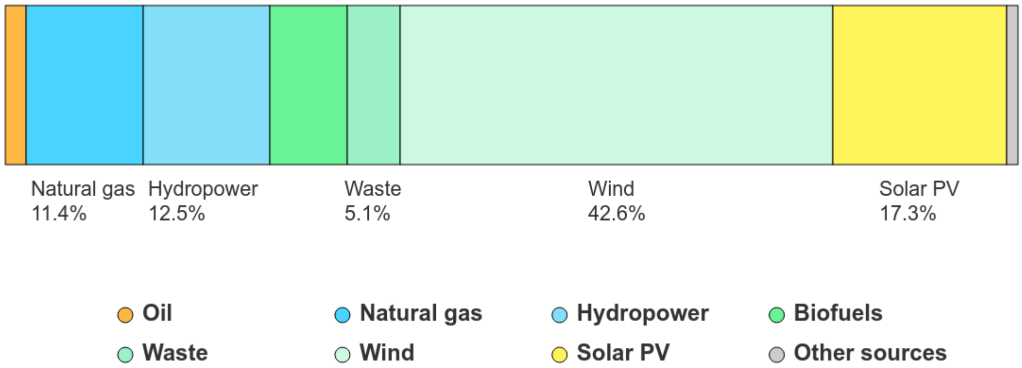
LITHUANIA

Total energy supply, Lithuania, 2024



Source: International Energy Agency. Licence: CC BY 4.0

Electricity generation sources, Lithuania, 2024

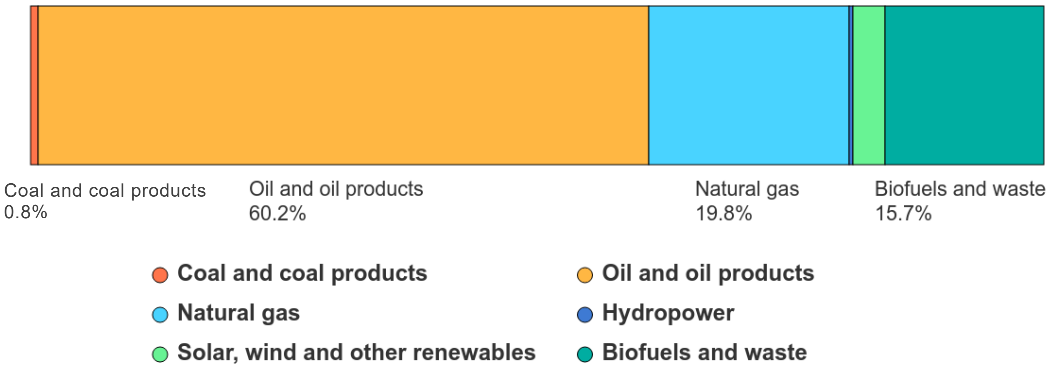


Source: International Energy Agency. Licence: CC BY 4.0

CO_2 emissions (2000-2022)	+8%
Energy-related CO_2 emissions (2022)	11 Mt CO_2
Electricty consumption per capita (2000-2024)	+74%
Energy intensity of the economy (2000-2024)	-57%

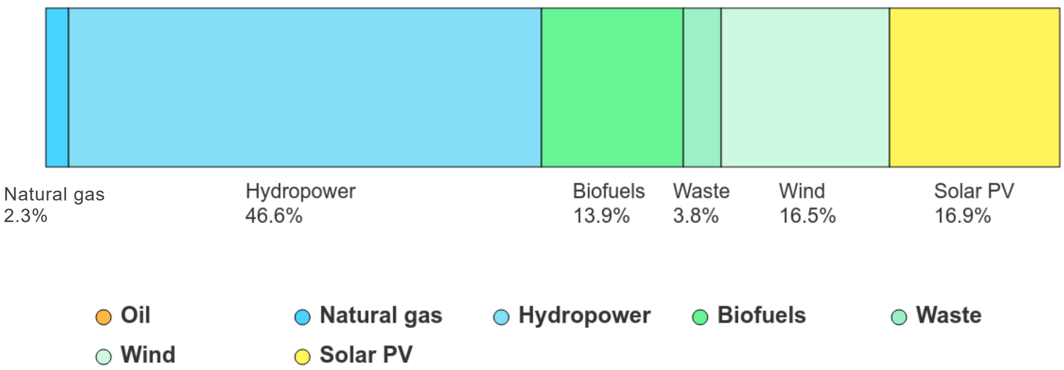
LUXEMBOURG

Total energy supply, Luxembourg, 2024



Source: International Energy Agency. Licence: CC BY 4.0

Electricity generation sources, Luxembourg, 2024

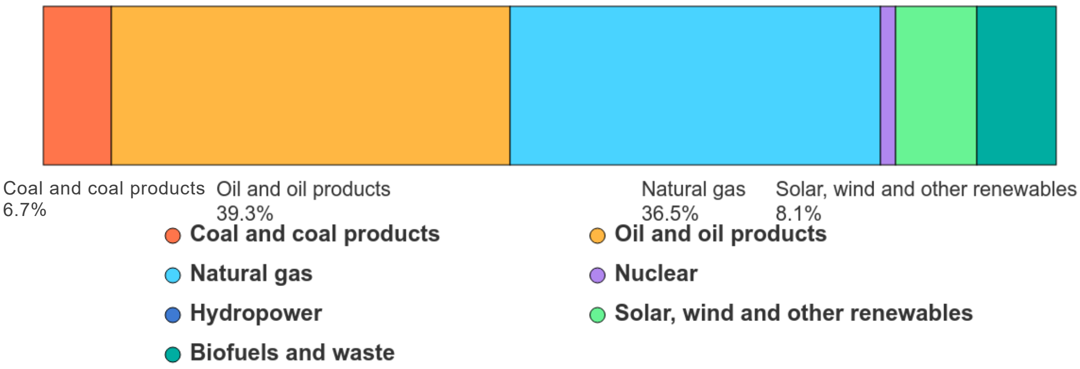


Source: International Energy Agency. Licence: CC BY 4.0

CO_2 emissions (2000-2022)	-16%
Energy-related CO_2 emissions (2022)	7 Mt CO_2
Electricty consumption per capita (2000-2024)	-25%
Energy intensity of the economy (2000-2024)	-47%

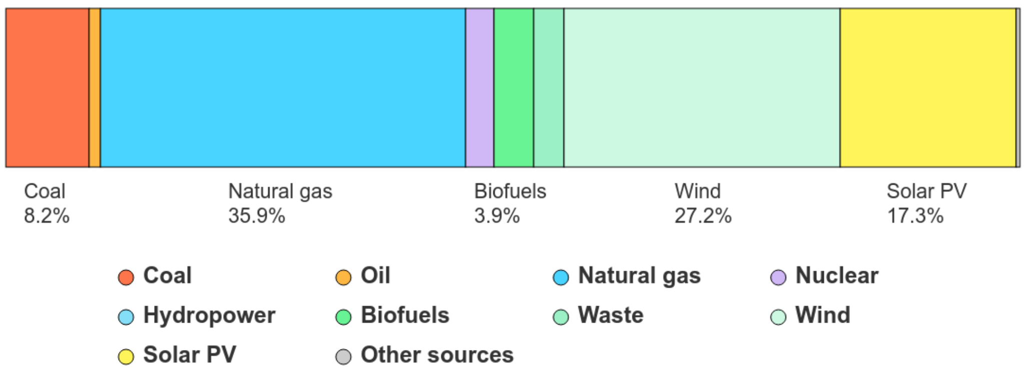
THE NETHERLANDS

Total energy supply, The Netherlands, 2024



Source: International Energy Agency. Licence: CC BY 4.0

Electricity generation sources, The Netherlands, 2024

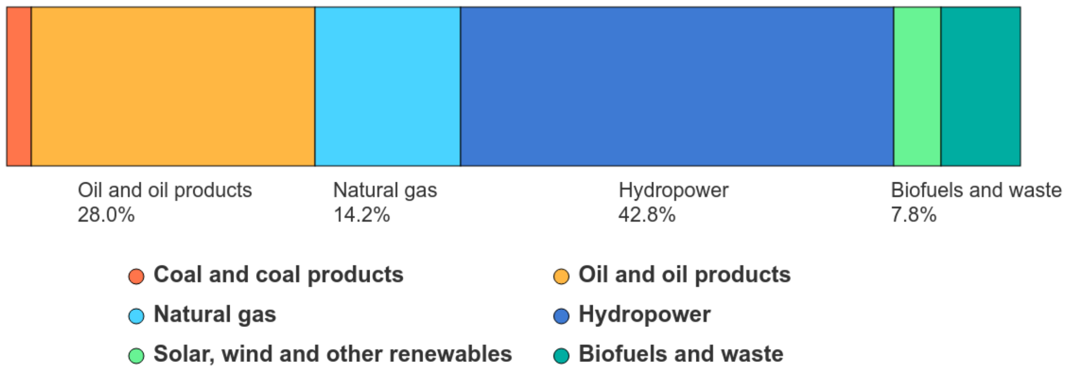


Source: International Energy Agency. Licence: CC BY 4.0

CO_2 emissions (2000-2022)	-25%
Energy-related CO_2 emissions (2022)	121 Mt CO_2
Electricty consumption per capita (2000-2024)	-3%
Energy intensity of the economy (2000-2024)	-43%

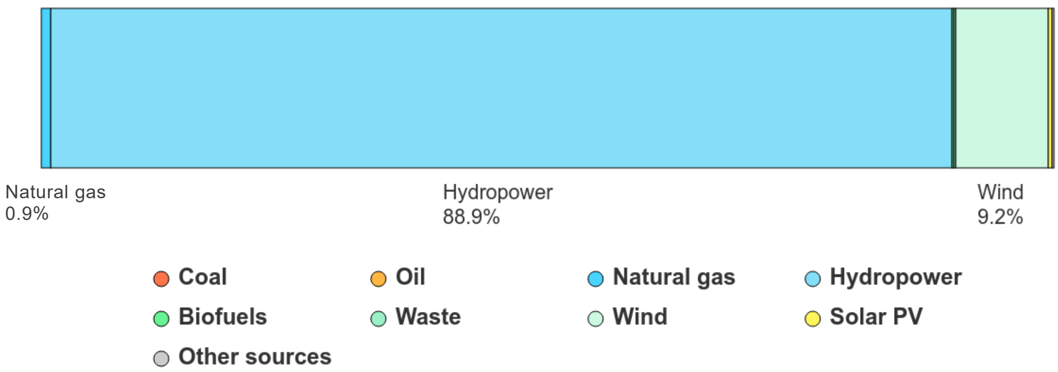
NORWAY

Total energy supply, Norway, 2024



Source: International Energy Agency. Licence: CC BY 4.0

Electricity generation sources, Norway, 2024

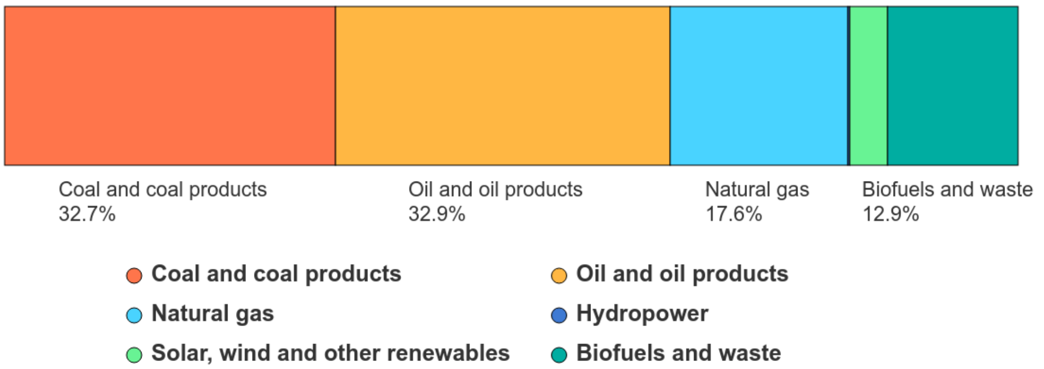


Source: International Energy Agency. Licence: CC BY 4.0

CO_2 emissions (2000-2022)	+12%
Energy-related CO_2 emissions (2022)	36 Mt CO_2
Electricty consumption per capita (2000-2024)	-5%
Energy intensity of the economy (2000-2024)	-30%

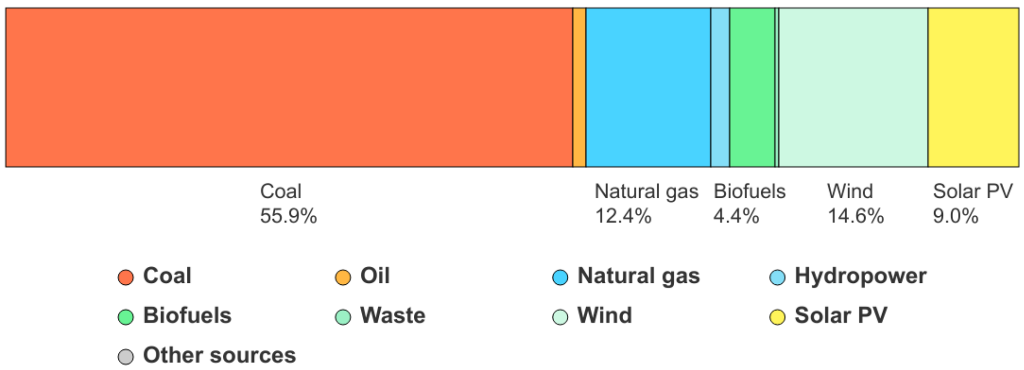
POLAND

Total energy supply, Poland, 2024



Source: International Energy Agency. Licence: CC BY 4.0

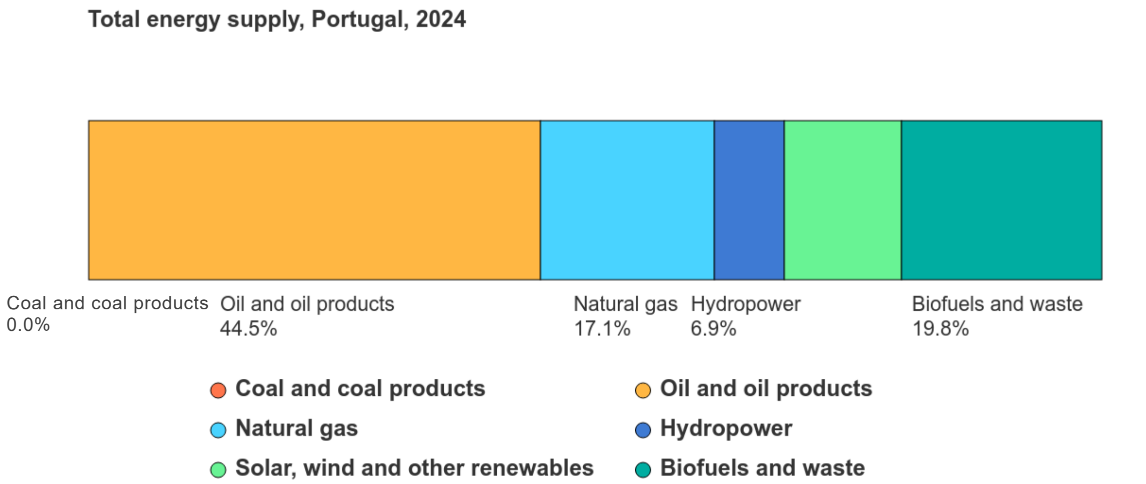
Electricity generation sources, Poland, 2024



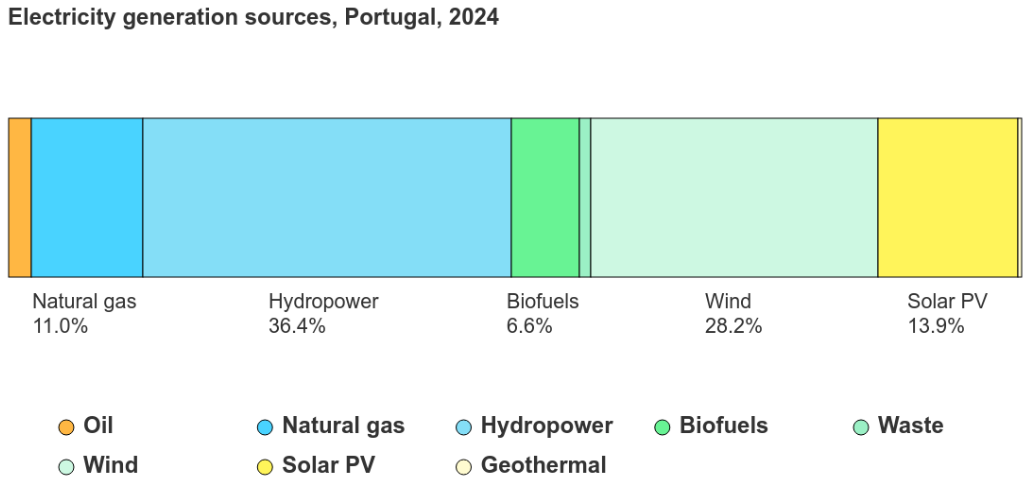
Source: International Energy Agency. Licence: CC BY 4.0

CO_2 emissions (2000-2022)	-2%
Energy-related CO_2 emissions (2022)	285 Mt CO_2
Electricty consumption per capita (2000-2024)	+31%
Energy intensity of the economy (2000-2024)	-53%

PORTUGAL



Source: International Energy Agency. Licence: CC BY 4.0

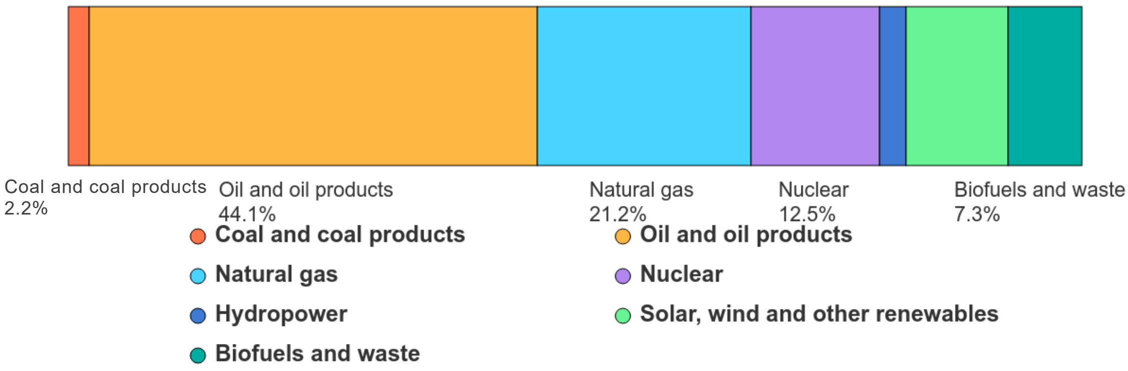


Source: International Energy Agency. Licence: CC BY 4.0

CO_2 emissions (2000-2022)	-38%
Energy-related CO_2 emissions (2022)	36 Mt CO_2
Electricty consumption per capita (2000-2024)	+33%
Energy intensity of the economy (2000-2024)	-37%

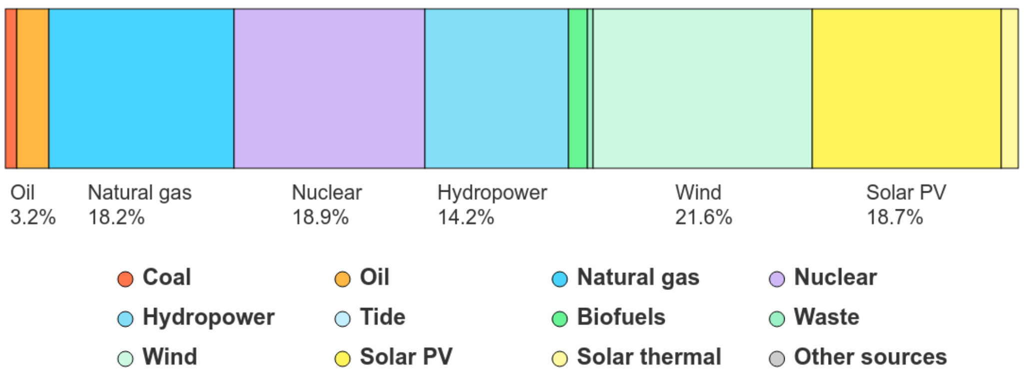
SPAIN

Total energy supply, Spain, 2024



Source: International Energy Agency. Licence: CC BY 4.0

Electricity generation sources, Spain, 2024

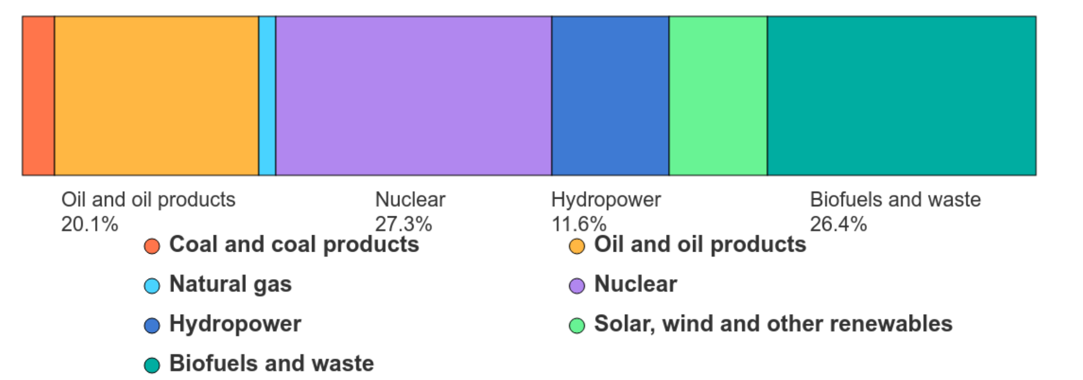


Source: International Energy Agency. Licence: CC BY 4.0

CO_2 emissions (2000-2022)	-22%
Energy-related CO_2 emissions (2022)	217 Mt CO_2
Electricty consumption per capita (2000-2024)	+1%
Energy intensity of the economy (2000-2024)	-37%

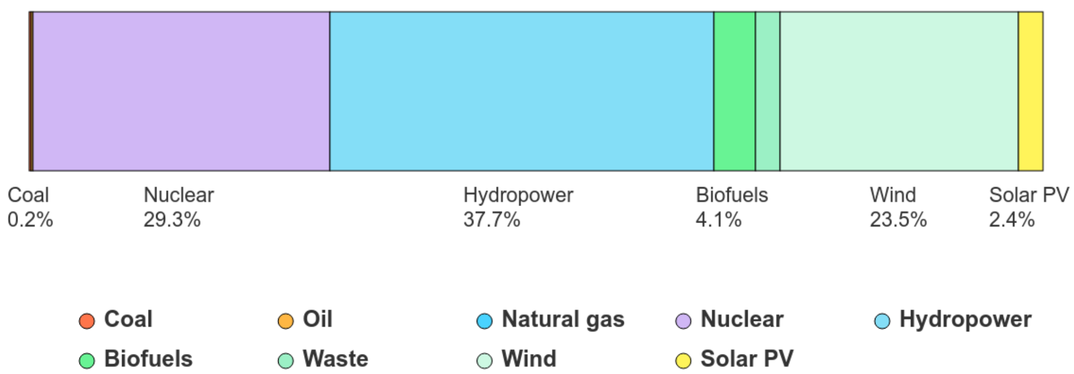
SWEDEN

Total energy supply, Sweden, 2024



Source: International Energy Agency. Licence: CC BY 4.0

Electricity generation sources, Sweden, 2024

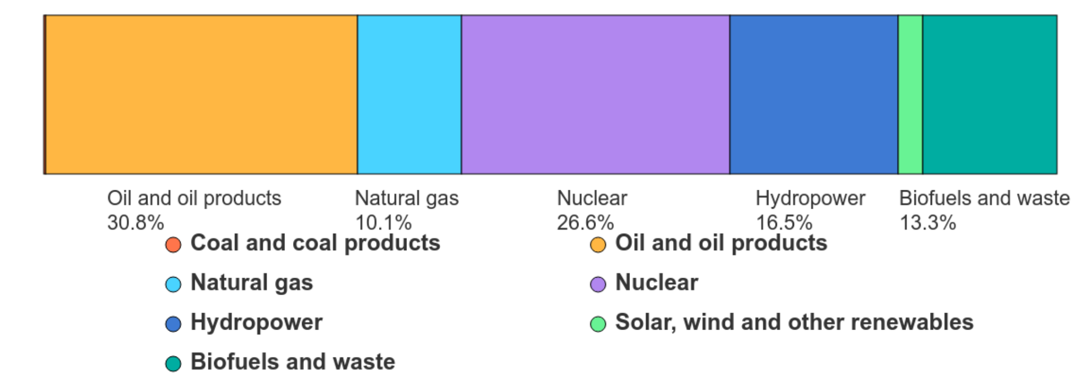


Source: International Energy Agency. Licence: CC BY 4.0

CO_2 emissions (2000-2022)	-38%
Energy-related CO_2 emissions (2022)	32 Mt CO_2
Electricty consumption per capita (2000-2024)	-22%
Energy intensity of the economy (2000-2024)	-39%

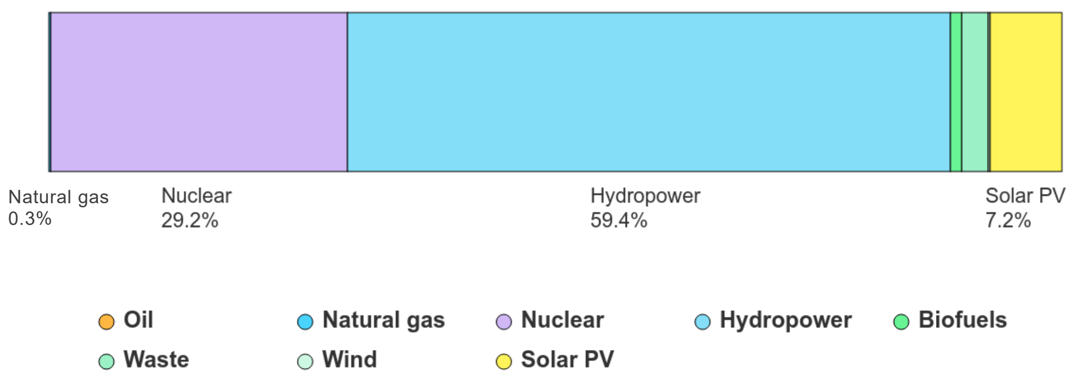
SWITZERLAND

Total energy supply, Switzerland, 2024



Source: International Energy Agency. Licence: CC BY 4.0

Electricity generation sources, Switzerland, 2024

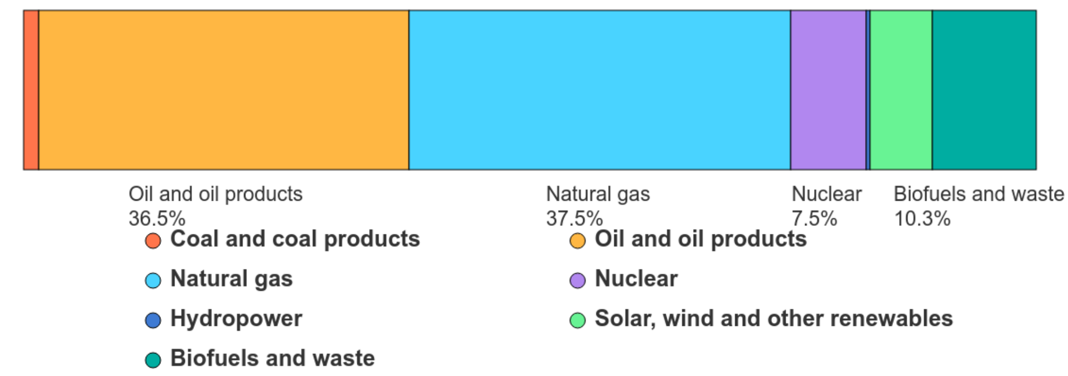


Source: International Energy Agency. Licence: CC BY 4.0

CO_2 emissions (2000-2022)	-24%
Energy-related CO_2 emissions (2022)	32 Mt CO_2
Electricty consumption per capita (2000-2024)	-9%
Energy intensity of the economy (2000-2024)	-41%

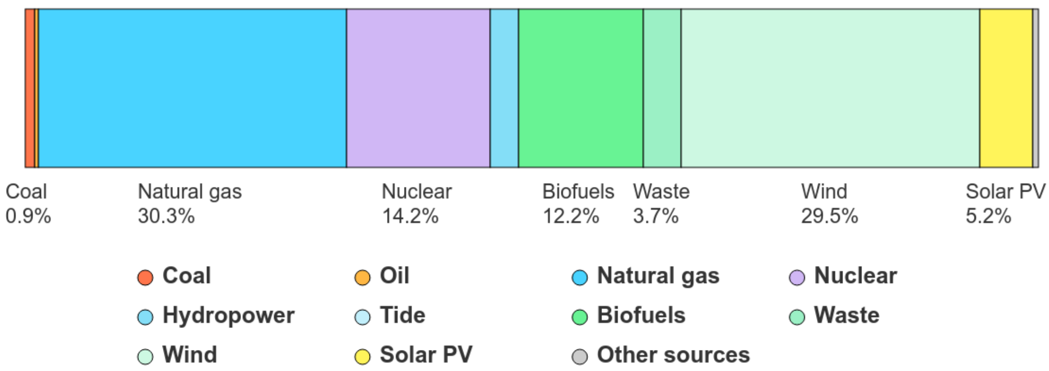
UNITED KINGDOM

Total energy supply, United Kingdom, 2024



Source: International Energy Agency. Licence: CC BY 4.0

Electricity generation sources, United Kingdom, 2024

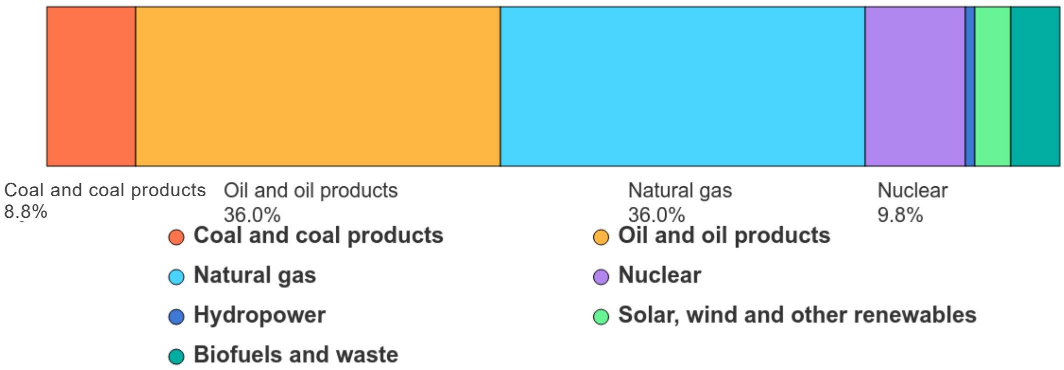


Source: International Energy Agency. Licence: CC BY 4.0

CO_2 emissions (2000-2022)	-41%
Energy-related CO_2 emissions (2022)	309 Mt CO_2
Electricty consumption per capita (2000-2024)	-31%
Energy intensity of the economy (2000-2024)	-55%

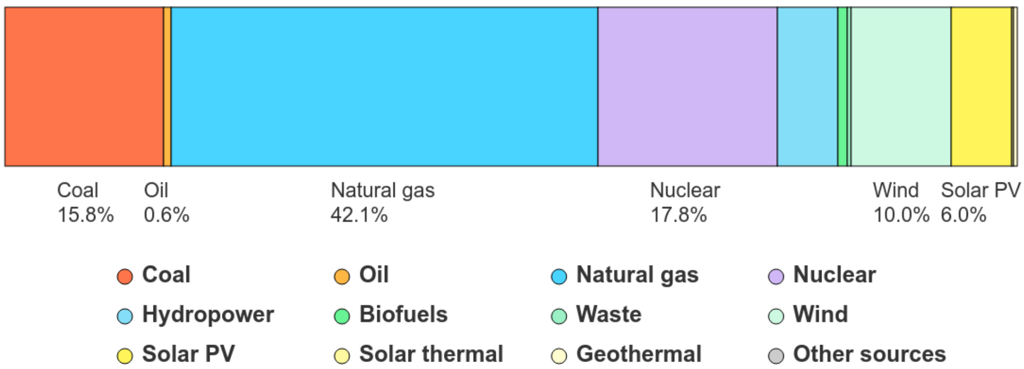
UNITED STATES

Total energy supply, United States, 2024



Source: International Energy Agency. Licence: CC BY 4.0

Electricity generation sources, United States, 2024



Source: International Energy Agency. Licence: CC BY 4.0

CO_2 emissions (2000-2022)	-20%
Energy-related CO_2 emissions (2022)	4608 Mt CO_2
Electricty consumption per capita (2000-2024)	-7%
Energy intensity of the economy (2000-2024)	-42%