Nuclear Phase-out

How renewables, energy savings and flexibility can replace nuclear in Europe

Report

PAC Paris Agreement Compatible Scenarios for Energy Infrastructure

EEB European Environmental Bureau

The European Environmental Bureau (EEB) is the largest network of environmental citizens' organisations in Europe. It unites 180 civil society organisations from 38 countries, working for a better future where people and nature thrive together.

The EEB is an International non-profit association /
Association internationale sans but lucratif (AISBL).
EC register for interest representatives:
Identification number 06798511314-27
BCE identification number: 0415.814.848
RPM Tribunal de l'entreprise francophone de Bruxelles

Published: March 2024
Responsible editor: Cosimo Tansini
Authors: Luke Haywood, Maya Perera, Cosimo Tansini
Contributors: Clémentine Buhl, Giovanni Maria Dettori
Editing and visuals: Hannah O'Sullivan, Alberto Vela

European Environmental Bureau (EEB)
Rue des Deux Eglises 14-16
1000 Brussels, Belgium
+32 (0)2 289 1090
eeb@eeb.org
eeb.org
meta.eeb.org

Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

With the support of the LIFE Programme of the European Union and the German Federal Ministry for Economic Affairs and Climate Action (BMWK).

Contents

List of Figures

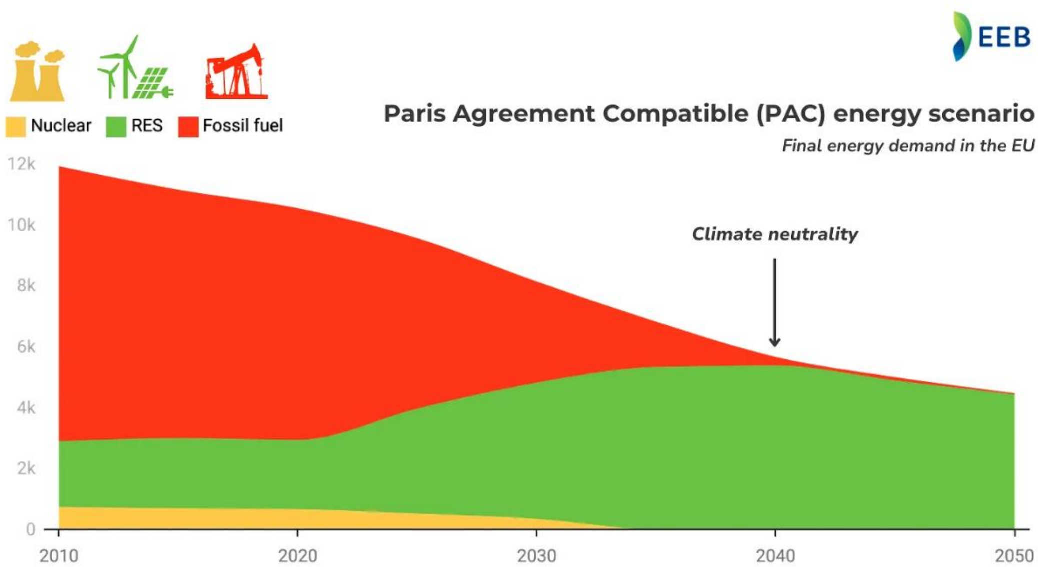
Executive summary

In the European Union (EU), nuclear power is once again being touted as a solution to climate change. However, **building new nuclear power plants to decarbonise Europe in time is unrealistic**.

Several factors contribute to this assessment. First, given the need to rapidly reduce emissions from the EU's power sector in line with climate targets, the long lead times and construction delays of nuclear significantly increase the risk of overshooting our remaining carbon budget. Second, high investment and maintenance costs render nuclear power plants uncompetitive with renewables, leading to a very heavy reliance on public funding and associated political lags – likely to reduce resources for phasing out fossil fuels rapidly. Third, uncertainties surrounding the safety profile and climate vulnerability of nuclear facilities that rely on river water cooling add further financial burdens and delays. Despite the many drawbacks of new nuclear capacity, shouldn't nuclear-dependent EU countries at least keep existing nuclear reactors in their energy mix to achieve carbon neutrality?

This report aims to show that **phasing out nuclear power alongside fossil fuels is feasible** and compatible with climate targets as the EU accelerates the deployment of renewables and energy savings. Based on the Paris Agreement Compatible (PAC) energy scenario, our report looks at the two main decarbonisation drivers displacing nuclear power from the energy mix over time:

1. A sharp **energy demand reduction**, driven by efficiency and sufficiency measures, improved circularity and recycling, and the electrification of processes that currently rely on fossil fuels.
2. Faster **renewable energy** deployment, replacing fossil fuels and the current share of nuclear-based electricity. Grids, storage, and demand-side management will maximise the penetration of renewables in electricity generation.



Projected composition of the final energy consumption (TWh) by type of energy source in the PAC scenario referred to the EU-27. Sources: Eurostat, ENTSO-E, PAC scenario. EEB own elaboration.

This report also underscores how limited the role of nuclear is in the energy transition:

- Nuclear currently makes a **limited contribution** to the EU's energy needs. Only 12 of the 27 EU countries generate nuclear power, which accounts for less than 5% of the bloc's final energy consumption.
- The PAC nuclear phase-out trajectory is in line with the planned retirement of the **ageing EU fleet**. Without further extensions, most of the capacity in operation in 2022 will reach retirement age by 2040.
- The combination of **renewables-based generation, energy savings** and **flexibility** tools can ensure stable energy security and fully replace fossil fuels *and* the remaining nuclear output in the energy mix.

To illustrate the feasibility of expanding renewables while phasing out nuclear, this report focuses on the 12 EU countries with installed nuclear capacities and examines the detailed PAC trajectories in five of these countries: France, Slovakia, Finland, Belgium, and Spain.

Introduction

The EU has adopted important greenhouse gas (GHG) emission reduction targets: -55% by 2030 compared to 1990 levels, with the aim of achieving climate neutrality by 2050 at the latest. To achieve climate neutrality, a binding and ambitious emission reduction target by 2040 will also be necessary.[1] The window of opportunity for a decisive shift away from fossil fuels is therefore extremely limited. **Technologies that can deliver** the required decarbonisation outcomes quickly and cost-effectively are already available and **will be central** to achieving these goals, leaving the EU at a crossroads: invest heavily in proven renewable energy and flexibility assets, or rely on the hypothetical promises of the nuclear industry?

The Paris Agreement Compatible (PAC) scenario is an EU-wide energy scenario developed by civil society in cooperation with grid operators, industry representatives, economists, and researchers, to demonstrate that Europe can reach **climate neutrality by 2040** – 10 years earlier than currently agreed by EU governments. The PAC scenario identifies four key areas for action: enabling sustainable lifestyles, improving energy use and processes, electrification combined with zero-carbon power generation, and decarbonising the remaining sectors. PAC has three main goals:

- 65% reduction in GHG emissions by 2030;
- Net-zero emissions by 2040;
- 100% renewable energy by 2040 across all sectors.

The PAC pathway to 100% renewables results in the phase-out of coal by 2030, fossil gas by 2035 and fossil oil products and **nuclear power by 2040.**

Twelve of the 27 EU countries rely on nuclear electricity – Belgium, Bulgaria, Czechia, Spain, Finland, France, Hungary, the Netherlands, Romania, Sweden, Slovenia, and Slovakia.[2] While political actors in several other EU countries have recently declared an interest in developing nuclear energy, notably Poland, Italy, and Denmark, this report focuses only on EU countries with currently operating nuclear capacity.

This report shows that that **energy savings and a faster deployment of renewables are the key factors to enable a nuclear energy phase-out in the EU**. After assessing the current contribution of nuclear power to the EU's final energy consumption and electricity generation, we discuss the specific factors that allow the replacement of both nuclear and fossil fuels in the EU energy mix in the PAC scenario results. We also provide an assessment of the age profile and expected decommissioning date of the current nuclear capacity in the EU, based on statistical information and historical trends. Finally, this report analyses five country cases to explore the specificities of the required energy savings and renewable energy deployment in countries that currently rely on nuclear energy.

[1] The European Commission's Communication on the EU's climate targets for 2040, published in February 2024, proposed a 90% reduction in greenhouse gas emissions by 2040 compared to 1990 levels. This opened a political debate that will inform the next Commission, which will take office after the 2024 European elections and be called upon to make the legislative proposal to include the 2040 target in the Regulation (EU) 2021/1119 establishing the framework for achieving climate neutrality (European Climate Law).

[2] For the sake of clarity, these 12 EU member states – i.e. those with operational nuclear capacities in 2022 - will be jointly referred to as the 'EU nuclear countries' throughout the text.

The role of nuclear energy is limited

The role of nuclear in the energy mix of the EU nuclear countries is limited. Figure 1 shows that even in France, the country with the largest nuclear energy capacity in the EU, nuclear energy accounts for less than 20% of final energy consumption in 2022. **No other EU country with nuclear capacity exceeds 12% of final energy consumption.** In Sweden, Finland, Belgium, Slovakia, and Slovenia the share is between 10 and 12%; in the other half of the EU countries with nuclear capacity (Spain, the Netherlands, Czechia, Hungary, Romania, Bulgaria), less than 10% of final energy consumption is met by nuclear energy.

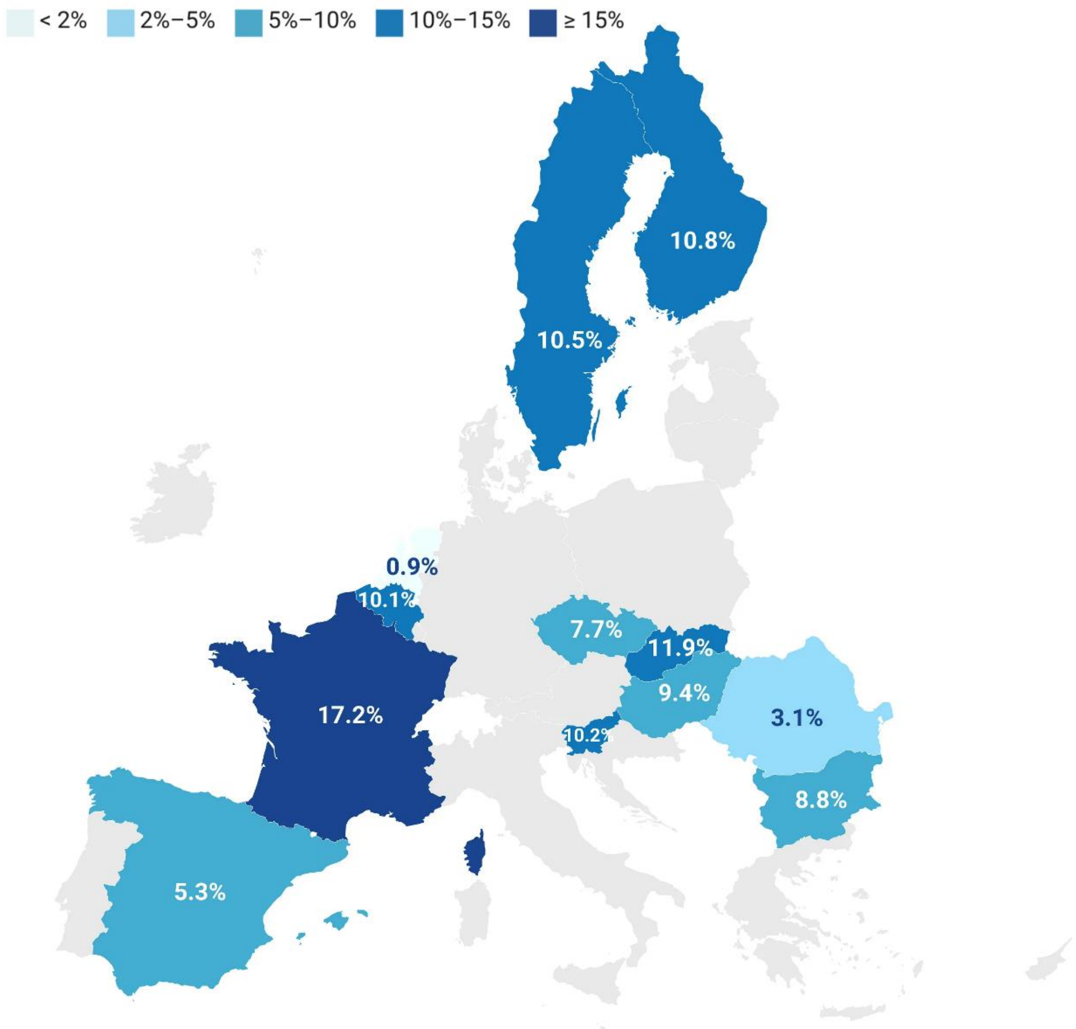


Figure 1 – Contribution of nuclear energy (%) to final energy consumption in EU countries with nuclear capacities in 2022. Source: Eurostat, ENTSO-E. EEB own elaboration. Created with Datawrapper.

This may seem surprising at first. While in the EU as a whole nuclear energy currently accounts for only a small share, 4.7%, of final energy consumption (10.1% if only the EU nuclear countries are considered) in some countries, nuclear generation currently makes a significant contribution to the electricity system, as shown in Figure 2 below.

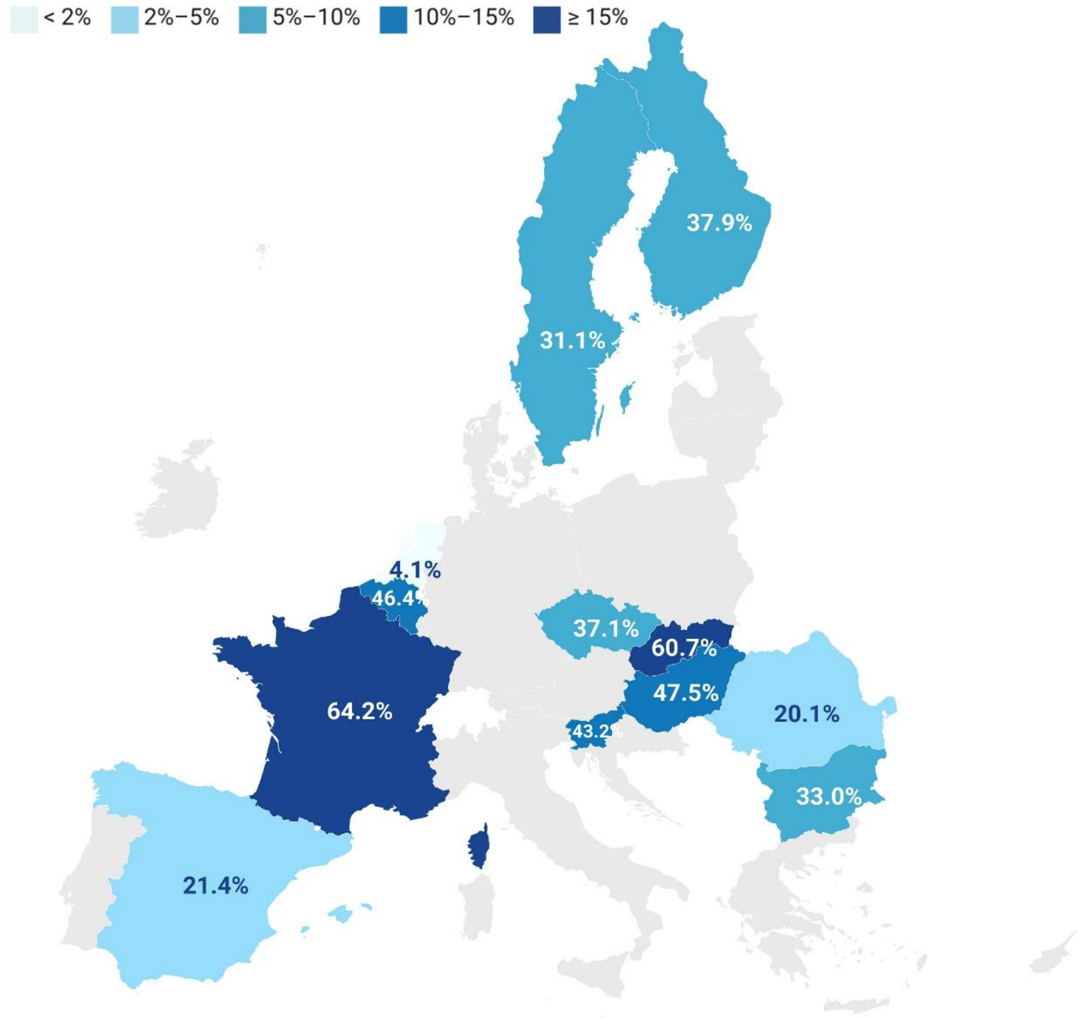


Figure 2 – Contribution of nuclear energy (%) to gross electricity production in EU countries with nuclear capacities in 2022. Source: ENTSO-E. Created with Datawrapper.

However, **electricity is currently only a limited part of the energy mix** in many EU countries. In 2022, electricity accounted for an average of 23% of the final energy consumption at EU level, ranging from 14.7% in Romania to 32.5% in Sweden. It would therefore be misleading to focus on the role of nuclear power solely based on today's electricity generation. It is important to focus on final energy when considering the potential of nuclear energy, as electricity is likely to displace other energy sources such as heating oil, gas, and petrol.

During the decarbonisation process, many sectors will be electrified that currently are not such as heating, and passenger and freight transport. In achieving the decarbonised energy system of the future, electricity demand will increase, but the share of nuclear in electricity generation will decrease – even in the most 'high nuclear' scenarios available. What's more, the increase in renewable energy capacity envisaged in all scenarios requires a complete overhaul of electricity generation, transmission and distribution, and demand patterns. In this report, we therefore believe it is more accurate to focus on the role of nuclear energy in meeting countries' final energy consumption.[3]

Nuclear baseload unnecessary in future EU grid

Discourses on nuclear energy often emphasise its role as a necessary baseload provider for grid stability, particularly during periods of low renewables production due to solar and wind variability. In situations when electricity demand exceeds supply, **grid stability must be maintained** by either increasing (fossil) dispatchable generation, importing the required excess electricity, releasing previously stored energy, or reducing demand. In all cases, these interventions have the effect of 'shaving' peak electricity consumption and making it manageable from a system perspective. To cope with the daily variations typically associated with solar photovoltaic (PV) generation and the weekly variations associated with changing wind patterns, short-term peak shaving solutions will be required and are likely to be delivered through a mix of interconnection, distributed storage and demand management. This contrasts with the seasonal load shifting function, needed to balance the grid on an annual basis. Nuclear supporters argue that this is the niche where nuclear backup generation is needed.

However, as we move beyond the traditional fossil fuel-based operating patterns of the electricity system, **nuclear power has little to offer** to complement a system based on renewable sources. Not only is it expensive to produce, subject to unplanned outages, vulnerable to water shortages and high temperatures, but nuclear generation is inherently inflexible and requires significantly more investment and time than a renewables-based system that relies on other grid balancing options. Nuclear reactors are optimised for baseload operation, meaning they operate continuously at a relatively constant output level. Unlike natural gas or coal-fired power plants, they cannot easily adjust their output to meet fluctuations in electricity demand. If nuclear power plants could be made more flexible, other problems would arise: Given the very high fixed investment costs, reducing the number of operating hours greatly increases the cost of electricity produced. This **lack of flexibility poses a risk to grid management**, especially as inherently variable renewable energy sources such as wind and solar become more important. Worse still, a fixed nuclear baseload could act as a bottleneck by taking up grid capacity and limiting renewables integration into the grid, particularly during periods of surplus wind and solar production - a lose-lose for the climate and for taxpayers.[4]

[3] Final energy consumption (FEC) is the total energy consumed by end users, such as households, industry and agriculture. Source: Eurostat. We will use this index when discussing energy demand figures, such as sectoral shares of energy savings. When discussing supply, in order to derive the amount (TWh) of nuclear energy in the FEC, we have based our calculation on the actual composition of the electricity mix (gross electricity production) and the share of electricity among the vectors used to meet the FEC. I.e. nuclear generation is calibrated to reflect its contribution to the actual FEC, excluding industrial feedstock, international air and sea transport, energy consumption of the power sector itself and network losses.

[4] While this is a real risk - see, for example, Romania, where the Cernavodă 3 and 4 reactors have been reserving grid capacity for years, blocking new renewable energy projects in the Dobrogea region, the most wind-intensive region in the country - the opposite can also be true. During periods of high solar and wind production, electricity prices may in fact fall to levels that are unaffordable for nuclear power plant operators, who are forced to close to avoid further financial losses. This happened in Spain in March 2024, when Almaraz, Cofrentes and Ascó requested grid operators to shut their reactors down.

The reliability of renewable energy sources, particularly solar PV and wind, to generate electricity throughout the year is also being proven. EMBER's assessment concludes that wind and solar already provide stable electricity generation throughout the year, and their reliability increases in proportion to their penetration. Furthermore, studies analysing the UK energy sector, show that a portfolio of **renewables combined with storage technologies outperform nuclear** in terms of cost efficiency and adaptability to growing electricity demand. Similar results have been obtained for the Baltic countries, showing that an interconnected system based entirely on renewables is the least expensive solution compared to the alternatives systems based on nuclear.

Greater interconnection between and within countries' transmission systems and appropriate distribution upgrades can optimise the dispatch of renewable electricity to provide the load shifts needed to rely solely on renewable generation. Distributed and utility-scale energy storage solutions and demand-side flexibility tools also have the potential to contribute massively to grid balancing. This combination can efficiently provide the load shifts needed for renewable generation assets to meet 100% of our future electricity needs in a stable manner, both intraday and in the long term.

Nuclear energy is in decline

Nuclear fission technologies have played a role in the EU's energy system since the late 1950s. Nuclear power **capacity additions peaked in the 1980s in the EU, before declining rapidly and plateauing since then**, as shown in Figure 3 below.

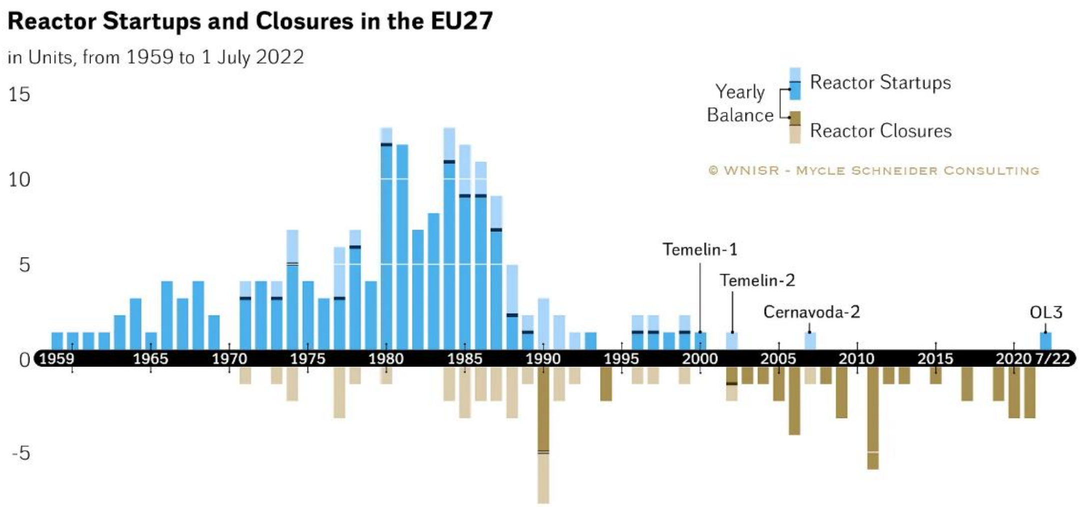


Figure 3 – Reactor startups/ closures in the EU27. Source: World Nuclear Industry Status Report 2023.

Since 2000, there have been only two construction starts in the EU: Flamanville-3 in France, where construction started in 2007 and is still ongoing, and Olkiluoto-3 in Finland, commissioned in 2005 and only connected to the grid in April 2023 after numerous delays. Only 10 reactors have been brought into operation this century, with a total generation capacity of 11 Gigawatts (GW). Mochovce-3 in Slovakia was commissioned in 1983 but only came online in October 2023, 40 years later. Together with Olkiluoto-3, these two are the only nuclear plants that have been connected to the grid in the EU since Cernavoda-2 in Romania was launched in 2007.

EU nuclear capacity is and remains limited. Today, there are 100 reactors in operation in EU countries, with a generating capacity of about 96 GW. More than half of the EU fleet lies in just one country - France. EU reactors are also ageing: the average age of EU nuclear reactors has increased steadily and is now almost 37 years. Unless further extended, most of these reactors will have to be **decommissioned by the end of the next decade.**

Country	No. of reactors	Capacity (GW)	2023 generation (TWh)	Reactors age (Years avg)	Expected retirement (Avg)[5]
Belgium	5	3.9	31.2	44.4	2025
Bulgaria	2	2	16.1	34.0	2039
Czechia	6	3.9	28.7	32.3	2041
Finland	5	4.3	32.6	35.8	2037
France	56	61.3	318.7	38.3	2035
Hungary	4	1.9	15.0	38.3	2035
Netherlands	1	0.4	0.4	50	2033
Romania	2	1.3	11.2	21.5	2041
Slovakia	5	2.3	18.1	25.4	2047
Slovenia	1	0.6	0.5	42	2031
Spain	7	7.1	54.3	38.6	2031
Sweden	6	6.8	46.6	41.3	2032
EU-27	**100**	**96.3**	**573.4**	**36.8**	**2036**

Table 1 – Nuclear reactors in operation in the EU as of January 2024. Sources: European Nuclear Society, Greenpeace, ENTSO-E.

Despite very few countries planning to phase out nuclear energy, even the European Commission's energy modelling predicts that the share of nuclear energy in final energy consumption will nevertheless fall by 2030. In the EU 2020 Reference scenario, only Finland, Czechia, Slovakia, and Hungary show an increase in the share of nuclear generation. Only six countries are predicted to rely on nuclear for more than 10% of final energy consumption in 2030 (and the same number of countries

[5] This is an average estimate. Where information was available, we averaged the announced, reported or already licensed extension for each currently operating reactor. Where this was not possible, we assumed a total lifetime of 50 years (10 years more than in the PAC scenario assumptions).

in 2050).[6] The picture contrasts strongly with the prominent place taken by nuclear power in EU policy discussions.

Recent analysis by EMBER has also confirmed the **continuing fall of nuclear generation in the EU**. The contribution of nuclear power to the EU electricity mix has been declining steadily over the last two decades, as shown below.

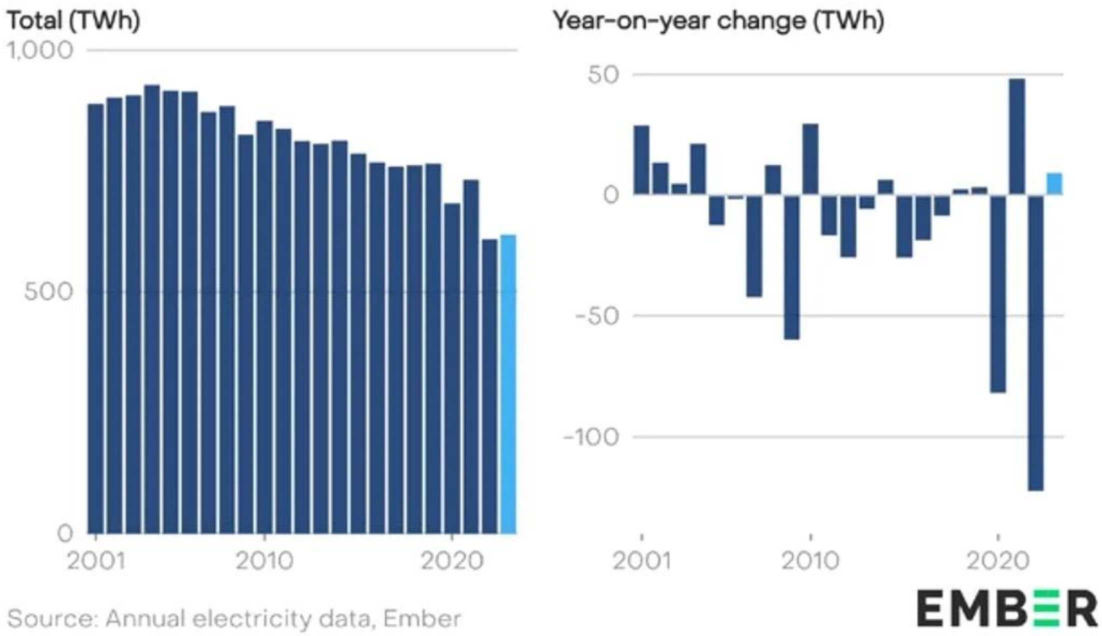


Figure 4 – Evolution of nuclear generation (TWh) in the EU from 2000 to 2023. Source: EMBER Electricity Review 2024.

Generation fell from 33% to 23% between 2000 and 2023, with 860 terawatt hours (TWh) generated in 2000 and 619 TWh in 2023. Importantly, at the same time, the share of fossil generation in Europe fell to its lowest level ever, just 33% of total generation in 2023, 6% lower than 2022. Gas remains the largest source of fossil generation at 17% (52TWh) in 2023, with coal at just 12% (333TWh).

For those countries that currently have nuclear capacities, we will discuss the factors that the PAC scenario foresees to compensate the decline, and eventual phase-out, of their nuclear power output. The PAC scenario does not rely on a one-to-one replacement of nuclear capacity by renewables. Energy savings also play a major role in achieving climate targets, independent of phasing out nuclear power.

[6] The EU Reference 2020 Scenario does not take into account the use of nuclear power in countries that are in various stages of planning to introduce new capacities, such as Poland. Whether these plans will be realized is not obvious.

Phasing out nuclear energy in the EU is feasible

To test the feasibility of phasing out nuclear energy from the EU mix, the PAC scenario makes three reasonable assumptions that lead to a reduction in nuclear energy use:

1. New nuclear plants suffer from **high investment costs, long development times and competition** from increasingly cheap renewables and are therefore not realistic.
2. The **lifetime of existing plants is limited to 40 years**, unless governments and operators explicitly extend them.
3. Rising maintenance, fuel, and decommissioning costs incentivise **earlier retirements**.

These hypotheses lead to a **rapid phase-out of nuclear power** in PAC. As shown in Figure 5 below, there is a significant reduction in nuclear energy use as early as 2030 compared to 2022.

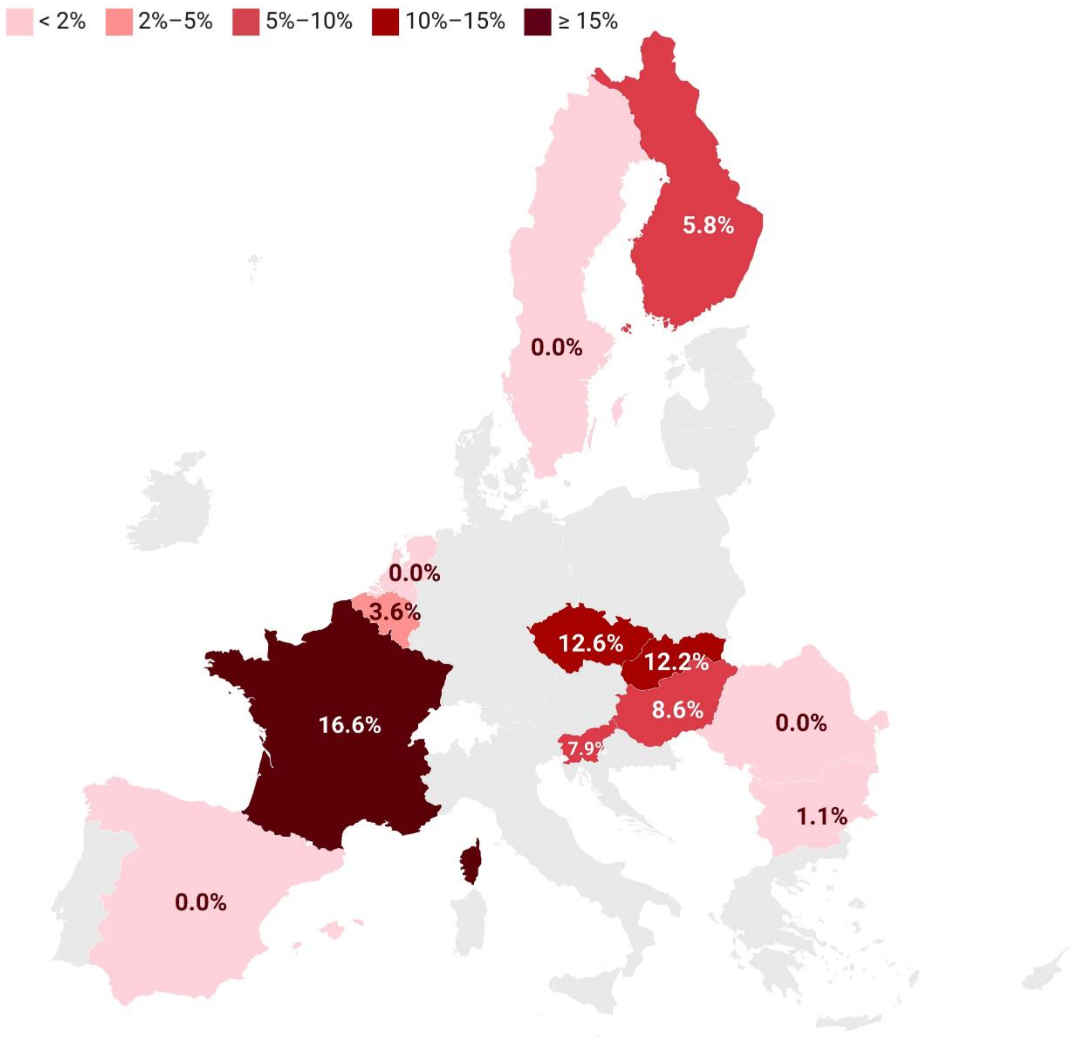


Figure 5 – Projected contribution of nuclear energy (%) to final energy consumption in 2030 in EU countries. Source: PAC scenario. EEB own elaboration. Created with Datawrapper.

In the PAC scenario, phasing out nuclear power from the EU's energy supply is not only feasible, but actually a relatively small challenge in the overall decarbonisation process, given the limited contribution of nuclear power to the bloc's energy needs (10.1% of the final energy consumption in 2022 in the EU nuclear countries in 2022, 4.7% when considering the EU-27). Beyond 2030, the trend is clear: **by 2040, the PAC scenario foresees no remaining nuclear output** in any EU country except France, as shown in Figure 6 below.

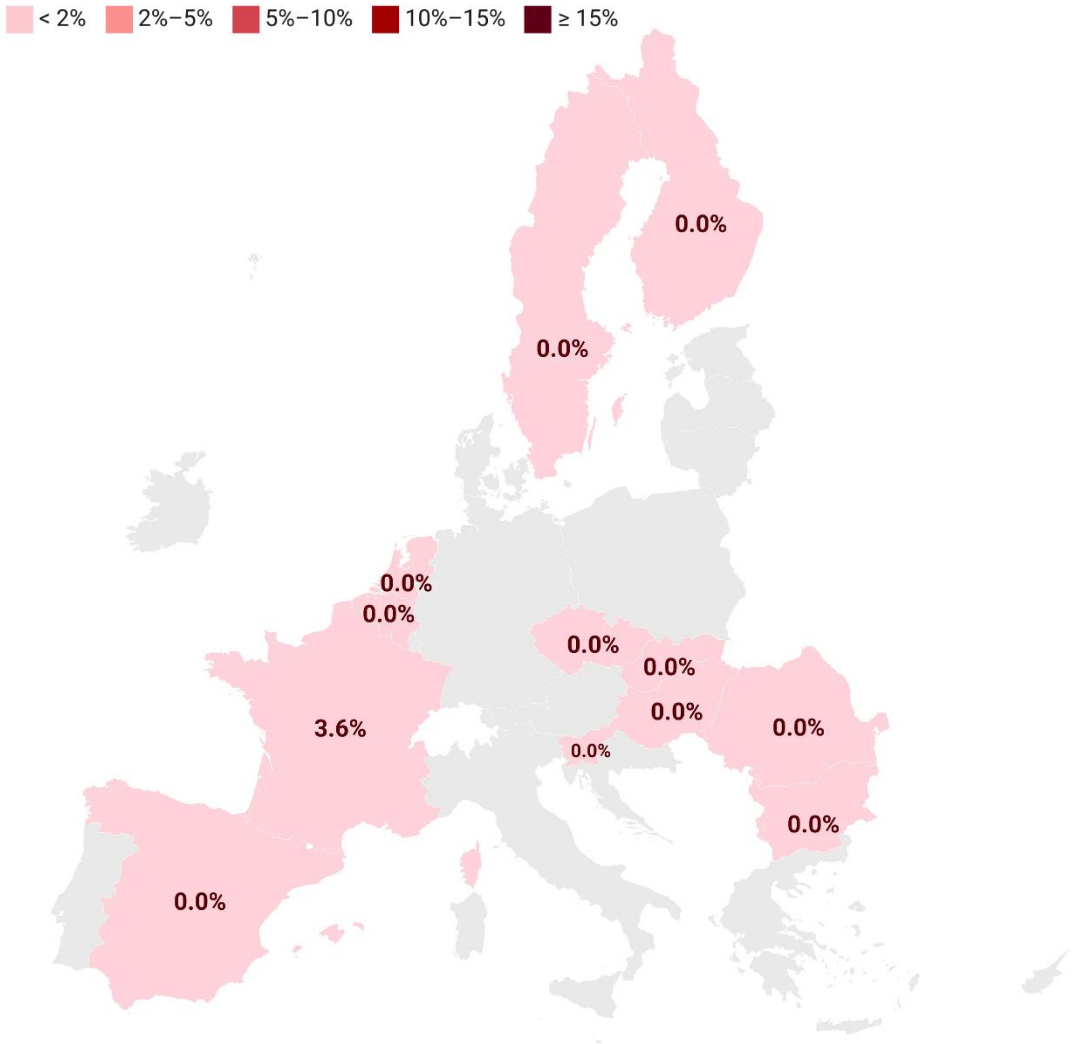


Figure 6 – Projected contribution of nuclear energy (%) to final energy consumption in 2040 in EU countries. Source: PAC scenario. EEB own elaboration. Created with Datawrapper.

Contrary to the debate in EU energy policy, the question of nuclear power was a marginal one for PAC modelling – for good reason. The focus is squarely on energy savings and renewables, since the contribution of nuclear energy to final energy consumption is small and the **real policy challenges lie in how to quickly replace fossil fuels**. Figure 7 shows that the magnitude of the changes in fossil fuels (the PAC scenario implies the continuous red line) and renewables is much larger than the scale of the nuclear phase-out (orange line).

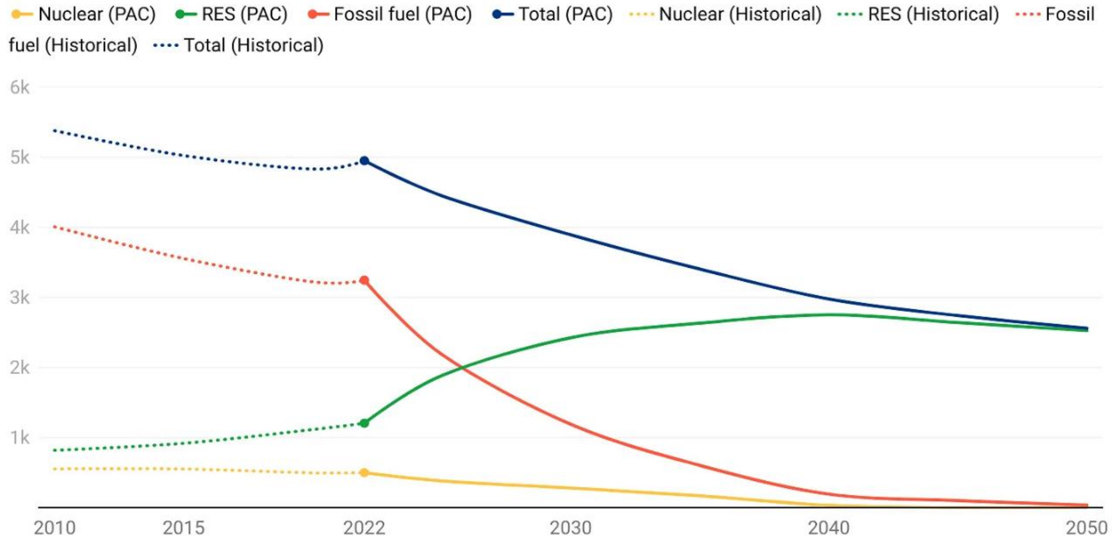
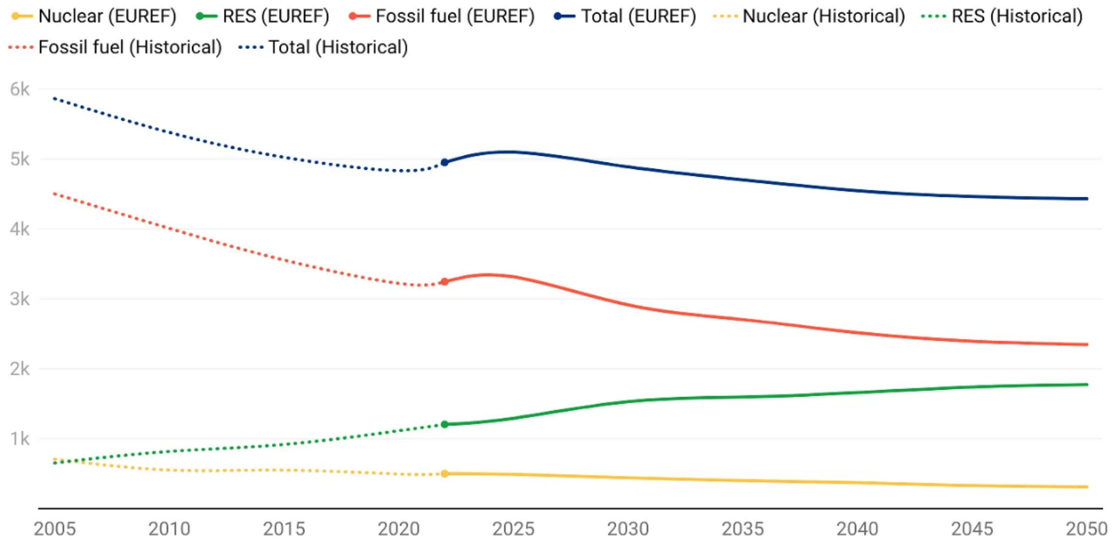


Figure 7 – Projected composition of the final energy consumption (TWh) by type of energy source in the PAC scenario for the EU nuclear countries. Sources: Eurostat, ENTSO-E, PAC scenario. EEB own elaboration. Created with Datawrapper.

Compared to the PAC scenario, the reduction of nuclear and fossil energy sources in the EU energy system is much more limited in the EU 2020 Reference Scenario, as shown in Figure 8. While the absolute growth of renewables-based electricity generation is not so different in the two scenarios,[7] the relatively stable energy consumption in the EU 2020 Reference Scenario implies a greater need to prolong the use of fossil fuels. Although less than in PAC, the share of nuclear still declines.



[7] In the PAC scenario, the amount of final energy consumption met with renewables in the EU nuclear countries grows from 1204 TWh in 2022 to 2526 TWh in 2050. The EU 2020 Reference Scenario results in a lower, but still significant figure in 2050: 1774 TWh of renewables contribution to the final energy consumption.

Figure 8 – Projected composition of the final energy consumption (TWh) by type of energy source in the EU 2020 Reference Scenario for the EU nuclear countries. Sources: Eurostat, ENTSO-E, EU Reference Scenario 2020. EEB own elaboration. Created with Datawrapper.

The PAC scenario shows that across all current EU nuclear countries, the **final energy consumption** (blue line in Figures 7-9) can be reduced by over 25% between 2022 and 2030 (from 4951 to 3894 TWh). The **contribution of renewables** (green line in Figures 7-9) also increases, with production more than doubling between 2022 and 2030. This increase in renewables is much greater than the **reduction in nuclear energy output** (yellow line in Figures 7-9). The real impetus for additional renewables, but above all energy demand reductions comes from the **rapid decrease in fossil fuels use** – of more than 2000 TWh (from 3246 to 1189) in the same 2022-2030 timespan, as shown in Figure 9 which compares the trajectories from the PAC and the EU Reference 2020 scenarios.

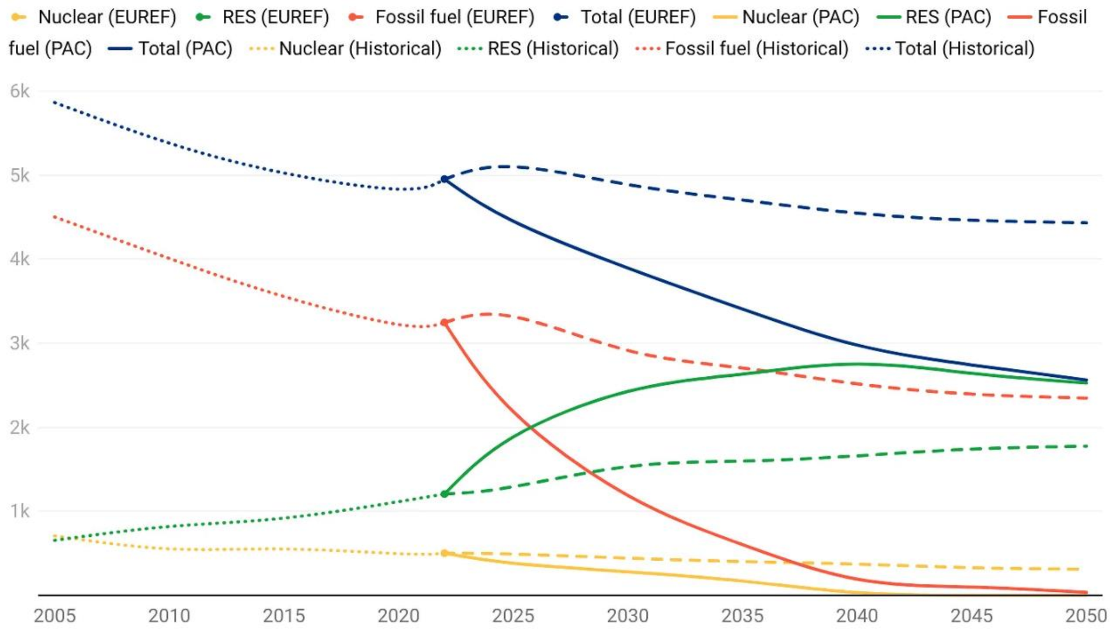


Figure 9 – Projected composition of the final energy consumption (TWh) by type of energy source in the EU nuclear countries, contrasting nuclear phaseout to reductions in fossil fuels and RES deployment in the PAC and EU Reference 2020 scenarios. Sources: Eurostat, European Commission, ENTSO-E, PAC scenario. Created with Datawrapper.

Reductions in nuclear power have little impact on the overall energy picture, which is dominated by reductions in fossil fuels and increased penetration of renewables. The additional ambition to reduce nuclear energy production in the PAC scenario can be attributed either to reductions in energy consumption or to increases in renewable energy production – with the latter increasing by much more (1547 TWh) than would be needed to compensate for the decline in nuclear production (-500 TWh) between 2022 and 2040. Even more so, the reduction in energy demand (1974 TWh) is almost six times higher than that needed to compensate for the lower nuclear production.

Greater ambition either in renewables roll-out or with energy savings can easily make up for reduced nuclear energy output. While EU nuclear countries vary significantly in their current reliance on atomic energy, the necessary changes brought about by decarbonisation dwarf the challenge of a nuclear phase-out in all countries. **Even in France**, the country with the largest nuclear energy capacity in the EU, the total 2023 nuclear production (320 TWh) is less than half of energy demand reduction foreseen by the PAC scenario (642 TWh) between 2022 and 2040.

Rather than creating an unsolvable puzzle, two different solutions to the future energy system can each replace the reduced nuclear production if we exploit them. Let's consider the two components in turn: energy savings and renewables.

What are the key sources of energy savings in PAC?

Given the critical importance of energy savings in decarbonising our economy, notwithstanding the nuclear challenge, we briefly review the main sources of savings underlying the PAC scenario.

Deep economic, social, technological, and also behavioural changes lead to sharp reductions in energy demand in the PAC scenario. All sectors show huge potential for energy savings, as shown in Figure 10 below. In particular, PAC foresees EU-wide energy savings between 2020 and 2040 of:

- 2153 TWh in the **buildings** sector, representing 40% of the total reduction. Increased use of renewable district heating networks and heat pumps in residential buildings, reduced hot water consumption in commercial buildings and high renovation rates are among the drivers of this reduction.
- 2114 TWh in **transport** (excluding international aviation and shipping), accounting for 39% of the decreased consumption. Reduced use of city cars, efficiency gains in battery electric vehicles (BEVs), increased use of cycling and rail are among the factors contributing to this.
- 1094 TWh in the **industry** sector (excluding feedstocks[8]). Industry will contribute around 20% of the total reduction through reduced use of packaging, material efficiency gains in the production of steel, aluminium and cement, and significant increases in recycling rates.

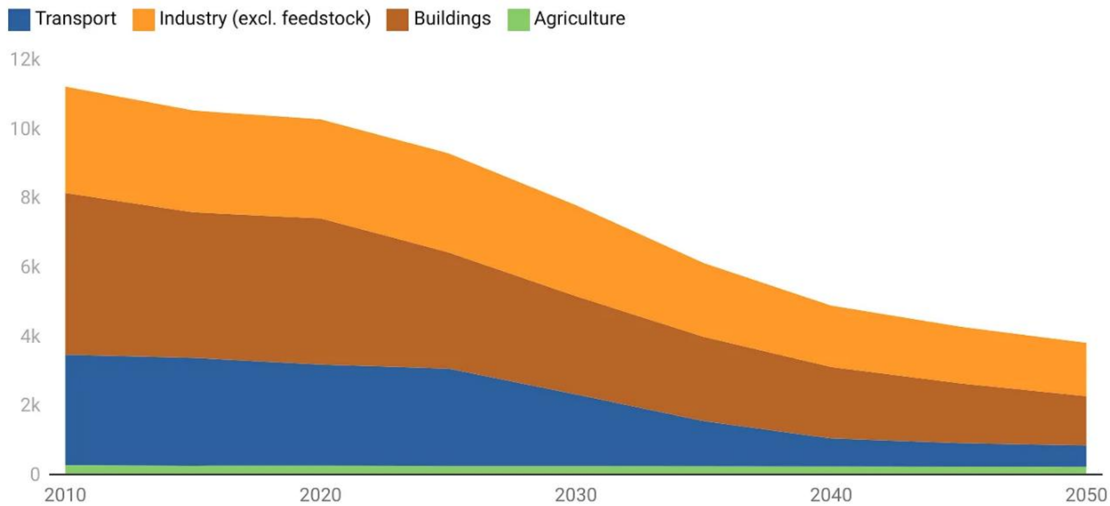


Figure 10 – Final energy consumption (TWh) by sector in the EU-27 in the PAC scenario. Source: PAC scenario. Created with Datawrapper.

[8] This excludes non-energy uses of energy carriers, like using hydrogen as a feedstock to make synthetic materials and chemical products such as plastics and fertilisers.

These three sectors together account for the vast majority of the total reduction in the EU's final energy consumption between 2020 and 2040 in the PAC scenario. Although final energy consumption excludes **international air and sea transport and industrial feedstocks**, these will still make a small contribution to EU-wide energy savings, with reductions of around 392 and 447 TWh, or 4.5 and 8% respectively. Although the contribution of the agricultural sector to energy savings will be negligible, its impact may be indirect. For example, a shift towards agro-ecological practices leading to a reduction in the use of fertilisers is likely to reduce the need for industrial feedstocks such as hydrogen and ammonia, the production of which requires energy. Declining demand for passenger and freight air and sea transport, combined with efficiency gains in aircraft and ships, will reduce energy consumption in this sector.

In the PAC scenario, the amount of reduction in final energy consumption (5385 TWh)[9] far outweighs the total reduction of nuclear generation (547 TWh by 2040, compared to 2022) making demand reduction the first source of decarbonisation in the PAC scenario.

What is PAC's renewable energy pathway?

The energy transition pathway in the PAC scenario results in a substantial uptake of renewables, supported by infrastructure developments to modernise and expand the electricity grid within and between EU member states, deploy the necessary balancing storage and enable demand-side flexibility.

In the PAC scenario, 105 GW of renewable electricity generation are added in the EU on an annual basis from 2023 onwards, assuming constant deployment rates. The additions come mainly from new and repowered wind and solar PV capacity, with a supporting role for hydro, solar thermal, geothermal and bioenergy. Flexibility options, such as demand side response, storage technologies, optimised operation, extension of grids and cross-border electricity interconnection are also harnessed and actively developed to integrate renewable generation effectively.

Between 2020 and 2040, the PAC scenario leads to an EU-wide increase in renewable generation of:

- 1099 TWh of **onshore wind** generation, accounting for 29% of the net increase in renewable electricity generation.[10] The new EU rules on mapping and spatial planning, if combined with participatory permitting and incentives for community projects, could facilitate the deployment of new onshore wind farms and the repowering of those nearing the end of their life.
- 917 TWh of **offshore wind** power, 24% of the net increase in renewable electricity production in the EU. Improved regional coordination, better auction design to encourage multiple uses of sea areas and rapid development of the necessary high voltage grid infrastructure will allow growing shares of offshore wind to penetrate large segments of the EU electricity market.
- 1380 TWh of **solar photovoltaic (PV)** production, representing 36% of the net increase in EU renewable electricity generation. Streamlined permitting rules for small-scale installations, a mandate for PV on commercial buildings, strategic spatial planning to

[9] This refers to the EU-27 final energy consumption, excluding international aviation and shipping and industrial feedstocks.

[10] I.e. only considering additions and discounting reductions in use of biomass, biomethane, solid biowaste.

concentrate solar development on degraded land are among current legislative changes that make the PAC figures on solar capacity deployment credible.

Solar PV and wind technologies together account for more than 90% of the growth in renewable electricity generation in the PAC scenario between 2020 and 2040. The remaining 5% is provided by limited and geographically-specific additions of Concentrated Solar Power (CSP) and geothermal capacity, as well as repowering and modernisation of the existing hydro fleet, as shown in Figure 11 below.

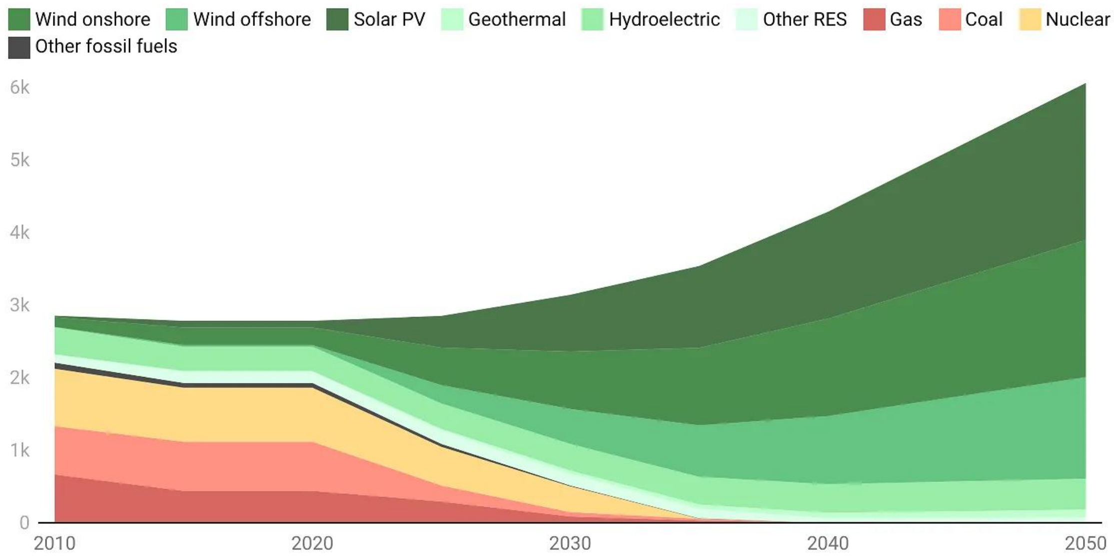


Figure 11 – Projected growth of renewable electricity generation and decline of fossil and nuclear-based generation (TWh) in the EU-27 in the PAC scenario. Source: PAC scenario. Created with Datawrapper.

As with the reduction in energy demand, the contribution of renewables in the PAC scenario is far greater than any reduction in - and potential contribution from - nuclear generation.

It should also be emphasised that direct electrification based on renewable generation is in itself a factor that greatly improves the efficiency of most energy systems. For example, heat pumps are up to seven times more efficient than a hydrogen boiler and six times more efficient than a gas condensing boiler. Electric vehicles are another example, as they are on average two to three times more energy-efficient than cars with internal combustion engines.

Decarbonisation pathways consistent with nuclear phase-out: five case studies

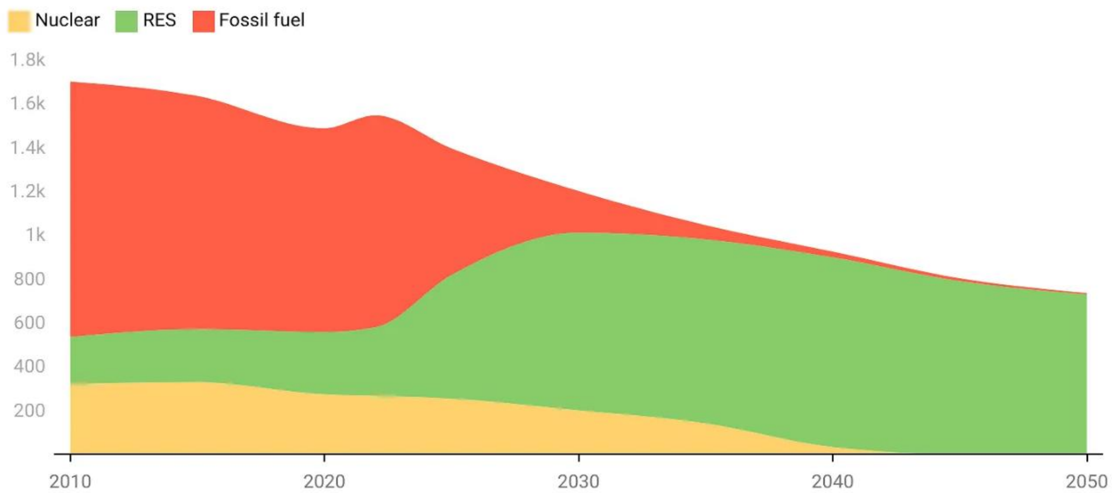
France

France is by far the country with the largest nuclear capacity in the EU. Its fleet of 56 reactors - managed by state-owned Électricité de France (EDF) - accounts for more than half of the total nuclear generation capacity currently installed in EU countries, as shown in Table 1 above (p.10).

In 2023, 65% of French electricity (320 TWh) was provided by its nuclear reactors, the highest share of nuclear generation in the EU.[11] This output was enough to meet around 17% of France's final energy consumption.

Even for France, the PAC scenario results in a decarbonisation path consistent with a complete phase-out of nuclear power. According to the PAC scenario, the last nuclear reactors in France could be shut down in the early 2040s, with production reduced significantly as early as 2035. Figure 12 helps us to understand the projected composition of France's final energy consumption by type of energy source in the PAC scenario.

In the PAC decarbonisation pathway, French nuclear power production decreases to 173 TWh in 2035, 39 TWh in 2040, and is completely phased out immediately thereafter. If the nuclear phase-out were implemented, the decrease in nuclear energy (-320 TWh from 2023) would have been significantly smaller than the increase in the contribution of RES (+646 TWh) and the decrease in final energy consumption (-583 TWh) over the same period, allowing both nuclear power and the vast majority of gas and oil to be phased out by 2040 at the latest.



[11] Most of the analysis in this brief is based on historical data up to 2022, mainly from Eurostat and ENTSO-E energy statistics. However, we prefer to use 2023 data here, as 2022 was characterised by an unusually low output due to the fact that France had to shut down part of its nuclear fleet for both safety and climate reasons.

Figure 12 – Projected composition of the final energy demand in France by type of energy source in the PAC scenario. Source: Eurostat, ENTSO-E, PAC scenario. EEB own elaboration. Created with Datawrapper.

To achieve this, the scale of renewable energy penetration on the supply side and the scale of energy savings on the demand side are key:

(a) Renewables uptake

In the PAC scenario, while electrification progresses rapidly throughout the 2020-2030 period, the French electricity mix becomes increasingly dominated by solar photovoltaic (PV) and wind technologies. Wind capacity in France increases to 27 GW onshore and 30 GW offshore by 2030, reaching a combined output of 167 TWh and accounting for around 29% of the electricity production and 14% of final energy consumption. Solar PV capacity increases from 17 GW in 2022 to 83 GW of generation capacity in 2030, reaching an output of 90 TWh which covers roughly 15% of the electricity production and 8% of final consumption.

Combined, such a deployment of wind and solar technologies could satisfy around **45% of France's electricity mix** and **21% of its final energy consumption in 2030**, as opposed to the projected 41% and 17% represented by nuclear's 239 TWh output.

In the 2030-2040 period, the share of renewables in the energy mix increases even more significantly. The increase is still driven by wind and solar electricity, combined with limited amounts of hydrogen and bioenergy from waste. By 2040, renewables will account for 93% of electricity production and 97% of final energy consumption in France. Over the same period, nuclear energy production decreases more than fivefold to 39 TWh, i.e. 7% of electricity generation, meeting 3.6% of final energy consumption.

It is between 2030 and 2040 that we see the largest reduction in nuclear energy in the PAC scenario. Even in France, to meet future energy needs while phasing out fossil fuels and moving towards carbon neutrality, a strong increase in renewable energy deployment is necessary, even in combination with high rates of electrification of end-use, transport and industrial processes. This is also independent of the production of nuclear energy, which becomes redundant in the PAC scenario and allows for a complete phase-out in the early 2040s.

(b) Energy demand reduction

Focusing on added renewables capacity is just one side of the coin: the reduction in energy demand is equally important to make nuclear generation redundant. As Figure 13 shows, in the PAC scenario, the energy demand in France is sharply reduced, mainly in the period 2020-2040. When considering transport, buildings, industrial combustion, and agriculture, PAC foresees a reduction of France's final energy consumption of roughly 50%.

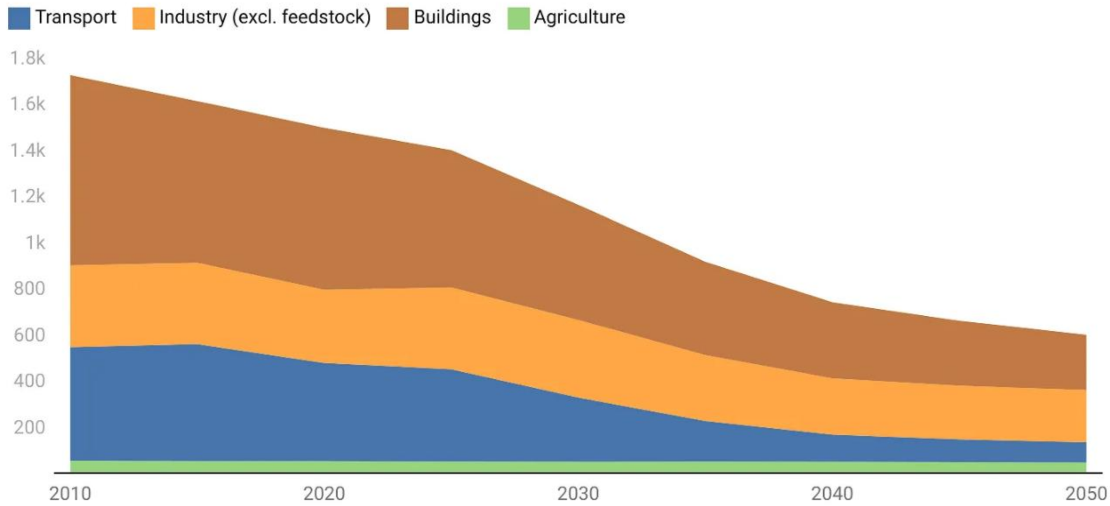


Figure 13 – Final energy consumption (TWh) by sector in France in the PAC scenario. Source: PAC scenario. Created with Datawrapper.

In the PAC scenario, the buildings sector is responsible for almost 50% of the total reduction in final energy consumption in the 2020-2040 period. Thanks to increasing renovation rates (3% per year from 2030 onwards) and the uptake of renewable heating appliances and renewable district heating networks, the energy consumption of the French building stock will be reduced by 371 TWh (from 702 TWh in 2020 to 330 TWh in 2040).

With its 40% share, transport determines another significant share of energy savings in France. Shifts in transport modes – towards cycling, rail – and the uptake of more efficient and cleaner vehicles, as well as increased car-sharing practices, result in an absolute reduction of French transport's energy demand of 308 TWh (from 425 TWh in 2020, down to 116 TWh in 2040).

In the PAC scenario, the total reduction in final energy consumption in France between 2020 and 2040 (-755 TWh) is more than double the required reduction in nuclear power output (-320 TWh).

Belgium

Belgium is somewhat of an emblematic case in the current EU debate on the possibility of the extension of nuclear reactors which are close to retirement. Belgium was one of the pioneers of nuclear power in the EU. Linked to Belgium's colonial past was its access to large uranium reserves discovered in the 1910s in what was then the Belgian Congo. Through its colony, Belgium became one of the main suppliers of uranium to the United States. It was this commercial relationship that gave Belgium access to nuclear technology for energy production. In 2003, however, Belgian lawmakers adopted a phase-out plan proposed in 1999 by the Verhofstadt I Government: no new power plants will be built, and existing reactors will be decommissioned after 40 years of operation.

Operated by Engie's subsidiary Electrabel, the seven reactors at the Doel and Tihange sites have produced 31.4 TWh of electricity in 2023, down 6% from the 41.8 TWh generated in 2022.[12] This was enough to cover 41.3% of the country's generation and around 7% of final energy consumption.

In the PAC scenario, the phase-out of nuclear power in Belgium does not appear challenging from an energy system perspective. As shown in Figure 14, nuclear power production decreases to 15 TWh in 2025 and 12 TWh in 2030 and is completely phased out in 2035. This decrease (-20 TWh between 2023 and 2030) is much smaller than the increase in renewable energy contribution (+127TWh) and the reduction in energy demand (-50 TWh) in 2022-2030 period.

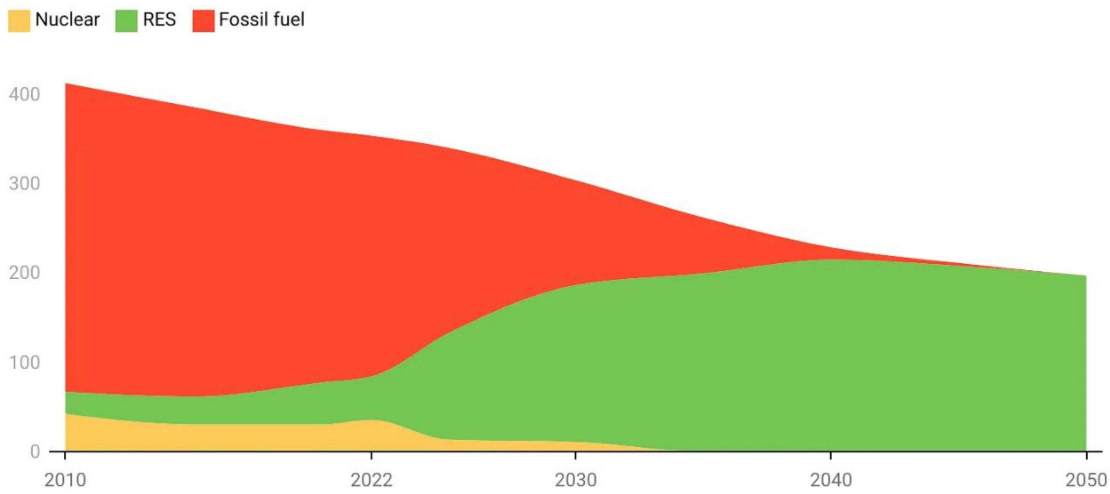


Figure 14 – Projected composition of the final energy demand in Belgium by type of energy source in the PAC scenario. Source: Eurostat, ENTSO-E, PAC scenario. EEB own elaboration. Created with Datawrapper.

(a) Renewables uptake

In the PAC scenario, the growth of renewable energy in Belgium is driven by a significant increase in wind power (both onshore and offshore) and solar PV (especially rooftop PV).

By 2030, wind capacity increases to 4.8 GW onshore and 4.5 GW offshore. This compares to around 3 GW and 2.5 GW for offshore and onshore respectively in 2022. In 2030, wind farms will be able to produce around 27 TWh of electricity, covering 34% of electricity demand. Over the same period, solar PV capacity, driven by building-integrated and rooftop PV in urban and industrial areas, will triple from around 7 GW to 21 GW between 2022 and 2030, capable of meeting around 27% of gross electricity production. Other renewable energy sources, such as geothermal and biomethane and biowaste-fired CHP plants, will contribute a further 5.5 TWh of electricity in 2030. Taken together, renewables will account for 68% of Belgium's electricity mix and 71% of the country's final energy consumption in 2030. In the same year, the remaining nuclear capacity will produce around 12 TWh of electricity, contributing 11% to the electricity mix and 3% to final energy consumption.

By 2040, renewable energy capacity will reach around 6.7 GW of onshore and offshore wind and almost 36 GW of solar PV. With 39 TWh from wind, 35 TWh from solar PV and 6 TWh from other sources, renewables can meet almost 99% of Belgium's electricity demand and 96% of the country's

[12] After the closure of the Doel-3 and Tihange-2 reactors in September 2022 and January 2023 respectively, only five reactors remain in operation in Belgium at the time of writing.

final energy consumption in 2040. Over the same period, the output of nuclear will be reduced from around 12 TWh in 2030 to zero, most likely by 2032-2033, and the remaining reactors will be decommissioned.

(b) Energy demand reduction

In the PAC scenario, Belgium's energy demand is sharply reduced between 2020 and 2040. In this period, the PAC scenario foresees a reduction in Belgium's final energy consumption of about 50% (from 375 TWh in 2020 to 191 TWh in 2040). Figure 15 provides a breakdown of the contribution of each sector to achieving the required energy savings in the period 2020-2040.

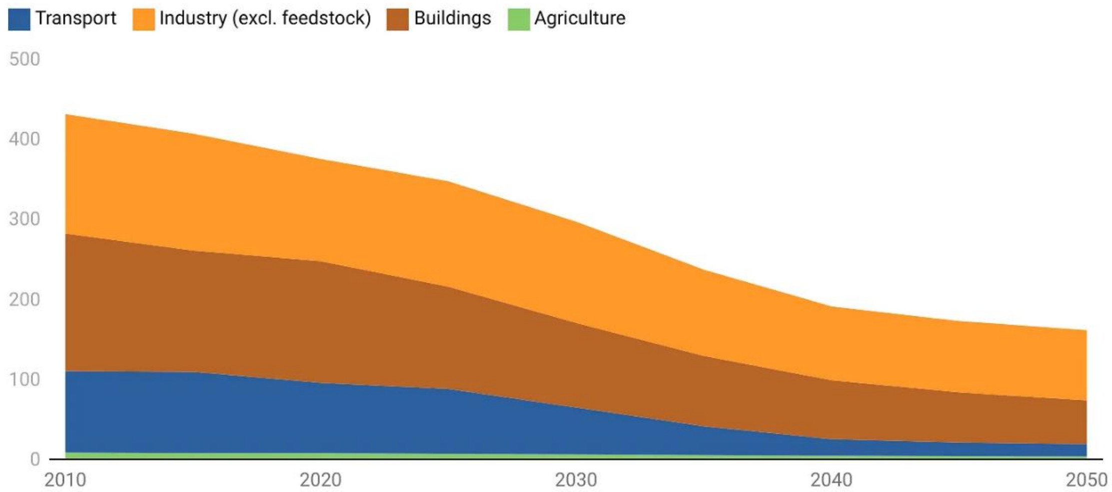


Figure 15 – Final energy consumption (TWh) by sector in Belgium in the PAC scenario. Source: PAC scenario. Created with Datawrapper.

In the PAC scenario, the transport sector is responsible for about 36% of the total reduction of final energy consumption in Belgium in the period 2020-2040. Factors such as the electrification of several modes of transport, reduced demand for passenger air travel, combined with strong growth in cycling (both urban and non-urban) and rail transport, reduce the energy consumption of the transport sector by 76% (from 88 TWh in 2020 to 21 TWh in 2040).

Increased energy efficiency of most appliances (computers, refrigerators, dishwashers), a high penetration rate of electric heat pumps (reaching 58% in the residential sector in 2040) and a moderate but significant penetration (21%) of district heating solutions for space heating in residential buildings. Overall, in the PAC scenario, the energy demand of the buildings sector in Belgium is reduced by about 52% (from 151 TWh in 2020 to 73 TWh in 2040) and accounts for 42% of the total demand reduction between 2020 and 2040.

Industry accounts for 19% of the total reduction of final energy consumption in Belgium between 2020 and 2040. The recycling rates of secondary aluminium and steel reach about 78% and 61% respectively in 2040, while the recycling of plastics is increasingly carried out by chemical rather than mechanical recycling. These are the main factors behind the 35 TWh of energy saved by the industrial sector (excluding feedstocks) in Belgium in 2040 compared to 2020.

In the PAC scenario, the total reduction in final energy consumption in Belgium between 2020 and 2040 (-184 TWh) is more than five times higher than the required reduction in nuclear power production (-32 TWh).

Spain

In the PAC scenario, Spain has one of the smoothest paths to a complete and early nuclear phase-out, largely completed by 2025 and reaching zero in 2030. This is broadly in line with the Spanish government's recently announced nuclear phase-out plan; barring earlier retirements, Spain's current nuclear power plants will be shut down from 2027 to 2035.

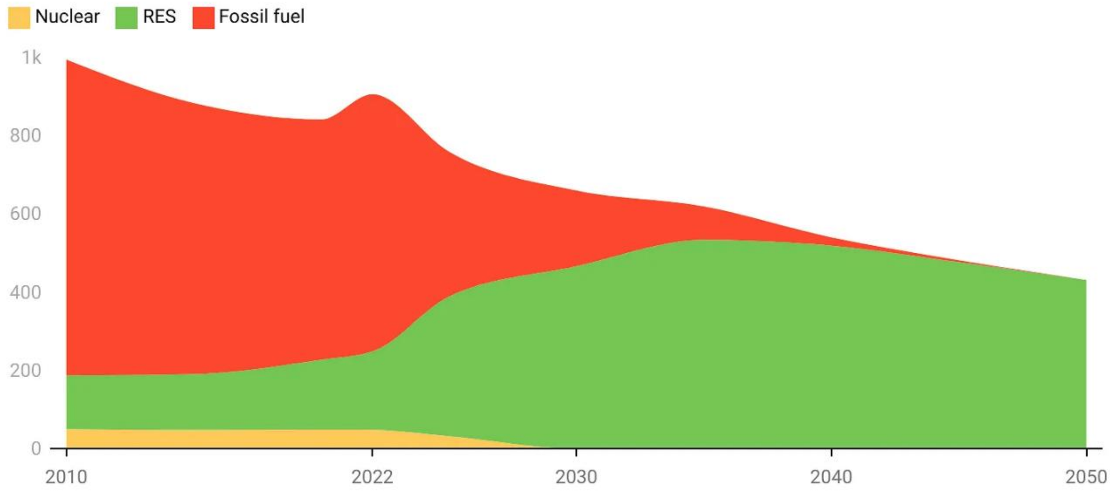


Figure 16 - Projected composition of the final energy demand in Spain by type of energy source in the PAC scenario. Source: Eurostat, ENTSO-E, PAC scenario. EEB own elaboration. Created with Datawrapper.

(a) Renewables uptake

In the PAC scenario, Spain deploys significant new onshore wind and solar PV capacity. By 2030, solar PV capacity in Spain increases to around 82 GW - second only to Germany - producing around 139 TWh. At the same time, onshore wind capacity in Spain will reach 66 GW, capable of producing 141 TWh per year.

While onshore wind and solar PV will meet around 86% of Spain's electricity demand and contribute to around 40% of the country's final energy consumption, other renewable energy sources will also play a role in decarbonising Spain's electricity and energy mix. In 2030, offshore wind, hydro, geothermal, and concentrated solar power (CSP) installations will produce around 39 TWh, providing a further 12% of Spain's electricity demand and 5% of the country's final energy consumption.

In the PAC scenario, the contribution of renewables to the energy mix continues to grow significantly over the period 2020-2040, reaching almost 518 TWh in 2040. This figure completely dwarfs the -55 TWh decrease in nuclear power generation between 2022 (historical data) and 2030, which is the time horizon for the complete phase-out of nuclear capacity in Spain.

(b) Energy demand reduction

In the PAC scenario, Spain's final energy consumption is significantly reduced, especially by 2040. By then, the PAC scenario foresees a reduction in Spain's final energy consumption of more than 55%

(from 838 TWh in 2020 to 370 TWh in 2040). Figure 17 provides an overview of the contribution of each sector to achieving the required energy savings over the period 2020-2040.

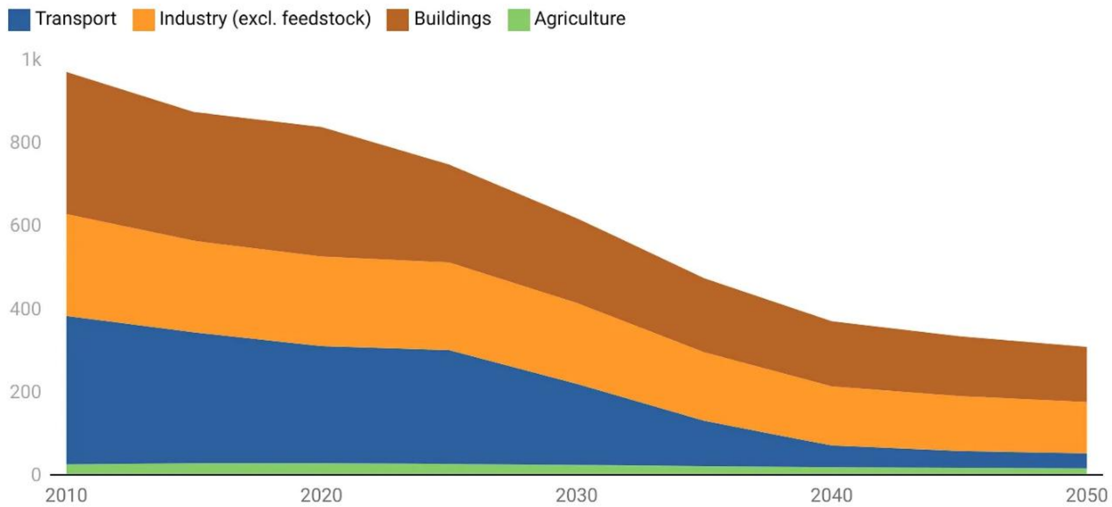


Figure 17 – Final energy consumption (TWh) by sector in Spain in the PAC scenario. Source: PAC scenario. Created with Datawrapper.

In the PAC scenario, the transport sector accounts for almost half (49.1%) of the total reduction in final energy consumption in Spain over the period 2020-2040. Factors such as the electrification of several modes of transport, including vessels (both domestic maritime and inland waterways), combined with higher car and bus occupancy rates, reduce the energy consumption of the transport sector (excluding international aviation and maritime bunkers) by about 229 TWh (from 281 TWh in 2020 to 52 TWh in 2040).

Increased energy efficiency of most appliances (computers, refrigerators, dishwashers), a high penetration rate of electric heat pumps (reaching 75% in the residential segment in 2040) and reduced hot water consumption in commercial buildings are among the drivers of the decreasing energy demand of buildings in Spain. Overall, the energy demand of the buildings sector is reduced by about 154 TWh between 2020 and 2040 (from 312 TWh in 2020 to 157 TWh in 2040).

Industrial production in Spain, which accounts for 17% of the total reduction in final energy consumption, is another important driver of the huge energy savings in the PAC scenario. For example, the increasing recycling rates of secondary aluminium and steel reach around 65% and 90% respectively by 2040. These two factors alone account for 8 TWh of the 73 TWh saved by the industrial sector (excluding primary products) in Spain in 2040 compared to 2020.

In the PAC scenario, the total reduction in final energy consumption in Spain between 2020 and 2035 (-467 TWh) is more than eight times higher than the required reduction in nuclear power output (-55 TWh).

Slovakia

In the PAC scenario, Slovakia has a relatively stable production of nuclear energy (12-13 TWh per year) from now until 2030, contributing to a low share of the country's final energy consumption - around 11%. From 2030, nuclear power production falls sharply to 3.9 TWh in 2035, allowing for a comfortable phase-out by 2040. This reasonably implies an early phase-out of the Mochovce-3 plant, which has a stated life expectancy of 60 years.

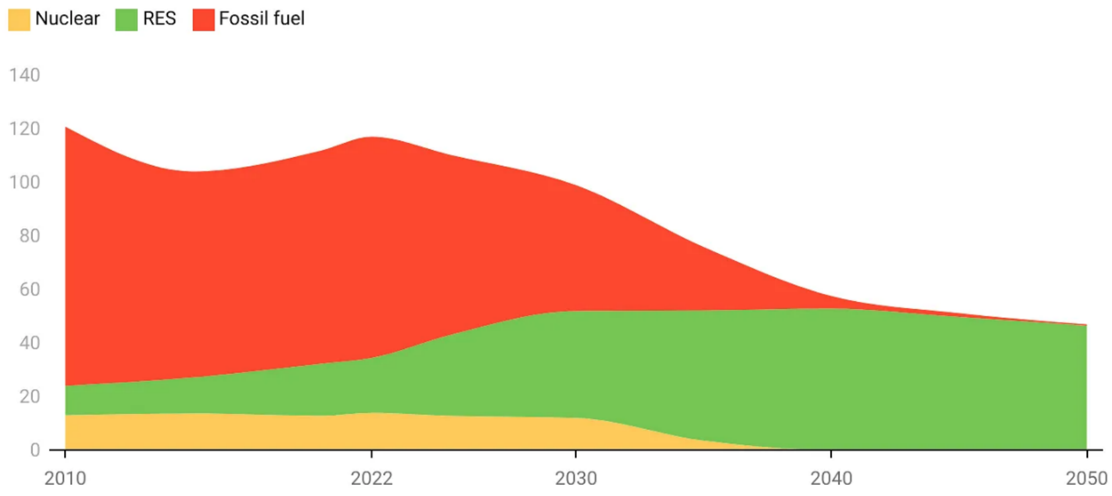


Figure 18 – Projected composition of the final energy demand in Slovakia by type of energy source in the PAC scenario. Source: Eurostat, ENTSO-E, PAC scenario. EEB own elaboration. Created with Datawrapper.

(a) Renewables uptake

In the PAC scenario, Slovakia sees a moderate uptake of solar PV and onshore wind generation before 2030. Thereafter, both technologies experience significantly higher deployment rates. The total capacity reached in 2035 is around 5.5 GW for onshore wind and 11 GW for solar PV. Hydropower capacity remains relatively stable until 2040 (around 2.5 GW), with only small increases due to repowering. Together, these three technologies will provide almost 27 TWh of electricity in 2035, representing 75% of the country's electricity and 56% of its final energy consumption.

Between 2030 and 2040, the share of renewables in the energy mix increases even further. In 2040, renewables account for 98% of electricity production and 96% of final energy consumption in Slovakia. Over the same period, nuclear power production falls from 14 TWh (2023 historical value), or 12% of the country's final energy consumption, to zero, allowing the closure of the nuclear reactors that will then be redundant.

(b) Energy demand reduction

In the PAC scenario, the energy demand in Slovakia is more than halved between 2020 and 2040. The PAC scenario foresees a reduction of the country's final energy consumption of roughly 57% (from 109 TWh in 2020 to 46 TWh in 2040), as shown in Figure 19 below.

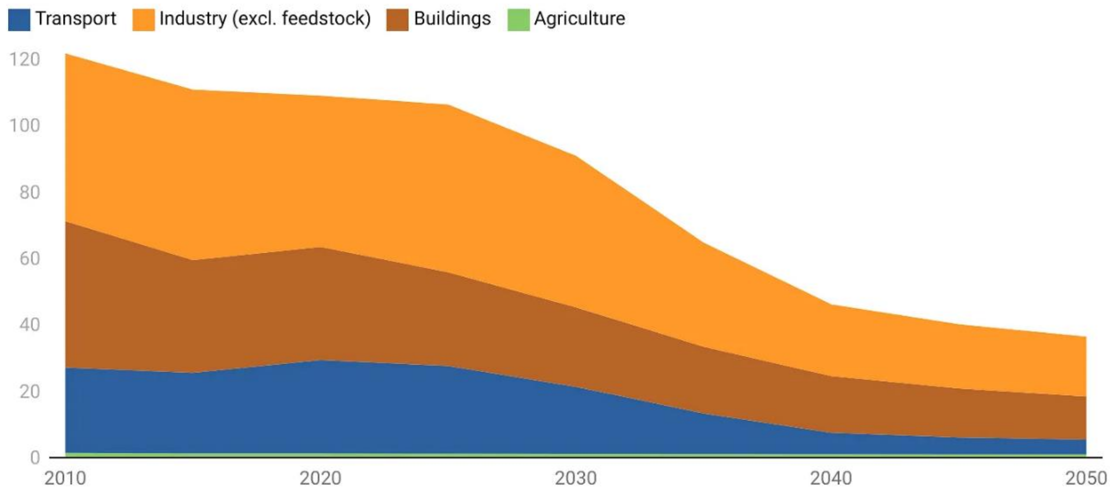


Figure 19 – Final energy consumption (TWh) by sector in Slovakia in the PAC scenario. Source: PAC scenario. Created with Datawrapper.

In the PAC scenario, the reduction in energy consumption in the industrial sector is more pronounced in Slovakia than in other EU countries. The energy consumption of the industrial sector (excluding feedstocks) decreases from 45 TWh in 2020 to 21 TWh in 2040, accounting for more than 38% of the total reduction over this period. Lower demand for plastic-based packaging and reduced fertiliser use in the agriculture sector are among the driving forces behind this reduction.

The transport sector is responsible for another significant share (34%) of the total reduction in final energy consumption in the period 2020-2040. The energy consumption of transport in Slovakia will be reduced from 28 TWh in 2020 to 6 TWh in 2040, due to the increased use of trains and buses for non-urban transport, reduced demand for inland freight transport, and more efficient electric motors.

The use of district heating solutions for space and water heating, reaching around 40% in residential buildings and 9% in commercial buildings by 2040, and the robust penetration of heat pumps and electric cookers are among the factors that allow the building sector in Slovakia to save around 17 TWh by 2040 compared to 2020, accounting for 27% of the demand reduction.

In the PAC scenario, the total reduction in final energy consumption in Slovakia between 2020 and 2040 (-62 TWh) is almost five times higher than the required reduction in nuclear power output, -14 TWh compared to 2023 historical data.

Finland

In the PAC scenario, Finland has a relatively stable production of nuclear energy now until 2030, contributing to a relatively low share of the country's final energy consumption – 6 to 8%. After 2030, nuclear power generation declines sharply, reaching 8.3 TWh in 2035 and leading to a complete phase-out by 2040. As in the case of Slovakia, this reasonably implies an early phase-out of the Olkiluoto-3 plant, which has a stated life expectancy of 60 years.

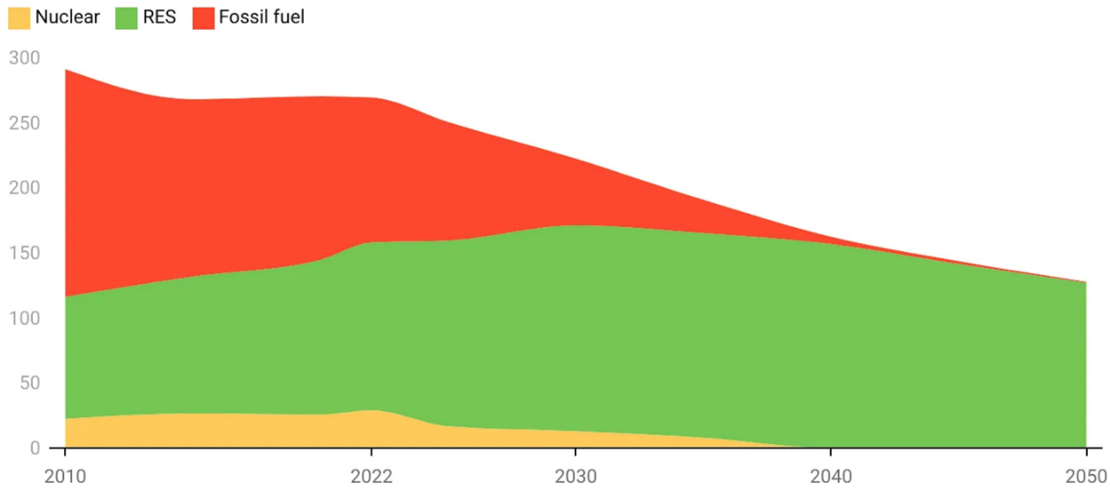


Figure 20 – Projected composition of the final energy demand in Finland by type of energy source in the PAC scenario. Source: Eurostat, ENTSO-E, PAC scenario. EEB own elaboration. Created with Datawrapper.

(a) Renewables uptake

In the PAC scenario, the growth of renewable energy in Finland is driven by a significant increase in wind power, with large potential for onshore wind installations especially in the North of the country.

By 2030, wind capacity increases to around 7 GW onshore and 4 GW offshore. This compares to around 2 GW and 1 GW for onshore and offshore respectively in 2022. In 2030, wind farms will be able to produce around 33 TWh of electricity, covering 40% of electricity demand. Over the same period, solar PV capacity in Finland will quadruple from around 1 GW to 4 GW between 2022 and 2030 but will only become capable of meeting around 3% of gross electricity production in 2030 due to the low level of solar irradiation throughout the country. Other renewable energy sources, such as geothermal and hydropower plants, will contribute a further 22 TWh, or 26%, of electricity in 2030. Taken together, renewables will account for 79% of Finland's electricity mix and 71% of the country's final energy consumption in 2030. In the same year, the remaining nuclear capacity will produce around 13 TWh of electricity, contributing 14% to the electricity mix and 6% to final energy consumption.

By 2040, renewable energy capacity will reach around 21.5 GW of onshore and offshore wind combined and around 8 GW of solar PV. With around 66 TWh from wind, 5 TWh from solar PV and 26 TWh from other sources, renewables can meet 100% of Finland’s electricity demand and 97% of the country's final energy consumption in 2040. Over the same period, the output of nuclear will be reduced from around 13 TWh in 2030 to 8.32 TWh in 2035, reaching zero in 2040 when it will be possible for the Olkiluoto-3 reactor to be decommissioned.

(b) Energy demand reduction

In the PAC scenario, Finland's energy demand is almost halved between 2020 and 2040: from 237 TWh in 2020 to 121 TWh in 2040. While buildings and transport account for a significant share of the total reduction, it is industrial processes that show the greatest potential for energy savings in Finland between 2020 and 2040, as shown in Figure 21 below.

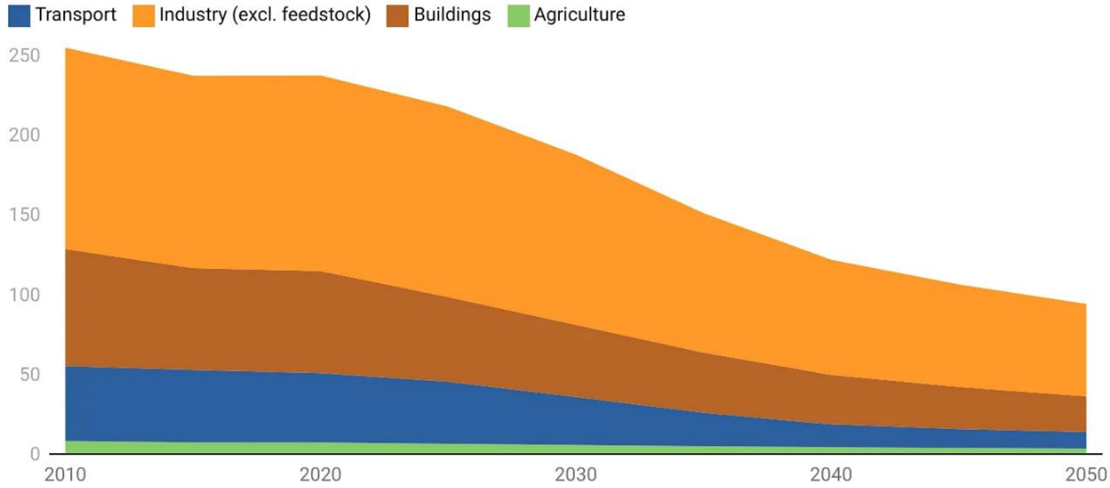


Figure 21 – Final energy consumption (TWh) by sector in Finland in the PAC scenario. Source: PAC scenario. Created with Datawrapper.

In the PAC scenario, the industrial sector - including combustion processes and excluding feedstocks- accounts for almost half (47%) of the total energy demand reduction in Finland between 2020 and 2040. This contrasts somewhat with the pathways of other EU countries, where transport and buildings tend to have a larger reduction margin compared to industry. High recycling rates for secondary chemical olefins (up to 43%) and paper (up to 76%), coupled with a shift towards electricity-based production processes for wood (33%) and paper (53%), are the main drivers of this transition in the PAC scenario up to 2040. Thanks to these factors, Finland's industrial energy consumption will decrease from 122 TWh to 72 TWh between 2020 and 2040, making it the primary contributor to the country's energy demand reduction.

The transport sector is responsible for about 25% of the total reduction of final energy consumption in Finland in the period 2020-2040. Factors such as the electrification of several modes of transport, reduced demand for passenger air travel, combined with the uptake of some e-fuels to power inland vessels navigation, reduce the energy consumption of the transport sector by 67%, from 43 TWh in 2020 to 14 TWh in 2040.

Increased energy efficiency of most appliances (computers, refrigerators, dishwashers), a high penetration rate of electric heat pumps (reaching between 60 and 77% in the residential sector in 2040) and a moderate but significant penetration (38%) of district heating solutions for space heating in residential buildings. Overall, in the PAC scenario, the energy demand of the buildings sector in Finland is reduced by about 49%, from 237 TWh in 2020 to 121 TWh in 2040.

In the PAC scenario, the total reduction in Finland's final energy consumption between 2020 and 2040 (-115 TWh) is exactly five times higher than the required reduction in nuclear power production, -23 TWh from 2022 based on historical data.

Conclusions and way forward

1. **The contribution of nuclear to the EU's energy needs is small: Although it accounts for** a significant share of today's electricity generation in a few EU countries, nuclear energy in the EU represents a small fraction of the bloc's final energy consumption (4.7%), even if we focus only on the subset of EU countries that have nuclear power plants (10.1% in total).
2. **Nuclear power production continues to decline:** Nuclear generation in the EU relies on an ageing fleet, with an average age of around 40 years, and has been in steady decline since the early 2000s. Most of the currently operating capacity is expected to close by 2040, while only two reactors have come online since 2010. The PAC scenario assumes a 40-year lifetime for nuclear power plants: retiring a significant proportion of EU reactors by 2040 is consistent with a climate-compatible path that limits global warming to 1.5 degrees by 2100.
3. **The suitability of nuclear in an evolving energy system is uncertain**: While nuclear generation is sometimes touted as a necessary baseload or back-up provider to cope with the variable patterns of renewables, the inflexibility of nuclear plants and the already good stability of renewables generation means that nuclear may not be needed at all to balance the grid. Optimising the penetration of renewables through a mix of grid expansion/modernisation, deployment of storage and flexibility resources, and enabling demand-side response are estimated to be the most cost-effective option to ensure the stability of the electricity system while achieving climate neutrality.
4. **Renewables and energy savings can replace both nuclear and fossil fuels**: The magnitude of the projected changes in energy demand and renewable energy production needed by 2030 and 2040 far outweighs the current and potential contribution of nuclear energy to meeting the EU's decarbonisation targets and ensuring the stability of Europe's energy system. Considering EU countries with installed nuclear capacity, when compared to 2022:
   (a) By 2030, the 220 TWh reduction in nuclear generation required is more than offset by an increase in renewable energy penetration and significant energy savings. In the EU nuclear countries, PAC leads to an increase of 1000 TWh and a reduction in final energy consumption of 1057 TWh. Between 2022 and 2030, the combined effect of energy savings and renewables is almost 10 times greater than the reduction in nuclear power.
   (b) By 2040, an increase in renewable energy generation of 960 TWh and a reduction in energy consumption of 916 TWh will more than compensate the additional reduction of 326 TWh needed to bring nuclear generation to zero in the EU nucelar countries. Following the 2022-2030 trend, between 2030 and 2040, energy savings and renewables dwarf the lost nuclear production by more than five times.

   The combination of a significant increase in renewable energy production and a sharp reduction in energy consumption can therefore make nuclear energy in the EU arguably unnecessary and allow its gradual phase-out by 2040, based on safe technical lifetimes.
5. **A strong increase in renewable energy use and decrease in energy consumption is imperative now**: across all EU countries, regardless of the evolution of nuclear capacity. Even if current nuclear capacities are extended in the short to medium term, the role of nuclear energy in the EU energy mix, including countries with nuclear reactors, will remain small and declining.

Investments in nuclear extensions may contribute too little and too late to the EU's transition away from fossil fuels.

6. **Competition with the wider energy transition must be avoided:** Prioritising nuclear power risks diverting crucial resources and political attention away from more cost-effective and timely solutions. Therefore, any potential investment or policy support for the nuclear fleet should be carefully weighed against the opportunity to invest heavily in renewables, flexibility and energy savings. Significant financial resources will also be necessary to ensure a just transition, community involvement and the increase of citizens' disposable income.

Nuclear power has captured the imagination of many Europeans for decades, and political interest in nuclear energy has increased sharply in the last twelve months. Despite its role in Europe's energy history, the contribution and importance of nuclear power is currently declining, and **its 'renaissance' seems increasingly unrealistic**. The long lead times and high construction costs associated with new reactors are the two main arguments that make nuclear power economically uncompetitive with renewables in the race towards climate neutrality. There is no evidence that the cost advantages of renewables will change in the future. On the contrary, renewables are getting cheaper every year, which is not the case for nuclear projects. High levels of public subsidies would be required to make nuclear generation viable, raising questions about the **wise use of limited public funds**. Given the constraints on public finances, there is a risk that spending billions of euros on nuclear power would reduce funding for essential and more cost-effective renewables or energy efficiency measures. Subsidising **nuclear power could actually undermine progress** on climate change mitigation and adaptation.

Arguments about the safety of nuclear power plants, given their operational characteristics, vulnerability to climate change, and responsibility for nuclear waste management, further weaken any pro-new nuclear arguments.

As the nuclear reactors currently operating in the EU reach the end of their technical lifetimes, the debate on whether to extend their operation inevitably comes to the fore. Here, the economics are different from those of new projects. The key questions are instead whether and to what extent such extensions **contribute meaningfully to future emission reductions** and can life extensions be implemented **safely and in a cost-effective way.**

Based on the updated PAC scenario, this report shows that **phasing out nuclear power in the EU is feasible**. Sensible allocation of limited public funds can enable a decisive shift towards a more flexible and decentralised energy system, powered by cheaper and faster-to-deploy renewables. Achieving robust energy savings as well as enabling circularity and more sustainable lifestyles is also possible. The key lies in political will.

Further information

This report was prepared by the European Environmental Bureau (EEB) in the framework of the **Paris Agreement Compatible Scenarios for Energy Infrastructure (PAC) project**. The PAC project was launched in November 2018 and completed its first phase in June 2020 – with the support by the German Federal Ministry of Economics and Energy (BMWi), now known as the Federal Ministry for Economic Affairs and Climate Action (BMWK). The PAC consortium includes the EEB, Climate Action Network (CAN) Europe, the Renewables Grid Initiative (RGI) and REN21.

The second phase of the project, running from September 2021 to August 2024, is implemented by the same consortium and supported by the same donor. CAN Europe is leading the development of the new PAC Scenario 2.0, run by professional modellers from CLIMACT, while maintaining the key assumptions of the first phase. The infrastructure analysis of PAC 2.0 focuses on achieving a 100% renewable energy system in the EU27 using specialised software, including Pathways Explorer and Python for Power Systems Analysis (PyPSA). PyPSA optimises the supply side based on costs, while demand assumptions are derived from Pathways Explorer.

In addition to the EU-27 level data, country-specific PAC scenarios are also **available on the Pathways Explorer** platform under an open licence, facilitating data sharing and adaptation. EEB members and civil society organisations can easily access relevant data for their activities.
In preparing this report, we have carried out extensive calculations using the updated PAC figures from Pathways Explorer, including recalibrating final energy consumption figures based on historical data from Eurostat energy statistics and ENTSO-E electricity statistics. In the future, we would like to extend our analysis to include data from PyPSA and explore the implications of the PAC scenario in terms of the investments and public policies needed to facilitate the accelerated deployment of renewables, dramatic energy savings and the phase-out of fossil fuels and nuclear energy in the EU.

The authors gratefully acknowledge Stephane Arditi, Patrick ten Brink, Elena Fazio, Riccardo Nigro, Davide Sabbadin (EEB); Almut Bonhage (Bond Beter Leefmilieu); Joni Karjalainen, Thomas Lewis, Dimitris Tsekeris (CAN Europe); Lorelei Limousin, Jan Haverkamp (Greenpeace Europe); Bram Claeys (Regulatory Assistance Project); Andrzej Ceglarz, Morjana Moreira dos Anjos, Alexandros Fakas Kakouris (RGI) for their invaluable input and feedback on this report. The responsibility for the content and any remaining errors remains exclusively with the authors.

Contact details

Cosimo TANSINI - Policy Officer for Renewable Energy
cosimo.tansini@eeb.org

Luke HAYWOOD - Policy Manager for Climate and Energy
luke.haywood@eeb.org

EEB
European
Environmental
Bureau

PAC
Paris Agreement Compatible
Scenarios for Energy Infrastructure

Supported by:

Federal Ministry
for Economic Affairs
and Climate Action

on the basis of a decision
by the German Bundestag