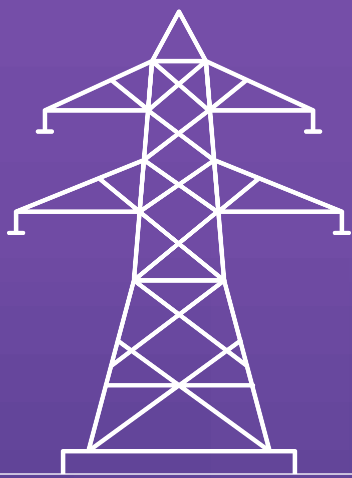
How Europe's grid operators are preparing for the energy transition



A snapshot of electricity transmission system operator practices and plans

May 2025

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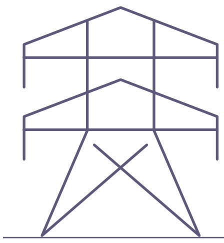
1

Key Findings & Recommendations

Europe's electricity grids will be the lifeline that drives economic growth and ensures energy security over the next decade. Yet, at present, many grid operators are heading into the future while looking in the rear-view mirror.



Transmission System Operators (TSOs) are responsible for planning, building, and operating high-voltage grids.

Ensuring that TSOs are aligning their long-term plans to achieve a fossil free renewables-based power system by 2035 will be a critical milestone in the successful decarbonisation of Europe's economy; supporting lower energy costs and the electrification of key sectors.

At the same time, the regulatory landscape needs updating to reflect new demands and realities, including better governance over the actions and investments of TSOs.

Beyond Fossil Fuels, Ember, E3G and the Institute for Energy Economics and Financial Analysis (IEEFA) investigated 32 electricity TSOs across 28 European countries to gain an insight into how they are planning for and facilitating the clean energy transition.

Key takeaways:

Grids remain a major bottleneck to growth in the clean economy.

Despite power grids remaining high on the political agenda, the scale of the challenge is immense. A conservative estimate suggests that as of 2024-2025, there were 1,700 GW of renewable energy and hybrid projects waiting for grid connections across 16 countries.[1] These projects represent billions of euros worth of investment being held back, thus hampering Europe's economic growth. Meanwhile, there are eye-watering costs associated with renewables curtailment: a total of €7.2 billion in 2024 across just seven countries.

A lack of long-term vision is hampering progress.

TSOs are in many cases being obliged to use outdated national energy plans to prepare for the future. These do not reflect exponential market growth in renewables, and can therefore hold back the level of anticipatory investment and foresight needed to integrate renewables and storage. This risks creating a self-fulfilling prophecy where gas is 'needed' for longer.

The prize is within reach, with pockets of good practice showing feasibility.

Across all areas, there is good practice on display across Europe. Were all of it combined into one TSO, it would provide a nearly perfect model. This shows that a rapid diffusion of good practices, driven by political leadership, will be key.

More robust governance and oversight is necessary to ensure TSOs are delivering.

Grid investments will be central to Europe's future security and competitiveness. Yet levels of independent oversight and transparency regarding their planning is generally low. More robust, fully independent system planning can help ensure value for money and effective delivery.

Key findings:

Grid operations

Significant queues of solar, wind and storage projects waiting for grid connections have built up across Europe. In fact, the volume of renewable energy projects waiting to connect far outstrips the additional installation required to reach 2030 national energy and climate plan targets. These queues are exacerbated by widespread use of outdated connection processes, which enable 'zombie' projects to join the line. Meanwhile, high levels of curtailment of renewable energy demonstrates the need for more investment in clean flexibility and improved grid balancing, with a need to mainstream demand side response, and rapidly build-out energy storage.

Grid planning

Of those we studied, only five TSOs are currently considering long-term scenarios aligned with a decarbonised power system by 2035. The vast majority of TSOs base their plans on national policies and targets that still assume significant fossil gas plant capacity by 2035. This risks a 'self fulfilling prophecy' in which the opportunity for faster action to phase out fossil fuels—where grid operators support a much quicker build-out of renewables and flexibility—gets missed. Our research highlights the need for stronger political leadership in the form of government commitments to clean power by 2035, as well as the inclusion of more ambitious scenarios from TSOs.

Finance

TSOs generally raise finance via either private and diversified markets, or via public investments. Given the costs associated with upgrading the grid, TSOs that are able to draw on commensurate sources of capital will be best positioned. 14 of the 23 TSOs we focused on in financial analysis are rated investment-grade by leading credit rating agencies, which could help increase their ability to raise capital. Meanwhile 11 have issued green bonds that have received third party review.

Governance and politics

Our research found that more can be done to bolster the independence of grid operators to ensure TSOs are acting in the public interest by limiting the potential for conflicts of interest. 11 TSOs operate under the minimum form of legal ownership "unbundling" (meaning the TSO is still part of a portfolio of companies involved in generating or selling electricity). Many TSOs and energy regulators are yet to reference the climate crisis among their responsibilities, with just 13 of the TSOs having any form of commitments or targets on climate. Among the countries studied, the UK is showing leadership with its new, fully independent energy system operator and corresponding 'net zero' duty for its energy regulator.

Key recommendations:

1

Governments should revise the legal mandates of energy regulators and TSOs to ensure these are consistent with delivering climate targets, allowing the long-term foresight needed to deliver clean power* by 2035. This will help TSOs ensure their plans support the build-out of a fossil free, renewables-based power system and electrified economy; with anticipatory investments to underpin delivery. In turn, energy regulators will be enabled to better scrutinise the adequacy of grid plans and proposed investments, ensuring measures are fair and efficient.

2

Governments should increase governance and oversight by establishing fully independent public bodies to undertake grid planning: This can ensure that grid operators are acting in the best public interest, while ensuring high levels of strategic oversight in designing and operating the future energy system.

3

TSOs should employ best practices to support the integration of renewable and storage projects: This includes working with governments to improve grid connection processes to end the phenomenon of 'zombie' projects, incentivising and enabling demand flexibility, and rolling out innovative solutions that allow best use of the existing grid, such as dynamic line rating.

*See page 10 for our definition of clean power.

2 Glossary

Ancillary services: services procured by TSOs from power market participants, such as voltage control, load-frequency control and power system restoration. Market mechanisms used to procure these services are called ancillary services markets.

Clean flexibility: a set of fossil-free technologies that can complement variable energy technologies, such as wind and solar, by exporting power to the grid in times of shortfall or storing it when there is an excess. Technologies include demand-side flexibility and energy storage. We use this term interchangeably with the term 'fossil-free flexibility'. In this report, we do not use 'clean flexibility' to refer to fossil-based technologies like gas power with carbon capture and storage (CCS) or hydrogen power.

Curtailment: the forced reduction of renewable power generation below its potential output, usually due to grid constraints and the need to retain balance between supply and demand.

Demand-side flexibility: the ability of households and businesses to shift the time that they use electricity to reduce demand at peak moments (i.e. hours of high consumption) and increase demand when there is a surplus of supply.

Dynamic line rating: a method using forecasting data to measure the maximum power flow that a grid line is capable of supporting with the aim of increasing the capacity of the line.

Hybrid projects: a combination of renewable energy and storage technologies developed at the same location.

Interconnectors: high voltage power cables that connect the power systems of neighbouring countries, allowing power to be traded across borders.

Long duration energy storage: a broad term that generally refers to energy storage technologies capable of discharging for a minimum duration, ranging from 6 to 10 hours.

Non-firm connections: a type of contract between a power producer and a grid operator whereby the power producer agrees to limit their ability to export power to the grid under certain conditions.

Open-source energy model: an energy model that uses publicly available source code. It can also mean that the input data is freely available, but we did not consider data availability in the context of this project.

Non-synchronous generation: renewables such as wind turbines and solar PV panels are considered non-synchronous because they do not all rotate at the same frequency (or in the case of solar do not rotate at all). This can have implications for grid stability because grid frequency is determined by how fast generators spin.

System non-synchronous penetration: a measure of the non-synchronous generation (namely, wind and solar) in the system at any moment in time.

'Zombie' projects: Speculative energy projects in the queue for grid connections, which add to the length of the queue but are unlikely to ever be built.

National Energy and Climate Plan: 10-year plans where EU Member States outline their strategies, policies, and measures to achieve their energy and climate targets, as required by the Governance Regulation on the Energy Union and Climate Action.

3

Introduction and background

Affordable and reliable electricity will be key for achieving Europe's political objectives of economic growth and energy security.

A modern, efficient and resilient electricity grid will enable the continent to become more self-sufficient, reaping the full benefits of the region's renewable potential, while helping to keep energy costs stable and insulated from the volatility of international gas markets.

Europe's electricity grids were designed in the fossil fuel era: a time before the exponential increase in renewable energy projects, the widespread electrification of industry, homes and transport, and the corresponding imperative to roll-out clean flexibility solutions in order to smoothly manage a clean power system. Power grids have been failing to keep up with the pace of change that has been seen in recent years.

Electricity systems are set to undergo even quicker and deeper changes in supply and demand over the coming decade. EU power demand has been predicted to rise by up to 40% between 2023 and 2035.[2] Meanwhile, Europe must quickly replace fossil fuels with renewable energy sources in order to keep climate targets within reach. Grid operators already play a critical role in enabling the rapid expansion of renewables and electrification. A new approach to system operations is now needed to support a flexible, resilient and affordable power system, underpinned by action from energy regulators and governments.

Electricity Transmission System Operators (TSOs) are responsible for planning, building, and operating transmission grids.[3] Ensuring that TSOs are aligning their operations, long-term plans and investment with the needs of the future power system is essential. This will require the right political conditions to be set by governments, as well as robust governance processes to ensure an independent, equitable and cost-effective approach.

Defining "clean power"

In this report, "clean power" is used to refer to a fossil-free, renewables-based power system, with solar and wind power providing the majority of generation. The International Energy Agency (IEA) has stated that European countries must decarbonise their electricity sectors by 2035 to play their part in keeping global temperature rise to 1.5°C.[4]

Achieving a clean power system by 2035 represents a critical milestone in the successful decarbonisation of Europe's economy and the electrification of key sectors (i.e. transport, buildings and industry). Upgrading Europe's grid infrastructure will be key to enabling clean energy projects to connect, and thus securely integrate renewable energy into the power system.

This will be complemented by fossil-free, clean flexibility solutions which reduce and shift energy consumption, and store renewable energy to be used when needed. This includes different forms of energy storage, interconnectors, as well as demand flexibility across industry and households. We do not include fossil-based 'flexibility' technologies, such as fossil gas combined with carbon capture and storage (CCS), or hydrogen produced from fossil gas combined with CCS, as these keep us locked into volatile fossil markets and have significant climate impact. New nuclear projects are not included as a credible option to decarbonise electricity further due to issues associated with costs and delays, and furthermore, they cannot provide clean flexibility.

The future power system needs to be fairer, more efficient and smarter than the one we have today. This means a fairer distribution of costs and benefits; ensuring right-sized infrastructure, while supporting economy-wide electrification; and greater digitalisation to enable smarter and more flexible solutions.

There are over 30 electricity TSOs across the EU, the UK, Switzerland and Norway. Most countries have one, but Germany has four and Austria has two. The report provides a summary of how TSOs perform in key areas, although limitations in data collection and transparency means there are significant data gaps (see methodology). Of the 32 TSOs we asked to complete a survey, only eight provided responses. Data available online was often limited and in differing formats. Nonetheless, based on our analysis, we identified trends and best practice examples to showcase how some TSOs are already leading the way.

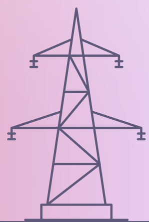


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Figure 1: European countries and TSOs included in the study

Country	TSO
AT Austria	Austrian Power Grid AG (APG)
	Vorarlberger Übertragungsnetz GmbH
BE Belgium	Elia System Operator SA
BG Bulgaria	Electroenergien Sistemen Operator EAD (Електроенергиен системен оператор) (ESO)
HR Croatia	HOPS d.d.
CY Cyprus	Cyprus Transmission System Operator
CZ Czechia	ČEPS a.s.
DE Germany	TransnetBW GmbH
	TenneT TSO GmbH
	Amprion GmbH
	50Hertz Transmission GmbH
DK Denmark	Energinet
EE Estonia	Elering AS
EL Greece	Independent Power Transmission Operator S.A. (IPTO)
ES Spain	Red Eléctrica de España S.A. (REE)
FI Finland	Fingrid Oyj
FR France	Réseau de Transport d'Electricité (RTE)
HU Hungary	MAVIR Magyar Villamosenergia-ipari Átviteli Rendszerirányító Zártkörűen Működő Részvénytársaság (MAVIR)
IE Ireland	Eirgrid plc
IT Italy	TERNA SpA
LV Latvia	AS Augstsprieguma tīkls (AST)
LT Lithuania	Litgrid AB
LU Luxembourg	Creos Luxembourg S.A.
NL Netherlands	TenneT TSO B.V.
NO Norway	Statnett SF
PL Poland	Polskie Sieci Elektroenergetyczne S.A. (PSE)
PT Portugal	Rede Eléctrica Nacional, S.A. (REN)
RO Romania	C.N. Transelectrica S.A.
SK Slovakia	Slovenská elektrizačná prenosová sústava, a.s. (SEPS)
SI Slovenia	ELES, d.o.o.
SE Sweden	Svenska Kraftnät
GB Great Britain	National Grid is a Transmission Operator. The National Energy System Operator is the system planner and operator.

The report provides a summary of how TSOs perform in key areas.

4

Methodology

Beyond Fossil Fuels, Ember, E3G and IEEFA developed the research methodology by first identifying important areas to examine in order to assess how TSOs are adapting their practices and plans for the clean energy transition. The objective of the research was to better understand how TSOs are preparing for that transition, to observe trends and themes influencing their approach, and to identify and showcase best practices.

We drew up a list of data points that would help monitor the role of TSOs in categories relating to grid operations, grid plans, finance, politics and governance. This list is available in Appendix 1, alongside the data available for different variables. The research was then undertaken in two phases. First, desk-based research identified the information available, with the raw data entered into a database (available on request). This was then complemented by a second phase, undertaken via surveying and engaging with TSOs.

While some data points were readily available online—mainly relating to governance and politics—others were more challenging to find. Certain critical information was particularly hard to source, such as the amount of non-thermal flexible resources TSOs could draw on to balance the grid, and whether there is a technical limit to the amount of renewables the system can integrate. This was due in part to TSOs not yet collecting this data, as well as a lack of transparency.

Beyond Fossil Fuels sent out a survey to 32 TSOs to collect outstanding information. However, the response rate was low, with just eight TSOs (Litgrid, National Grid, TSO Cyprus, Fingrid, RTE, Elia, MAVIR, Energinet and PSE) providing a full or partial response. We also provided the TSOs an opportunity to provide feedback on our desk-based findings and analysis; only seven came back with comments.

We have sought to standardise the data, although this was not feasible in all cases. TSOs operate in different regulatory regimes with different approaches to financing, and thus like-for-like comparisons were not always possible.

The objective of the research was to better understand how TSOs are preparing for the transition to clean energy.

32

TSOs were surveyed

5

Grid Operations

Unlocking Europe's enormous potential for home-grown renewable energy will be vital to support energy security.

Alongside providing for the rapid electrification of our homes, industries and transport; developing this capacity will make it possible for Europe to decouple itself from the volatile fossil fuel markets which drove the last energy crisis. Supported by government policies, TSOs will play an essential role in facilitating the rapid integration of clean energy projects through robust grid connection processes, while ensuring that operational practices reflect the needs of a secure, fossil-free system.

The smooth integration of renewables will require smart solutions to deal with seasonal, as well as daily, changes in supply and demand. This may differ across countries; for example, colder countries with electric heating will see winter spikes, whereas air conditioning units in warmer regions could be a significant factor. Nonetheless, in each case a number of 'no regrets' solutions stand out—namely interconnectors, storage, demand flexibility and smart system management.[5] Each of these can help reduce costs while ensuring system reliability.

Our research sought to identify the extent of grid connection queues, as well as the connection processes used by TSOs. We looked into levels of annual renewables curtailment, and the costs associated with this. We investigated whether TSOs are deploying solutions that can help the smooth integration of clean energy projects, including by offering non-firm grid connections, use of dynamic line rating, and interconnectors. Finally, we sought to understand the maximum percentage of renewable sources that different TSOs are able to operate, and whether any self-imposed limits are in place which could hamper the roll-out of renewables.

Our research illustrates that while some TSOs are implementing useful measures, many are struggling with the challenge – with long queues of projects waiting to connect to the grid, and insufficient

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storage and demand flexibility in place to efficiently run a renewables-based energy system. In fact, the volume of renewable projects currently waiting in queues already outstrips the additional installation required to reach 2030 National Energy and Climate Plan targets (561 GW wind and solar combined between 2024 and 2030). Nonetheless, pockets of good practice can be a source of inspiration for further action across Europe.

Dealing with grid connection issues: cutting the queue for renewables

Long waiting times faced by renewable projects for securing grid connections is a well-documented problem that is slowing down the clean power transition.[6] This is compounded by a lack of rigorous grid connection processes, which mean that queues can be artificially inflated by 'zombie' projects (submitted by speculative developers), as well as projects that submit multiple connection requests in view of the long time frames.

Only six TSOs disclosed easily accessible data regarding how long the average waiting time was for projects to be connected. For those TSOs, average waiting times stood between 1 and 5.5 years (noting that some projects will face much longer than average queues).

In the UK, the energy regulator notes that projects face average waiting times of 5.5 years between the requested date and the connection offer.[7] Industry reports warn that more than €240 billion (£200 billion) worth of projects are stuck in a connectivity waiting list in the UK alone, that in some instances could last up to 15 years.[8] Unclogging grid connection queues not only unleashes renewable energy, but also supports investment in the energy sector.

Similarly to the UK, MAVIR in Hungary said the average connection delay is around five years. Litgrid, the Lithuanian TSO, told us that projects took an average of 4.6 years from meeting the initial preconditions for connection. The Finnish TSO Fingrid said the connection delivery time is around two to three years from signing the connection agreement. In the Netherlands, TenneT reports an average of 12 to 18 months to realise a new connection to the high-voltage grid, but that the grid remains highly congested with little available capacity.

We looked into the size of connection queues in different countries. Again, this data was not always readily accessible via the TSO, but it was sometimes available via third parties such as renewable energy associations. Queue sizes are in constant flux, and it is hard to make like-for-like comparisons between different TSOs due to different timeframes and definitions in reporting. Nonetheless, the table below provides a snapshot of available data.

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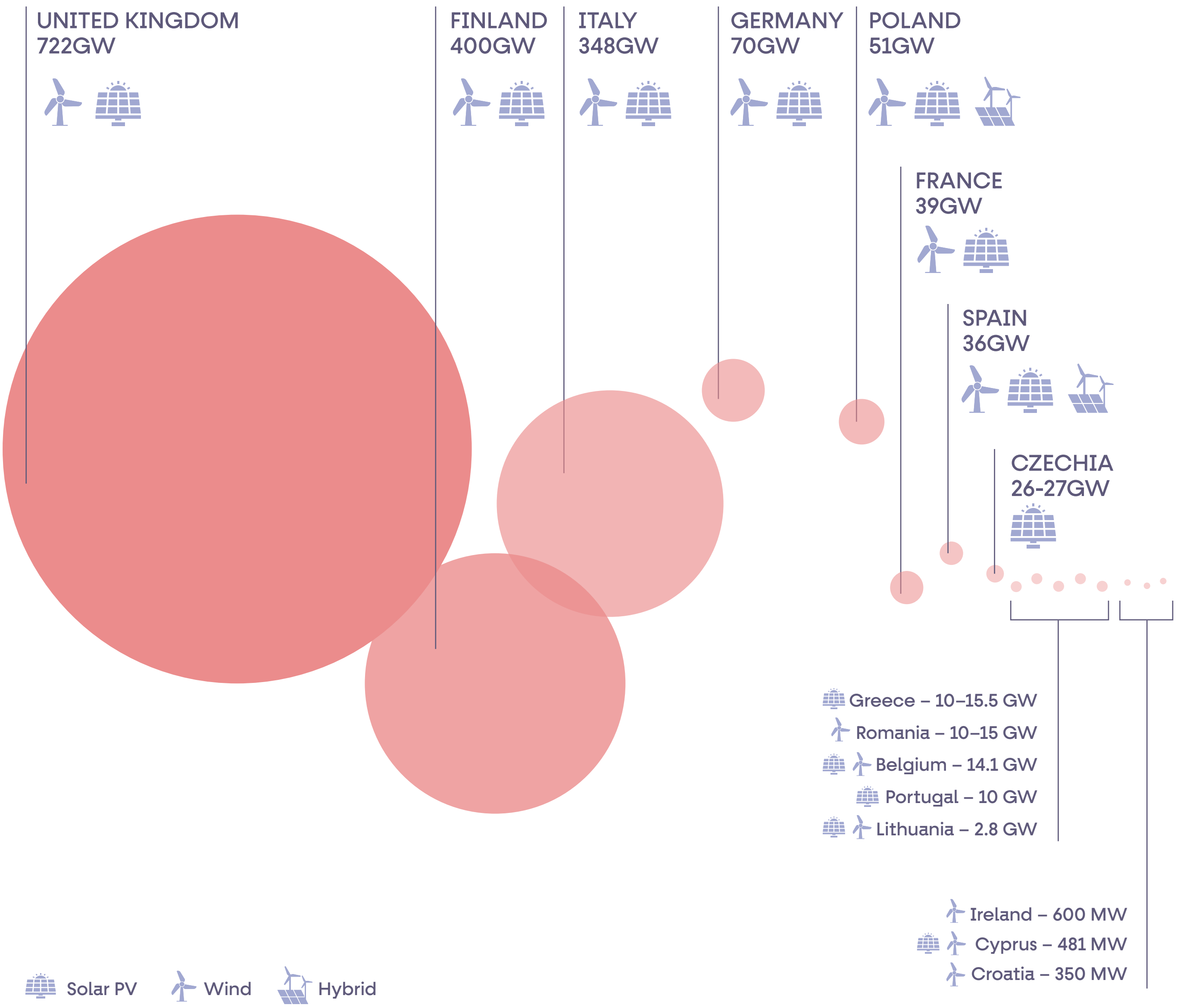
Queue sizes are in constant flux

Figure 2: Grid connection queues for renewable and hybrid projects in different countries[9]



Content in figure 2 is not uniform across countries due to differences in data collection and publication across TSOs, including different timeframes used to collect data, and different technology types covered.

Three TSOs have approaches which prioritise projects deemed strategically important.

We sought to understand how different countries were addressing these queues. This included whether TSOs were using a 'first come, first served' approach, or whether they were being more deliberate about prioritising strategic renewable projects.

'First come, first served' has been criticised for resulting in a less strategic allocation of grid capacity and an imbalanced mix of assets technologically and/or geographically. IRENA warns that this approach can intensify grid congestion and renewables curtailment which increases costs, and can result in inefficient grid development.[10] A more strategic and coordinated approach would fast-track to the front of the queue those projects that can add most value for the system.

The majority of TSOs (19 of 25) still use a 'first come, first served' approach.[11] Some are currently looking to change these practices, including in France, the Netherlands and Great Britain. In Great Britain, the independent National Energy System Operator is updating its process so that projects must demonstrate both their strategic importance for the 2030 clean power mission, and that they are ready to connect. This is designed to remove so-called 'zombie' projects from the queue.[12]

Three TSOs have approaches which prioritise projects deemed strategically important. In Greece, wind farm connections are being prioritised in order to complement existing solar capacity.[13] In Lithuania, grid capacity is reserved based on a priority system[14] that puts strategic and legislative projects first (such as those identified in national energy development programs); next come renewable projects under special legal provisions (including rooftop solar); these are followed by projects combining renewable energy sources with storage systems; next are prosumer projects; then energy sources without storage provisions, and finally 'general renewable energy projects'.[15] In Latvia, in order to diversify the renewables portfolio away from solar, criteria are being introduced to encourage a more secure mix of assets.[16]

Other TSOs have tendering or bidding processes to help determine which projects to connect, including in Hungary, Portugal and Spain. For example, the Portuguese government recently launched auctions to support large-scale solar power plant projects and for floating solar to be installed within seven dams across the country.[17]

Another option to help address grid queues is to offer "non-firm connections"—a flexible connection which is usually cheaper and faster—to renewable and storage projects. This means that the TSO can temporarily limit the project's connection to the grid. We identified 12 TSOs that offer non-firm connections,[18] while TSOs in Poland, Latvia, Finland and Spain are currently looking to introduce them.

Hosting capacity maps: greater transparency enables smarter electrification

Capacity maps provide information about the available space on the power grid for new capacity at particular locations, based on the current and expected future status of the grid.[19] It is now mandatory for all TSOs to publish capacity maps under the revised EU Electricity Market Directive.

While some users (such as existing industries or households) have no or limited options to choose the location of their grid connection, others do, including project developers looking to develop new renewables, electrolysers, or large electric vehicle chargers. Having visibility on available capacity at various locations would enable these users to factor it into their decisions and make smarter applications.

This could reduce the desperate scramble by project promoters to submit multiple grid connection requests for various locations, as is currently common practice. It would enable users to make the best use of the existing network by identifying where new capacity can be connected as well as where flexibility solutions such as storage and demand-side flexibility are in high demand.

Changing the operating model to ensure smooth integration of renewables into the grid

In order to reap the benefits of cheap, homegrown renewable energy, it is important for grid operators and governments to support the integration of flexible solutions alongside the build out of new grid infrastructure. These include storing energy at times when renewables are plentiful, for use during times of higher demand; encouraging businesses and households to adjust energy consumption to reflect energy generation; and building interconnectors with neighbouring countries. Where this is not currently being done sufficiently the result is high levels of curtailment, which occurs when renewable generators are hindered from feeding electricity into a congested grid.

Few TSOs were able to provide information about the current level of renewables curtailment, nor the costs associated with doing so. The data we were able to collect is displayed in the table below. While limited – and sometimes collected by TSOs using different methodologies which may not allow for a like-for-like comparison – it gives a sense of the scale of the problem in major economies across Europe.

Figure 3: Total renewable energy curtailment volumes and costs

Country	Technology	Curtailment (GWh)	Curtailment (%)	Cost	Year
Cyprus[20]	Solar PV	167	29		2024
France[21,22]	Wind and solar PV	1,700 (2024)		€272 million (2023)	2023/2024
Finland[23,24]	Wind	236 (2024)	0.5	€7.1 million (2023)	2023/2024
Germany[25]	Wind	9,289	6.8	€3.3 billion[26]	2023
Germany[27]	Solar PV	696	1.1		2023
Greece[28]	Wind and solar PV	860	3		2024
Hungary	Wind and solar PV			€2.7 million	2024
Ireland[29]	Wind	1,124	9.7		2023
Ireland[30]	Solar PV	39	7.4		2023
The Netherlands[31]	Wind and solar PV	3,000	4.9		2024
Poland[32]	Wind and solar PV	731.4		1.3 million PLN (€310,000)	2024
Spain	Wind	1,373	2.2	Up to €2.5 billion[33]	2024
Spain	Solar PV	346	0.6		2424
United Kingdom	Wind	8,300	10	£966 million (€1.16 billion)[34]	2024
United Kingdom	Solar PV				2023

Note: The costs cited refer to curtailment payments, re-dispatch and/or counter-trading costs depending on the country.

One important solution to reduce curtailment is to boost cross-border transmission capacity: a more interconnected European power grid would allow for geographical and temporal complementarity of renewable sources across countries. In 2019, a minimum requirement known as the "70% rule" for the Margin Available for Cross-Zonal Trade (MACZT) in the EU was introduced. This obliges all TSOs to guarantee, by the end of 2025, that 70% of the physical capacity of critical network elements is available for cross-zonal trade. Deviations are allowed for operational security reasons.

When looking at figures from 2023, only a few Member States (such as Czechia and Slovenia) already had a MACZT higher than 70% for most of the year.[35] That said, overall our research suggests that most European TSOs are on track to successfully align with the "70% rule". Improvements in regional coordination and harmonised monitoring methodologies are key to ensuring the timely implementation of the requirement. While most European TSOs seem to be fulfilling their transitional targets, Transelectrica only managed to do so for 18% of Market Time Units[36] in 2023 due to cross-border capacity adjustments requested by the neighboring Bulgarian TSO – these particular adjustment requests did not occur in 2021 nor 2022[37].

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Implementing solutions for smooth renewables integration

Dynamic line rating (DLR) is a tool that can reduce congestion on power lines, optimise asset utilisation, improve efficiency and reduce costs.[38] DLR uses sensors to determine when temperature and wind conditions can allow lines to carry more electricity, boosting capacity by up to 40%.[39] This can unblock short-term bottlenecks on transmission lines.

Despite DLR's potential, many TSOs are still in the pilot stage of this technology, with opportunities available for more comprehensive roll-out. Of the 19 TSOs we identified as utilising DLR,[40] only three appeared to have fully implemented all overhead lines: Elia, Energinet and ELES. Others, including Fingrid and Litgrid, reported that they would be expanding to the whole grid in due course—a step we encourage other TSOs to undertake.

Different solutions will be appropriate for different countries. Below, we have highlighted examples of how countries are integrating renewables through smart solutions, boosting storage, and supporting demand side flexibility.

Spain's Centro de Control de Energías Renovables (CECRE): Real-time monitoring and management to support secure integration of renewables

In Spain, Red Eléctrica's Renewable Energy Control Centre was the first of its kind to be dedicated exclusively to the supervision and control of renewables in real time, covering over 4,000 renewable energy projects. It is the first worldwide to have control over all wind farms above 10 MW. CECRE allows the maximum amount of renewable energy production, especially wind, to be integrated under secure conditions.

The Red Eléctrica control centre has capacity for the control, command and monitoring of the generation assigned to them, enabling 24/7 functionality and guaranteeing projects a secure dialogue with Red Eléctrica. This allows for almost instantaneous activation or deactivation of renewable generation parks, and also for demand response from large industries. Diagnoses and assessments are carried out in real time, allowing the centre to foresee the operating measures that should be applied in each case to ensure the system can return to a secure state.

Openness to flexibility: Poland is leapfrogging towards a more accessible market

In its 2025 European market review on demand side response, smartEn noted progress in Poland towards becoming more accessible for demand side flexibility (DSF).[41] A number of variables were identified as having supported this progress.

In the last year, Poland has seen important market reforms that have increased the accessibility of DSF in ancillary services markets, which help the TSO to 'balance' the energy system.[42] This includes increasing DSF accessibility when procuring balancing reserves which differ in terms of minimum bid sizes, activation, duration and ramp rates. In Eastern Europe, Poland also stands out for offering flexible tariffs with variable and day-ahead wholesale tariffs.

In addition, Poland operates a capacity mechanism with heavy participation of DSF and independent aggregation. Almost 1.1 GW was procured in the latest Y-5 auction (i.e. for the assets to be delivered in five years) and a quarterly average of 371 MW in the Y-1 auctions (assets to be delivered in one year). Research for Beyond Fossil Fuels found that Poland is Europe's leader in providing capacity market contracts to storage energy assets.[43] This has been in part driven by the economics of batteries being preferable to fossil fuels.

Accelerating clean flexibility in Denmark: Widening the market

Denmark has recently seen a major increase in the number of businesses providing clean flexibility services to help balance the energy grid, including ice rinks, nurseries, swimming pools and horticultural farms. 2024 saw a seven-fold increase in the number of organisations that had prequalified to deliver so-called ancillary services to the national TSO Energinet, bringing the total up to 550.

Energinet has developed the balancing market through a long series of changes that are intended to make it more attractive to a wider range of players. This includes Energinet making use of tariffs and the terms and conditions of grid connection to increase incentives for co-location and sector coupling.[44] At the same time, higher energy prices and fluctuations have created greater business opportunities and interest.

The actors involved have shown great creativity, and many new types of market participants and technologies have come onto the scene, such as cooling systems, saunas and ice rinks.

Assessing upper limits on renewables input

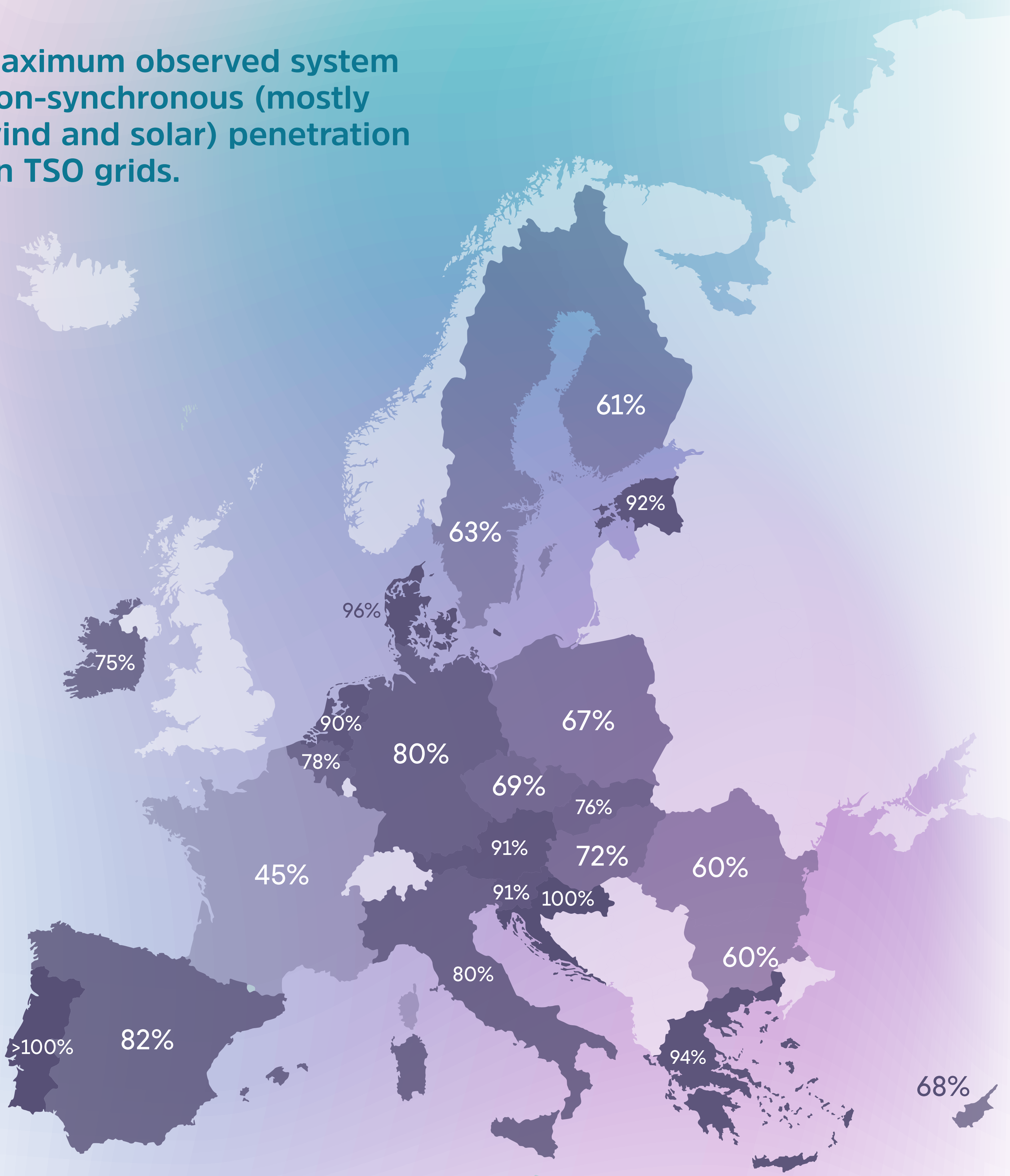
We looked at the percentage of renewables that different TSOs could currently operate the grid with, and potential limits. Only Eirgrid is publicly transparent about having a technical upper limit, defined as System Non-Synchronous Penetration (SNSP). This refers to the amount of non-synchronous (inverter-based) sources (namely wind and solar) that the electricity system can safely accommodate at any one time. Ember calculated hourly SNSP for 23 national systems, with the results displayed in figure 4 below.

Examination of the hourly distribution of SNSP suggests that most TSOs do not impose an upper limit for renewables input, or if they do it is high enough to be without effect at present. However, some systems show signs of having a potential upper limit. This may be directly enforced by the TSO, but more likely it results indirectly from a requirement for must-run thermal assets, a lack of flexibility in the thermal fleet, or a reliance on thermal assets for grid services such as inertia.

Five TSOs confirmed that they don't have a limit in place, and in many other cases (13) there was no evidence to suggest such a limit. In the case of both Poland and Spain, analysis by Ember of hourly generation data suggests a technical upper limit may be in place. In both cases, the maximum SNSP to date was reached in 2023, and wasn't exceeded in 2024 despite significant growth in renewable installed capacity in both countries.

Figure 4: System non-synchronous penetration

Maximum observed system non-synchronous (mostly wind and solar) penetration on TSO grids.



6

Grid Planning

How TSOs plan for the future will be critical for determining whether they are making the upgrades and investments needed to underpin a clean energy system.

As changes to grid infrastructure often have a longer lead time than developing renewable generation, storage, or other energy assets, conservative grid plans risk exacerbating the problems already outlined regarding long connection times and curtailments. These plans will therefore be vital to ensuring Europe's energy security, and its ability to build-out the energy infrastructure assets that can lower and stabilise bills.

Most TSOs create a Network Development Plan (NDP) every two years which sets out their planned network expansions, proposed investments and innovations (timeframes may vary slightly across Europe, with some TSOs publishing an updated plan annually, and others every four years). These generally contain a number of potential scenarios which are themselves based on visions of the future energy system that consider variables like economic growth, electricity demand, and the roll-out of renewable energy.

In order to understand whether Europe's TSOs are doing enough to ensure their NDPs can accommodate the rapid integration of clean energy projects, this section looks at three key factors. Firstly, whether TSOs are considering scenarios that envision a renewables-based power system by 2035[45]—even where this goes beyond national targets. Secondly, whether they undertake independent, integrated system planning to consider how future cross-sectoral energy trends will impact the grid. And thirdly, which energy models were being used as the basis for planning, and whether these were transparent and open-source.

These plans will be vital to ensuring Europe's energy security.

Our research showed that very few TSOs are currently considering forward-looking scenarios that anticipate sufficiently high levels of renewable energy build-out, with just five considering a fully renewables-powered system by 2035. In many cases, this is due to legal mandates. Nonetheless, there are compelling reasons why TSOs should be enabled by regulators to view national renewables targets as a floor rather than a ceiling.

Renewable deployment rates have consistently been underestimated, and there is strong evidence that the transition is accelerating beyond official targets. Analysis by Ember finds that European year-on-year growth in solar is already above what the latest national targets would require.[46] TSOs should be encouraged to consider market and technological trends, alongside official targets, so as to plan for a wider range of eventualities that would support a timely energy transition.

Aligning plans with the rapid acceleration of renewables

The direction of travel in Europe has been for renewable targets to increase over time. TSOs should be anticipating higher future renewables targets and factoring this into their plans. The EU's 2030 renewable energy target has gone from 27% as agreed in 2014 to 32% in 2018 and finally to 45% in 2024. The EU is now looking to propose a 2040 climate target to reduce net emissions by 90%,[47] which would entail that power systems will essentially need to be fossil free, and ready to meet significant increases in electricity generation and demand. 13 of the countries studied have targets for clean power by 2035 or earlier.[48]

The vast majority of TSOs are forecasting significant reliance on gas power in 2035 in their scenarios.

Despite this, the vast majority of TSOs are still forecasting significant reliance on gas power in 2035 in their scenarios. This is out of step with climate targets, as well as the rapid growth of renewables and clean flexibility solutions.[49] As noted in the previous section, a lack of foresight to upgrade the network in line with the exponential growth in renewable projects is holding back their integration, and in turn delaying their ability to lower wholesale costs for consumers. This creates a self-fulfilling prophecy whereby fossil gas is used for longer because renewables and clean storage projects haven't been able to connect to the grid.

We found only five TSOs that are considering scenarios in which renewables replace nearly all gas[50] by 2035: Energinet, Fingrid, Eirgrid, NESO and Litgrid. Crucially, such forecasts generally correlate with stronger policy commitments in these countries, demonstrating the importance of political leadership.

TSOs that have not included high renewable-based scenarios are often following the direction of travel set by government policies and targets. Nonetheless, there are risks associated with failing to keep up with trends in the rapid penetration of renewables, electrification of heating and transport, and the associated need for storage and flexibility.

Some NDPs demonstrate the potential pitfalls of holding back latent renewables potential. For example, Italian TSO Terna considers two scenarios in its NDP: one aligned with Italy's National Integrated Energy and Climate Plan (Piano Nazionale Integrato Energia e Clima, or PNIEC); and one less ambitious scenario which it calls the 'PNIEC slow' scenario.[51] However, for 2030, it doesn't consider a 'PNIEC fast' scenario in which Italy moves faster to capture its full renewables potential.

For 2035 and 2040, Terna's Plan adds additional scenarios: Distributed Energy Italia (DE-IT) and Global Ambition Italia,[52] with DE-IT representing a higher level of ambition. However, the 350 GW of renewables projects currently in the grid connection queue in Italy already stands at nearly double that of the most ambitious scenario that Terna considers for 2040.[53] From the 350 GW queue, it is reasonable to assume that some projects are speculative applications and may not come to fruition. Nonetheless, even if two thirds were proven unfeasible, the total available today would still stand higher than Terna's PNIEC 'slow scenario' for 2040.

TSOs in many countries are prescribed via a legal mandate to use scenarios contained in government national energy plans, despite the potential for the clean energy transition to go much further and faster. In some cases, TSOs are falling even further behind. Since national policy sometimes moves faster than the timeframes for preparing grid development plans, Ember found that 11 of 26 TSOs were using outdated national plans and targets.[54] This underscores the importance of regulatory change and political leadership.

While it is reasonable to reflect national policy frameworks and targets within plans, this should be seen as a floor rather than a ceiling – in recognition that the transition is happening much faster than the speed of legislative processes. For example, despite Spain's incredible renewable potential, Red Eléctrica uses the national target of an 81% share of renewable electricity by 2030 in its NDP, whereas modelling by Climate Analytics suggests this could be up to 89%.[55] Red Eléctrica has an opportunity in the development of its forthcoming NDP to raise these expectations.

TSOs in many countries are prescribed via a legal mandate to use scenarios contained in government national energy plans, despite the potential for the clean energy transition to go much further and faster.

Some TSOs are indeed looking beyond national targets in their planning. One example is Hungary's MAVIR, which is already planning for a significant increase in battery storage capacities, beyond the NECP target of 1 GW installed capacity by 2030. This is being advanced with the support of the government and the wider market to complement unprecedented growth in solar capacity (there were more than 70 days in 2024 when solar was able to meet more than 80% of the country's total demand at its peak production hour; a significant jump from 2023, when peak solar generation met over 80% of domestic demand on only 10 days). Additional battery storage will help ensure the safe and reliable integration of solar, allowing energy to be stored at times of excess production.

Another example comes from the Netherlands, where the latest national target for solar in 2030 (26 GW) was so unambitious that it was already reached in 2024. Dutch system operators have now gone beyond this and are working with multiple scenarios in their integrated energy system plan[56], with levels of solar between 40-75 GW by 2030.

Integrated network planning

To meet climate targets, integrated energy infrastructure planning may be helpful to identify synergies and efficiencies between sectors and geographies. Fulfilling the demand for green energy in all sectors (i.e. industry, building, heat, and transport) can be supported by joint grid planning activities that allow for the evaluation, selection, and coupling of effective project combinations. This requires coordination across different energy sectors: including with gas TSOs as they decommission existing gas assets, as well as local Distribution System Operators (DSOs). It should also include a cross-border element, working with neighbouring TSOs.

Integrated system planning must be carried out by an independent body and coupled with climate targets, otherwise it could lead to adverse outcomes. For example, TSOs could overinvest in fossil infrastructure if the role of gas or potential of CCS is overstated, locking in emissions.

There are different levels of integration carried out by TSOs at present. Some electricity TSOs note that they have engaged with their gas counterparts and considered future hydrogen generation. This includes TSOs in Finland (although it should be noted that gas does not play a substantial role in Finland) as well as Hungary, Poland, Spain, Belgium and Germany. In many cases, this level of engagement and coordination may be sufficient to check assumptions and make determinations.

Integrated system planning must be carried out by an independent body and coupled with climate targets, otherwise it could lead to adverse outcomes.

Some TSOs are undertaking more detailed, joint scenario planning and modelling which take a cross-sectoral approach to considering the future of different grid infrastructure. This includes TSOs in Austria, Denmark, France, the UK, Italy, Lithuania, and the Netherlands. The UK leads the way with its fully independent National Energy System Operator (NESO), which is responsible for considering holistic system design in line with net zero (for more details, see the following chapter on governance).[57] Meanwhile, some TSOs do not appear to be considering integrated network planning, including in Ireland and Cyprus.

The UK leads the way with its fully independent National Energy System Operator (NESO).

Energy modelling

The use of transparent and open-source energy modelling software is important to enable proper oversight and scrutiny of the assumptions going into planning, thus supporting good governance, as well as enabling constructive feedback on planning. Benefits can include greater sharing of ideas and information, improved quality, and wider engagement and adoption.[58] This allows for the continued development of scenarios to test new ideas that come out of different modelling exercises.

However, at the moment, the vast majority of TSOs are not using open source models. The table below provides a snapshot of the different models used, with RTE, MAVIR, Elia, APG, Transnet and TenneT leading the way in using open source models. Notably, RTE developed the Antares model and then made it publicly available, including to other TSOs.

Figure 5: Energy modelling software used by European TSOs

7

Governance and Politics

A combination of robust governance practices and political leadership on clean power will be a critical enabler for ensuring that Europe's grid operators are making the right decisions for the energy transition.

As noted in previous sections, the decisions and plans of TSOs are shaped by the regulations and mandates they operate within. This includes requirements for them to plan in line with national energy targets, as well as grid connection processes that contribute to long queues and curtailment.

We examined the level of independence of TSOs from commercial interests that might influence their approach to planning and operating the grid. Additionally, we looked at national energy and climate targets and how they have been embedded in the activities of the respective TSOs and regulators. This allowed us to assess government level input and how it is received by regulators and system operators who need to take a long-term view that enables anticipatory investments and modernisation of the grid in line with clear long-term targets. We also considered how TSOs are able to influence European policy discourse on energy infrastructure.

We found that more progress is needed to ensure that grid planning and operations are independent from commercial interests, as 10 TSOs are not unbundled to the highest degree envisaged in EU regulation (see explanation below). However, EU requirements currently set only minimum parameters. There are examples of independent system planners being established, fully separated from the TSO, who owns and manages the grid.

Meanwhile, a worrying number of TSOs and regulators have not embedded long-term climate action into their strategic approach, which could prevent decision-making aligned with a rapid clean energy transition. Finally, as a result of mapping out which TSOs hold important positions in European policy discussions, we conclude that TSOs must use their voice to advance the positive changes needed to boost renewables and clean flexibility, rather than embedding reliance on incumbent fossil fuels.

More progress is needed to ensure that grid planning and operations are independent from commercial interests.

Independence and "unbundling"

Vertical unbundling is the separation of energy supply and generation from the operation of transmission networks. If a single company operates a transmission network and generates or sells energy at the same time, it may have an incentive to obstruct competitors' access to infrastructure.[59] EU regulation requires unbundling to take place in one of three ways. These are listed here in hierarchical order, with the first providing the greatest level of unbundling and independence.[60] While all of these are deemed sufficient, they offer different levels of effectiveness in managing perceived or actual conflicts of interest.

1. **Ownership unbundling:** all integrated companies sell off their gas and electricity networks. In this case, no supply or production company is allowed to hold a majority share or interfere in the work of a transmission system operator.
2. **Independent system operator:** energy supply companies may still formally own gas or electricity transmission networks but must leave the entire operation, maintenance, and investment in the grid to an independent company.
3. **Independent transmission system operator:** energy supply companies may still own and operate gas or electricity networks, but must do so through a subsidiary. All important decisions must be taken independently of the parent company.

Since the entry of the Clean Energy Package, the trend has been towards higher levels of ownership unbundling; yet our research suggests that 10 TSOs fall short of the most robust form of legal ownership unbundling. The several instances where the TSO is still part of a portfolio of companies involved in generating or selling electricity show that more needs to be done to reduce potential conflicts of interest, including France, Romania, Switzerland, and two of the German TSOs (Amprion and Transnet).[61]

Governance arrangements are also evolving beyond the EU minimum requirements. For example, the UK recently created the National Energy System Operator (NESO)— a fully independent public body to plan and operate the transmission grid. NESO is tasked not only with day-to-date operations, but also long-term, strategic oversight and providing expert trusted advice on government policy. With clear government direction, this new body is expected to ensure the efficient development of the grid while continuing to open markets to renewables and flexible resources (see case study below).

10 TSOs fall short of the most robust form of legal ownership unbundling.

Figure 6: Hierarchy of independence of TSOs and system operators

The UK has shown it's possible to go beyond the EU's unbundling hierarchy by taking grid planning responsibilities away from the TSO (National Grid) and forming a new public body (NESO) to undertake that function.

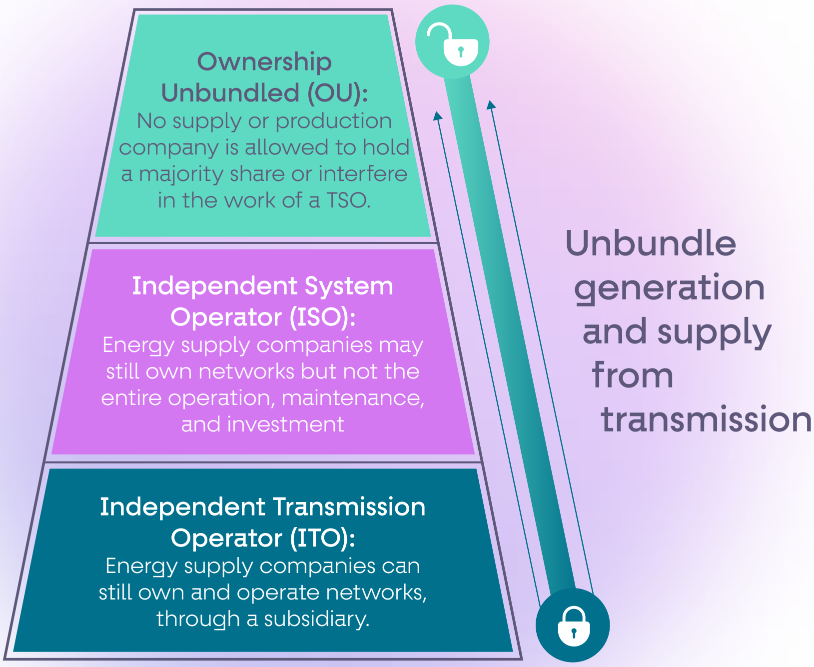


Figure 7: Unbundling models by TSO

Country	TSO	Unbundling model
Austria	APG	ITO
	VUEN	OU
Belgium	Elia	OU
Bulgaria	ESO	OU
Croatia	HOPS	ITO
Cyprus	Cyprus TSO	ITO*
Czechia	ČEPS	OU
Denmark	Energinet	OU
Estonia	Elering	OU
Finland	Fingrid	OU
France	RTE	ITO
Germany	TenneT DE	OU
	Transnet	ITO
	Amprion	ITO
	50Hertz	OU
Greece	ADMIE	OU
Hungary	MAVIR	ITO

Country	TSO	Unbundling model
Ireland	Eirgrid	ITO*
Italy	Terna	OU
Latvia	AST	OU
Lithuania	Litgrid	OU
Luxembourg	Creos	OU*
Malta	Enemalta	No unbundling*
Netherlands	TenneT	OU
Poland	PSE	OU
Portugal	REN	OU
Romania	Transelectrica	ITO
Slovakia	SEPS	OU
Slovenia	ELES	OU
Spain	REE	OU
Sweden	Svenska Kraftnat	OU
Norway	Statnett	OU
Switzerland	Swissgrid	ITO
United Kingdom	National Grid	OU**

*Not Subject to Unbundling Regulation
**The UK has recently set up an independent system operator, the National Energy System Operator (NESO), which is a seperate legal entity to National Grid

OU: Ownership unbundled
ITO: Independent Transmission Operator

Fully independent system operation and planning: UK's National Energy System Operator

The National Energy System Operator (NESO) is the UK's independent system operator and planner (ISOP). NESO was created in 2023 as a public body, independent from government control, and overseen by the regulator Ofgem. Prior to NESO, the electricity and gas systems were managed by the Electricity System Operator and the Gas System Operator respectively. The electricity network was and is still owned by three companies – including National Grid. National Grid also owns the gas transmission network in Great Britain. It was recognised that National Grid might be able to leverage its position to make decisions that would benefit its wider business at the expense of consumers or other parties in the industry.

The 2023 Energy Security Bill transferred capabilities and functions of what was previously ESO and National Grid Gas to the body that would become NESO. NESO brings together the planning for the electricity and gas systems into a single institution.

NESO has three primary duties: to support the achievement of net zero targets; to promote efficient, coordinated and economical systems for electricity and gas; and to ensure security of supply for current and future consumers of electricity and gas.

Being publicly owned, NESO is similar to other system operators in Europe, and is also operationally independent from the government. However there are important differences – for example, unlike other organisations (e.g. in France, Bulgaria), NESO is not part of any other government-linked group. NESO is responsible for both electricity and gas, while other system operators may only be responsible for one of these (with some exceptions – e.g. Denmark). NESO also has a clear government mandate to support the delivery of its 2030 clean power mission and additional roles such as strategic planning, reducing risks, and strengthening the UK's energy security.

Embedding climate targets: Governments, TSOs and regulators

The underlying political and policy framework within which TSOs operate plays a crucial role in informing the direction of travel and level of climate ambition seen. To better understand this, our research looked into national climate targets set by governments and how regulators and TSOs have incorporated them into their approach.

Governments play a crucial role in setting climate objectives and the corresponding policy choices to achieve them. Their commitment and ambition is essential for driving the necessary transformation in the energy system. Among EU countries, Czechia and Poland have not set any climate neutrality targets, thus failing to take the first step toward the 2050 commitment outlined in European Climate Law. In contrast, 20 countries have aligned their targets to the 2050 deadline, with some setting slightly earlier goals: Germany, Denmark and Sweden by 2045; Austria by 2040; Finland stands out with its 2035 goal.

Governments play a crucial role in setting climate objectives and the corresponding policy choices to achieve them.

Beyond setting national targets, governments play a key role in defining the mandates of energy regulators. In most countries TSOs are either fully or partially government owned. It is therefore essential for national level governments to step up in setting clear targets as well as enabling the actors in the system to deliver on them.

While governments set the strategic direction enabling the transition, regulators influence the pathway by supporting the delivery of government policy choices, encouraging innovation through incentives, and overseeing network company plans and performance. Their role is also important for ensuring that TSOs are able to take a sufficiently long-term view, and that they are being monitored and incentivised to support the adoption of measures aligned with the clean energy transition.

Worryingly, we found that many energy regulators do not publicly mention climate in their responsibilities with 19 of 30 regulators making no such reference.[62] While some do include renewables targets, this does not amount to a full climate neutrality target which, beyond being the ultimate objective under EU Climate Law, would allow for a long-term and integrated perspective on the investments and planning needed. By not referencing climate neutrality as an underpinning principle, regulators fail to actively contribute to the developments needed to enable system change.

Figure 8: What reference to climate targets TSOs/regulators make

Country	TSO	Public reference to climate neutrality - Regulator	Public reference to climate neutrality - TSO
Austria	APG	Yes	Yes
Austria	VUEN		Not found
Belgium	Elia	Not found	Yes
Bulgaria	ESO	Not found	Not found
Croatia	HOPS	Not found	Not found
Cyprus	Cyprus TSO	Not Found	Not Found
Czechia	ČEPS	Not found	Not found
Denmark	Energinet	Not found	Yes
Estonia	Elering	Not Found	Partially
Finland	Fingrid	Yes	Yes
France	RTE	Partially	Yes
Germany	TenneT DE	Yes	Yes
Germany	Transnet		Not found
Germany	Amprion		Not found
Germany	50Hertz		Yes
Greece	ADMIE	Not found	Yes
Hungary	MAVIR	Not found	Not found
Ireland	Eirgrid	Partially	Yes
Italy	Terna	Partially	Yes
Latvia	AST	Partially	Partially
Lithuania	Litgrid	Not found	Partially
Luxembourg	Creos	Not found	Partially
Malta	Enemalta	Not found	Not found
Netherlands	TenneT	Partially	Yes
Poland	PSE	Not found	Partially
Portugal	REN	Partially	Yes
Romania	Transelectrica	Yes	Not found
Slovakia	SEPS	Not found	Partially
Slovenia	ELES	Not found	Partially
Spain	REE	Partially	Partially
Sweden	Svenska Kraftnat	Not found	Partially
Non-EU			
UK	National Grid, NESO	Yes	Yes
Norway	Statnett	Not found	Not found
Switzerland	Swissgrid	Not found	Not found

Only 13 of the surveyed TSOs have commitments or targets on climate.

Six regulators made a passing reference to climate responsibilities, but did not fully embed them into their mission. Only five energy regulators fully acknowledge and are committed to climate neutrality, with the UK having a legally binding duty.[63] This duty was considered helpful by the energy industry for enabling the energy regulator, Ofgem, to prioritise a long-term perspective on the energy transition over short-term obligations, creating more investment confidence.[64]

In parallel, we investigated TSOs' references to climate. In total, only 13 of the surveyed TSOs have commitments or targets on climate, with differing levels of ambition. These generally had a correlation with government and regulator targets, but not always. For example, Germany's regulator references a commitment to climate neutrality, but corresponding targets could not be found for German TSOs Transnet and Amprion. Similarly, Greece's energy regulator makes no reference to climate targets, while the Greek TSO ADMIE seeks to achieve carbon neutrality by 2050.

Finland leads the way with a commitment to achieving climate neutrality by 2035 (this is set to include nuclear). Concerningly, 11 TSOs made no reference at all to climate targets. Bulgaria, Croatia, Cyprus, Czechia and Hungary stand out, with neither regulators nor TSOs referencing climate or energy targets. In some cases, this reflects the government's lack of position on clean power and climate neutrality, emphasising the importance of political leadership to drive change. Overall, this uneven approach risks creating inconsistencies in decision-making, hindering progress towards climate objectives for the EU as a whole.

Influencing European policy discussions

All EU electricity TSOs are members of the European Network of Transmission System Operators for Electricity (ENTSO-E)—the association responsible for the secure and coordinated operation of Europe's electricity system. Its tasks, as mandated by European law, include the alignment of infrastructure planning through the ten-year network development plan (TYNDP) and the European Resource Adequacy Assessment. In addition, ENTSO-E is a powerful voice on technical questions related to the power system, with formal responsibilities stemming from EU law, including developing methodologies for evaluating the need for power system flexibility to reach climate objectives.

14 TSOs are represented within the main bodies of ENTSO-E (the board and the committees), which play a role in driving the association's strategic direction and ultimately impacting the overall electricity grid and market development. Participating TSOs ultimately gain an important voice in shaping the discussion and decision making in the association and in the wider European policy space (see table below).

Figure 9: Overview of high-level positions within ENTSO-E

TSO	Board Member or Head of Assembly	Committee Chair
Austria (APG)	✓ (Vice chair of the Board)	✗
Czechia (ČEPS)	✓ (President of the Assembly)	Information & Communication Technology Committee
Denmark (Energinet)	✓	✗
Finland (Fingrid)	✓ (Vice-President of the Assembly)	✗
France (RTE)	✓ (Chair of the Board)	System Operations Committee
Germany (TenneT)	✗	Legal & Regulatory Group
Germany (Amprion)	✗	System Development Committee
Germany (50Hertz)	✓	✗
Ireland (Eirgrid)	✓	✗
Italy (Terna)	✓	✗
Netherlands (TenneT)	✓	✗
Poland (PSE)	✓	✗
Slovenia (ELES)	✗	Research, Development & Innovation Committee
Spain (Red Electrica)	✓	✗

As well as influencing European discussions, TSOs also engage in policy debates in the countries where they operate. In some cases, TSOs are lobbying for capacity mechanisms to support fossil gas plants, whilst others are against it. For example, the German TSOs are active proponents of a new capacity mechanism and gas plant tenders, which could underpin the construction of up to 20 GW of new fossil gas plants.[65] On the other hand, in Denmark, Energinet has warned that a capacity market could cause national and international market disruption.[66] Other TSOs are calling for more investment to be channelled towards clean flexibility solutions to help balance the energy system, including National Grid in the UK, as well as Transelectrica in Romania.[67]

8

Finance

Undertaking the necessary grid updates requires TSOs to have sufficient access to the capital necessary to invest in cable and non-cable upgrades.

Analysis by Climate Action Network Europe highlights the need to frontload investments in the 2020s, in order to realise 2040 energy scenarios that see a phase-out of gas from the power sector.[68] Thus, it is critically important that TSOs have available finance, and make the right investments to build-out a resilient future grid network.

TSOs' earnings are largely determined by permitted revenues as set under a regulatory framework that considers the cost of transmission operations and invested capital, which are then passed on to end-consumers in energy bills. TSOs get additional funding through public and/or private equity and debt capital to support the upfront investment required.

Our research examined how well-positioned TSOs are to raise capital, and the different ways that they can draw upon investment. Areas we considered included the level of data transparency, and whether key financial metrics were readily accessible. We also considered factors that would impact how easily a TSO would be able to raise funds to invest in clean grid solutions, including their investment grade ratings, funding allocated from parent companies, support from public institutions, as well as any sources of green finance they were drawing upon. We found that, depending on their sources of investment, TSOs would have to adopt different means of financing the energy transition.

It is critically important that TSOs have available finance, and make the right investments to build-out a resilient future grid network.

TSOs show varying financial strength in terms of reporting quality, access to funding, and credit metrics. The best-positioned TSOs generally report comprehensive financial indicators and CAPEX (capital expenditure) plans, have diversified funding channels—including green-labelled bonds, loans and equity—and maintain credit metrics commensurate with an investment-grade rating.

As noted in the governance section, independent oversight of these investment plans will be essential. Long-term investments will be essential for enabling the transition, cutting costs associated with curtailment, and boosting growth in clean industries. At the same time, TSOs must be incentivised to use non-CAPEX solutions such as dynamic line rating to ensure a cost-effective upgrade to the grid and to ensure that progress can be made immediately in reducing grid bottlenecks.

Long-term investments will be essential for enabling the transition, cutting costs associated with curtailment, and boosting growth in clean industries.

Transparency and finances

The 23 electricity TSOs analysed display a wide spectrum when it comes to data disclosure and transparency. Some, such as National Grid, Statnett, Terna, REN and Elia and 50Hertz clearly disclose data online. However, others do not readily report on key metrics such as planned capital investment breakdown and regulated asset base (RAB), which makes it difficult to assess companies' financial positioning and preparedness for the energy transition.

Good reporting quality in Portugal

Portugal's REN is an example of best practice in financial reporting. All material financial indicators are clearly disclosed, including RAB. The CAPEX plan is clearly presented, with a breakdown between different businesses: electricity (power lines, substations); gas (transmission assets pipelines, storage, LNG); and other activities. However, as with all the other TSOs analysed, there is no distinction between the CAPEX dedicated to asset maintenance and that dedicated to investment in new grids, interconnections and smart grid solutions. The company has identified €2.9 billion of eligible investments into electricity grids as of 2023.

Investment-grade ratings

14 of the 23 TSOs are rated investment-grade by leading credit rating agencies. This indicates generally strong access to external private debt funding, which could help TSOs raise the finance needed to underpin grid upgrades without solely relying on higher network tariffs. The investment-grade ratings are supported by the relatively low perceived risks of electricity transmission activities and good revenue visibility, underpinned by clear and established regulatory frameworks. In some cases, government ownership supports TSOs' credit quality and TSOs' funding access may be limited by the sovereigns' credit quality.

11 of these TSOs have issued labelled green bonds, which shows the cohesiveness of their grid expansion, sustainability and funding strategies. TenneT and Terna are among the top 20 largest non-financial corporate green bond issuers in Europe. TSOs that issue green bonds typically exhibit better transparency, as they report on their allocated proceeds, project progress and impacts.

Amprion in Germany: Cohesive sustainable finance and grid development strategies

Amprion has clearly defined its use of proceeds from its green bonds as exclusively for the renovation, upgrading and expansion of the transmission grid, stations and interconnectors. Its sustainable finance framework aligns with the company's overall strategy to improve transmission capacity, grid resilience and renewable power integration. The company plans to invest around €27.5 billion between 2024 and 2028 in grid expansion. Amprion disclosed the breakdown of its €6 billion green financing portfolio into new financing and refinancing, and by project type, including grid connection of offshore and onshore projects and substations.

Funding allocated from parent companies

TSOs unrated by credit rating agencies are usually an operating subsidiary of a government-related utility.[69] These TSOs tend not to obtain external fundings themselves and are usually debt-free entities. They are largely reliant on internally generated cash flow under their respective regulatory frameworks. They may also obtain income injections from their respective parent utilities to fund capital spending plans, depending on the latter's willingness and capacity to support. Reliance on such support could create a situation where the ability of the TSO to finance the clean energy transition is more strongly tied to the political leanings of the government-related parent company.

For example, APG is a subsidiary of Verbund (Austria's largest electricity provider) rated at A2. Verbund disclosed in its green bond report that it has allocated half of its 2021, €500 million green sustainability-linked bonds into new grid construction by APG. As the company plans to invest around €9 billion in grids by 2034, continued funding through Verbund, supported by government backing for clean power, will be crucial.

ESO is a wholly owned subsidiary of Bulgarian Energy Holding EAD (BEH) rated at BB+/Ba1/BB, with a portfolio that includes power generation, coal, and gas activities. ESO is a largely debt free entity. BEH issued bonds amounting to 2.34 billion BGN (€1.2 billion) as of 2023, but the extent to which these funds are being used to support grid investments remains unclear and limited.

Public institutional support

EU level public institutions show modest financial support for European TSOs. For example, in October 2024, the European Investment Bank and the Belgian TSO, Elia Transmission Belgium (ETB), signed a €650 million green credit facility to support the first phase of the Princess Elisabeth Island project. Meanwhile, the European Investment Bank (EIB) and Terna have signed a €400 million loan agreement to upgrade the Italian power grid. As of 2023, ADMIE/IPTO had an outstanding loan of €690 million from EIB, accounting for more than half of its total indebtedness. The EIB also committed a €450 million green loan to support REN's upgrading of its electricity transmission network.

There are some instances where TSOs received direct grants from the EU. In December 2022, Terna received a total grant of €307 million under the EU Connecting Europe Facility to support the Italy-Tunisia interconnection project.

CAPEX plans and debt limits

Growing investments in electricity transmission grids are likely to weigh on TSOs' net debt leverage, but will ensure a grid that is stronger and therefore more adjusted to a higher share of variable renewables. TSOs such as Elia, TenneT, 50Hertz, and Statnett, which have announced sizable CAPEX growth plans, may require external funding before returns rise with the growth of their RAB. For example, 50Hertz's €20.7 billion plan over 2024-2028 represents more than four times its net debt level as of 2023. Without adding pressure onto debt leverage, TSOs may require equity fundraising to support asset base growth.

Variables impacting TSOs' financial strength

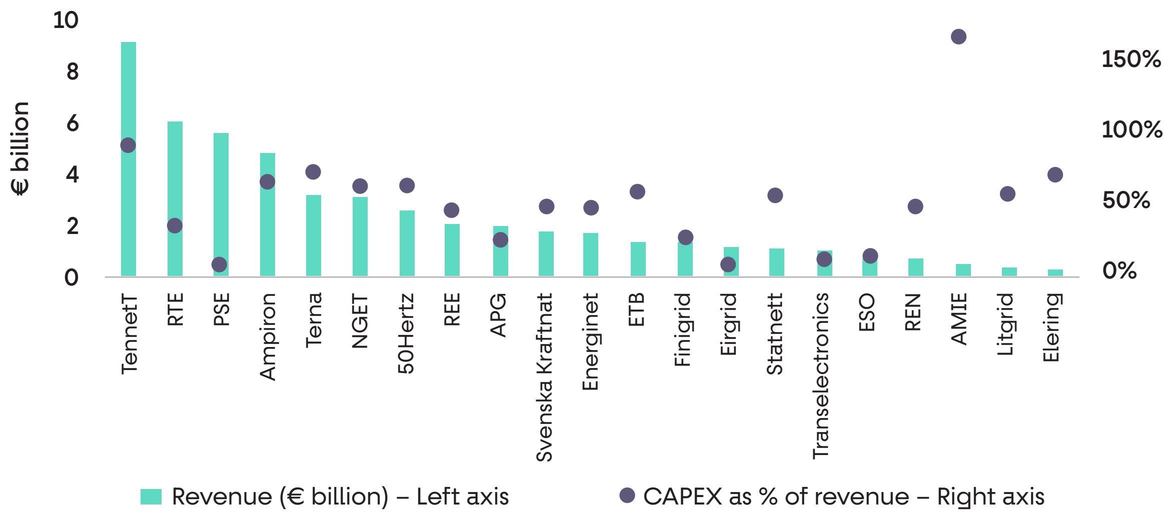
TSOs show varying financial strength. Most bond-issuing TSOs have a net leverage[70] reflected in net debt-to-fixed asset ratios ranging between 50% and 70%. A few TSOs including Elering, Litgrid and Fingrid have seen recent improvements in net leverage, supported by significant congestion income received. Elering's low debt level follows the redemption of its €225 million bond in May 2023, which is partially funded by the congestion fees of €118 million it received in 2023. TSOs may earn congestion revenues when the capacity of transmission lines is not sufficient to meet electricity demand. The company also received government grants of €39 million. Litgrid's low leverage has enabled an outstanding loan of €266 million as of end-2024 to its parent company EPSO-G UAB under a cash pool agreement. These factors could put the TSOs in a better position to support the clean energy transition. Meanwhile, Statnett exhibited relatively weak cash flow metrics in 2023, but this was caused by timing of customer rebates and is likely to normalise.

Figure 10: Overview of key financial metrics across TSOs

Country	TSO	Data transparency level	Credit ratings (S&P/ Moody's/Fitch)	Green financing
Austria	**APG**	Average	Unrated	✗
Belgium	**Elia**	Average	BBB+/-/-	✓
Bulgaria	**ESO**	Average	Unrated	✗
Czechia	**CEPS**	Limited	-/A1/-	✗
Denmark	**Energinet**	Average	Unrated	✗
Estonia	**Elering**	Average	-/A2/-	✗
Finland	**Fingrid**	Average	A+/A2/A+	✓
France	**RTE**	Average	A/-/-	✓
Germany/Netherlands	**TenneT**	Average	A-/A3/-	✓
Germany	**Amprion**	Good	-/Baa1/BBB+	✓
Germany	**50Hertz**	Average	BBB/Baa2/-	✓
Greece	**ADMIE**	Good	Unrated	✗
Hungary	**MAVIR**	Limited	Unrated	✗
Ireland	**Eirgrid**	Limited	Unrated	✗
Italy	**Terna**	Good	BBB+/Baa2/-	✓
Lithuania	**Litgrid**	Limited	Unrated	✗
Poland	**PSE**	Limited	Unrated	✗
Portugal	**REN**	Good	BBB/Baa2/BBB	✓
Romania	**Transelectrica**	Average	-/Baa3/-	✗
Spain	**REE**	Good	A-/-/A-	✓
Sweden	**Svenska Kraftnat**	Average	Unrated	✗
Norway	**Statnett**	Good	A+/A2/-	✓
UK	**National Grid**[71]	Good	BBB+/Baa1/BBB+	✓

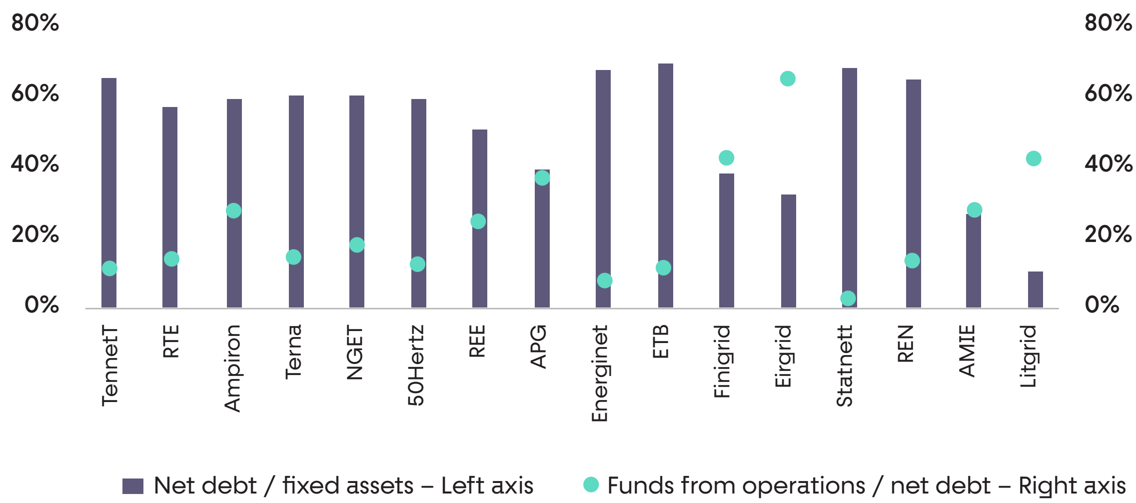
Source: IEEFA analysis based on company reports, LSEG Workspace, as of 31 March 2025.

Figure 11: CAPEX as a share of revenue by TSO (2023)[72]



Source: company reports, IEEFA calculations and adjustments

Figure 12: Net leverage and debt servicing capacity by TSOs (2023)[72]



Source: company reports, IEEFA calculations and adjustments

It can be noted that RTE and PSE, with low levels of CAPEX compared to their revenues, seem to be underinvested. On the other hand, we see small TSOs such as ADMIE showing a high level of investment compared to their ability, but these metrics are slightly distorted due to the very small size of these TSOs. The majority of energy transition investments for grid expansion and smartening will be carried out by the largest five to ten European countries.

8

Conclusions & Recommendations

As Europe seeks to ensure its energy security and unleash economic growth, a great grid upgrade must remain a political priority. Attention needs to be turned from high-level statements into action on the ground, implementing available solutions to enable the secure and smooth build-out of renewables and economy-wide electrification. At the same time, policy and regulatory changes will be vital to enable TSOs to play their role in the clean energy transition.

Based on the findings of our report and a wider literature review, we have compiled a full list of recommendations for governments, regulators and TSOs.

Governments

- Set clear national targets for climate neutrality, committing to deliver a fossil free, renewables-based power system by 2035, and to contribute to the decarbonisation of the economy through electrification and clean flexibility.
- Provide a climate mandate to the energy regulator to strengthen their oversight of the national TSO(s). This will help ensure TSOs can take a suitably long-term outlook in their planning and investments.
- Establish a public body to act as an independent energy system planner, as seen in the UK and Australia, to undertake grid planning and operations and to provide rigorous assessments into the needs of the energy transition, aligned with ambitious climate targets.
- With regulators, implement the highest standards of legal unbundling for TSOs.
- Offer political support to speed up the interconnection process with neighbouring countries to maximise the economic and security benefits of renewables.
- Work with TSOs and public and private financial institutions to support affordable financing of grid infrastructure, including green bonds.

Regulators

- Strengthen oversight of TSO network development plans and investment plans to ensure that they present a timely and efficient pathway to a clean energy system, supportive of an inclusive approach to electrification and flexibility.
- Adopt regulatory best practice on incentive structures to encourage TSO use of non-wire solutions (e.g. by implementing a TOTEX model and incentive-based schemes), addressing the current "CAPEX bias" that can occur. Incentivise the widespread adoption of solutions that maximise the existing grid: such as dynamic line ratings, cable pooling, non-firm connections, use of storage and demand flexibility for grid balancing.
- Ensure there are no upper-limit restrictions on the energy scenarios that TSOs can utilise in their network planning, which might prevent more ambitious levels of renewables, electrification and flexibility than seen in national plans and targets.
- Regulatory approaches must be adapted to the new challenges for capital and operational costs. This includes lowering barriers to speed up conventional solutions and anticipatory investments. Frameworks for anticipatory investments should allow for higher uncertainty and be more comprehensive and better coordinated, for example, through accelerating permitting processes and ramping up innovation.

- Ensure that the costs of grid upgrades are fairly distributed, and do not unduly increase the energy bills of vulnerable and low income households. Monitor TSO investment plans to ensure sufficient balance of CAPEX and OPEX solutions to support a cost-effective approach.
- Mandate TSOs to regularly publish data on key indicators, including but not limited to grid connection queues, available grid capacity and planned investments. This data should be in an easily accessible format. Grid operators should be required to publish the energy scenario(s) used for identifying necessary grid investments, to allow for better scrutiny and monitoring.

TSOs

- Work with governments to cut connection queues for important electrification, renewable and storage projects. This can include via strategic project prioritisation; mobilising participants in congestion management; shared connection and colocation of assets; and rolling out alternative connection contracts. Publish grid capacity maps, as specified in the Electricity Market Design revision.
- Ensure that grid planning scenarios are based on the latest data about renewable deployment and reflect the needs of an electrified economy. Such scenarios may point to a faster pace of change than anticipated by the government of the day. The grid plan should include not only a ten-year investment plan, but also a long term vision for the network until 2040 or 2050 to allow identification of anticipatory investments.
- Ensure that investments are aligned with supporting a renewables-based energy system by 2035, undertaking anticipatory investments to underpin delivery.
- Reduce curtailment by boosting non-thermal flexibility, storage and interconnection with other countries. Increase transparency on current curtailment levels and locations to better inform potential investors and enable roll-out of solutions.
- Invest in digitalisation, rolling out smart systems and streamlining processes to support a more efficient and cost-effective operation, including with dynamic line rating technologies.
- Use open-source energy models to enable proper oversight and scrutiny.

Annex 1: List of indicators considered for each data category

The table below gives an overview of all the different data categories researched for the report. It also considers the level of data completeness for each. “Good” indicates that data was easily available online via desk-based research, and therefore we have a nearly full data set for these categories. “Medium” indicates that it was challenging to find data, but with a combination of desk-based research and engagement, we were able to find over two thirds of the relevant variables. “Poor” suggests it was very hard to find accessible data, either via desk-based research or engagement, and indicates that we were able to find data for a third of the TSOs or less.

Data category	Subcategory	Data completeness
Governance	Ownership (public share)	Good
Governance	Ownership (detailed)	Good
Governance	Company structure	Good
Governance	Unbundling model	Good
Governance	Legislative mandate	Good
Governance	Government climate neutrality targets	Good
Governance	TSO reference to climate targets	Good
Governance	Regulator reference to climate targets	Good
Finance	Total revenue and profits	Good
Finance	Credit metrics	Good
Finance	Regulated asset base	Few
Finance	Funding structure	Medium
Finance	CAPEX plan	Good
Finance	CAPEX breakdown	Few
Grid operations	Grid connection delay	Poor
Grid operations	Grid connection queue	Medium
Grid operations	Grid connection process	Good
Grid operations	Non-firm grid connection offers	Poor
Grid operations	Use of dynamic line rating	Medium
Grid operations	Annual RES-E curtailment	Medium
Grid operations	Congestion - redispatch costs	Poor
Grid operations	Interconnector use (70% rule)	Medium
Grid operations	Maximum RES load	Poor
Grid planning	Carries out integrated grid planning	Medium
Grid planning	At least one 2035-aligned scenario in NDP	Medium
Grid planning	Vision document 2035-aligned	Medium
Grid planning	Energy model used for grid planning	Medium
Grid planning	Uses open energy model	Medium
Politics	Government has 2035 clean power target	Good
Politics	Current national share of renewables	Good
Politics	Position on Capacity Remuneration Markets	Medium
Politics	Global progressive TSO coalition member	Good
Politics	ENTSO-E board member	Good
Politics	ENTSO-E committee chair	Good

References

1 See figures in Chart 1 which give an overview of connection queues in different countries. The total number incorporates different timelines and technologies in each country, so should be taken as a rough estimate for 2024.

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5 IEA (2024): Integrating Wind and Solar - technology report

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9 Content in this table is not uniform across countries due to differences in data collection and publication across TSOs, including different timeframes used to collect data, and different technology types covered. The data was sourced from:

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Figure 12 only:
Excludes TSOs with a very low or negative net debt position: ESO, Elering, PSE, Transelectrica and Kraftnat. FFO refers to reported funds from operations as calculated from reported cash flow from operating activities before working capital changes. Net debt includes interest-bearing financial debt and lease liabilities but excludes hybrid securities booked as equity.