Putting the mission in transmission: Grids for Europe's energy transition

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Lead author: Elisabeth Cremona
Other authors: Dr Chris Rosslowe

Contents

About

This report aims to contribute to the current debate on power grids by offering an analysis of the present state and future developments of national transmission grids in Europe, framed within the context of the energy transition. The report analyses data related to national electricity transmission networks across 35 European countries (EU-27, Norway, Switzerland, UK and Western Balkans), assessing their readiness to deliver on power sector needs for the energy transition, and concluding with key recommendations.

Energy scenarios used by national electricity Transmission System Operators (TSOs) to develop their grid plans are benchmarked against established policy targets and market outlooks. We find a number of grid plans are based on under-ambitious energy scenarios, risking that transmission networks will be inadequately prepared to support the expected wind and solar build out.

Highlights

11 of 26	205 GW	€5 bn
National transmission grid plans based on outdated wind and solar targets	Grids are being designed using scenarios with more than 200 GW less new solar than anticipated by market forecasts	REPowerEU underestimates annual grids spending by at least €5 bn

Executive Summary

Transmission networks risk holding back the turbocharged energy transition

Grid investments across Europe must be stepped up and planning processes fully aligned with the new reality of the energy transition.

Grids have recently skyrocketed onto the political agenda. As clean technology deployment surges forward, it is increasingly coming up against the bottleneck of insufficient grid capacity, leading to connection delays, curtailment and increased costs for consumers. While the overall challenge is clear, the underlying causes are not always apparent, particularly for national transmission networks where there is little accessible information.

Our analysis, based on 35 national grid development plans from European Transmission System Operators (TSOs) of electricity, shows that planned network developments in a number of countries are out of step with the reality of the energy transition. This risks that grid investments will be insufficient to deliver on 2030 energy security and climate ambitions. This must be urgently addressed, particularly as grid developments are characterised by much longer timescales than clean technologies. Additionally, failing to address grid capacity issues in a timely manner will be expensive, and already constitutes a substantial cost for many countries. In 2023, Spain spent more to manage its already congested transmission grid than it invested in its development.

Some positive steps are already being taken towards addressing grid challenges. TSO plans reveal a trend of increasing grid expansion over the coming decade, alongside network refurbishments and upgrades. TSOs are also prioritising non-wire solutions to urgently alleviate grid congestion. Several TSOs have ambitious grid expansion plans, proving the feasibility of rapid grid development if there is political prioritisation. More bold action on grids will be needed across Europe in the coming years, however, to unlock the benefits of transitioning rapidly away from fossil fuels.

01 11 out of 26 grid plans are based on lower wind and solar deployment than national targets

A lack of alignment between grid plans and national targets is apparent in many countries, risking insufficient preparation to integrate wind and solar. Solar tends to be more affected, with its capacity underestimated by a total of 60 GW across the 11 countries, and wind by 27 GW. This appears to be primarily a consequence of the grid planning process lagging behind energy policy updates.

02 205 GW of solar could hit gridlock by 2030

19 out of 23 national grid plans examined undershoot the deployment of solar expected under SolarPower Europe's business-as-usual scenario, by a total of 205 GW by 2030. Wind is underestimated in ten out of 31 plans analysed, by a total of 17 GW. These discrepancies imply grid congestion may worsen in the short-term as grids are ill-equipped to manage the rapidly growing renewable fleet.

03 REPowerEU underestimates annual grid investment by at least €5 billion

Spending on grids today in EU Member States reaches approximately €63 billion, with an average of €28 billion per year earmarked for transmission grids and €35 billion invested in distribution grids in 2022. This spending surpasses the European Commission's estimate for annual grid investment of €58.4 billion until 2030. Furthermore, it is likely that investment in national transmission systems will need to be augmented to make them "fit-for-purpose" in those countries where grid plans lag behind existing energy policy.

The current high-level discourse and political attention on grids presents a crucial opportunity to tackle the obstacles hindering adequate grid development. Grid planning must become more nimble and anticipatory, instead of being tied to outdated assumptions and targets, as it presently is in many cases. Decisions made today will shape Europe's future power grid for decades to come.

"We can't afford to overlook grids. They risk holding Europe's supercharged energy transition back if plans aren't updated. Making sure solar and wind can actually connect to the system is as critical as the panels and turbines themselves. There is no transition without transmission."

Elisabeth Cremona
Energy & Climate Data Analyst, Ember

Gridlock

Grid outlooks suggest the energy transition is at risk

Decisions made today will shape Europe's future power grid for decades to come. The challenge lies in ensuring that network planning is sufficiently forward-looking to adapt to an accelerating transition with many faster moving pieces, notably wind and solar.

The energy crisis and Russia's invasion of Ukraine has turbocharged Europe's shift from fossil fuels to renewables. The results of this are already evident, with renewables rising to a record 44% of the EU's electricity mix and fossil fuels dropping by 19% to their lowest ever level in 2023.

However, as clean technology investment reaches record highs, its deployment has started to come up against previously overlooked challenges. One of these challenges is a lack of grid capacity.

In some places, grid capacity is reaching its limit due to insufficient expansion, ageing infrastructure and inadequate flexibility. Signs of stress in the form of lengthy grid connection queues and increasing curtailment of renewable electricity have drawn attention to the central role of grids in decarbonising Europe's economy, pushing grids far up the political agenda for perhaps the first time. Notable developments include the High-Level Forum on the "Future of our Grids" in September 2023, organised by ENTSO-E with the patronage of the European Commission, and the EU Action Plan for Grids published in November.

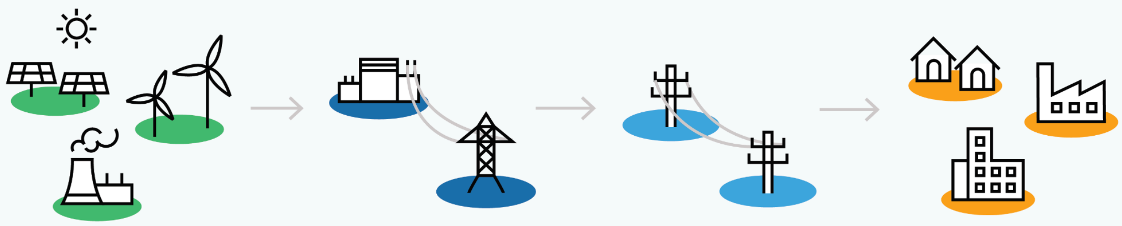
Research on investment needs in the distribution grid and interconnectors exists, but comparatively little information is available on the national transmission networks, hindering problem assessment, solution identification and evaluation of this piece of the puzzle.

What makes up the grid?
Electricity grids can be broadly classified based on their voltage levels, typically into distribution systems (medium and low voltage), managed by Distribution System Operators (DSOs), and transmission systems (extra-high and high voltage), managed by Transmission System Operators (TSOs).

The transmission network consists of both:

- National transmission lines which transport electricity long-distances within a country — the focus of this report.
- Cross-border lines, also known as interconnectors, which connect two neighbouring electricity systems. These bring unique benefits to Europe's power system.

How electricity grids work



A

Large-scale generation
Electricity is generated in power plants - such as wind and solar farms, thermal and hydro units. Large-scale generators are typically connected directly to the transmission grid, other generators such as small solar PV units are connected to the distribution grid.

B

Transmission
The skeleton of the electricity grid - high-voltage lines that connect main substations, carrying electricity between key generation and demand centers. This also includes cross-border connections between neighboring countries.

C

Distribution
Medium and low-voltage lines and transformer stations. The distribution network carries electricity from transmission grid nodes to end users.

D

Consumption
End users of electricity such as households, factories, office or public administration buildings.

Source: Ember

As the energy system becomes increasingly renewable, electrified and decentralised, each part of the power grid and its operators play a distinct role, involving different stakeholders and policy processes.

While much of this transformation is taking place at the lower voltage levels managed by DSOs, TSO activities are also growing in importance and complexity. TSOs must balance regional variations in supply and demand and integrate an increasingly diverse electricity generation mix, all while continuing to ensure secure and continuous supply. Active cooperation between TSOs and DSOs in both planning and operation of power grids is crucial to integrate new technologies efficiently across voltage levels.

Insights from grid plans

Grid development plans by Europe's TSOs provide the clearest window into the current status and outlook of countries' internal transmission networks. In line with Directive (EU) 2019/944 for the electricity market, TSOs publish their ten-year grid plans approximately every two years, setting out the actions necessary to ensure security of supply, efficiency and achievement of decarbonisation targets while keeping costs low. The plans detail the main transmission infrastructure that needs to be built or upgraded over the next ten years, outlining ongoing and new investments. This is a separate process to the development of the Ten-Year Network Development Plan (TYNDP) undertaken by the European Network of TSOs for electricity which focuses exclusively on cross-border transmission lines.

Grids must move in step with renewable generation and clean demand-side technologies in order to deliver the benefits of the energy transition to consumers. The grid plans from TSOs provide valuable insight into future alignment. Energy supply and demand scenarios lie at the core of the grid plans, with the need to expand or upgrade infrastructure highly dependent on which forecasts are explored. To assess how these match up to the current trajectory of Europe's energy transition, our analysis benchmarks these scenarios against the latest national energy targets and recent market outlooks for wind and solar. The degree of alignment provides a high-level indication of the preparedness of national transmission grids to accommodate the envisioned changes in the energy system necessary to achieve policy goals and facilitate the integration of accelerating renewable deployment.

Given the uncertainties that come with a minimum ten-year outlook, TSOs often incorporate multiple scenarios to represent a range of possible futures for electricity demand and generation patterns. The infrastructural needs assessment, however, is usually based on one specific scenario — this is the scenario we use in our analysis. In the few cases where the needs assessment is based on more than one scenario, the full range of scenarios is used.

Details of the grid plans and energy scenarios examined in this report can be downloaded here, alongside all of the data presented.

Grid plans misaligned with national policy targets

Analysis of grid plans shows that planned transmission grid developments may be insufficient to cater for the renewable uptake that is necessary to achieve energy policy targets. The energy scenarios in the latest grid plans from European TSOs show a high degree of misalignment with current policy targets in certain countries. This is particularly evident in the foreseen installed capacity of wind and solar in 2030. Since it takes far longer to increase grid capacity than it does to deploy wind and solar projects, grids may not be prepared to meet the scale of future increases.

Planned wind and solar capacities are in some cases misaligned with targets

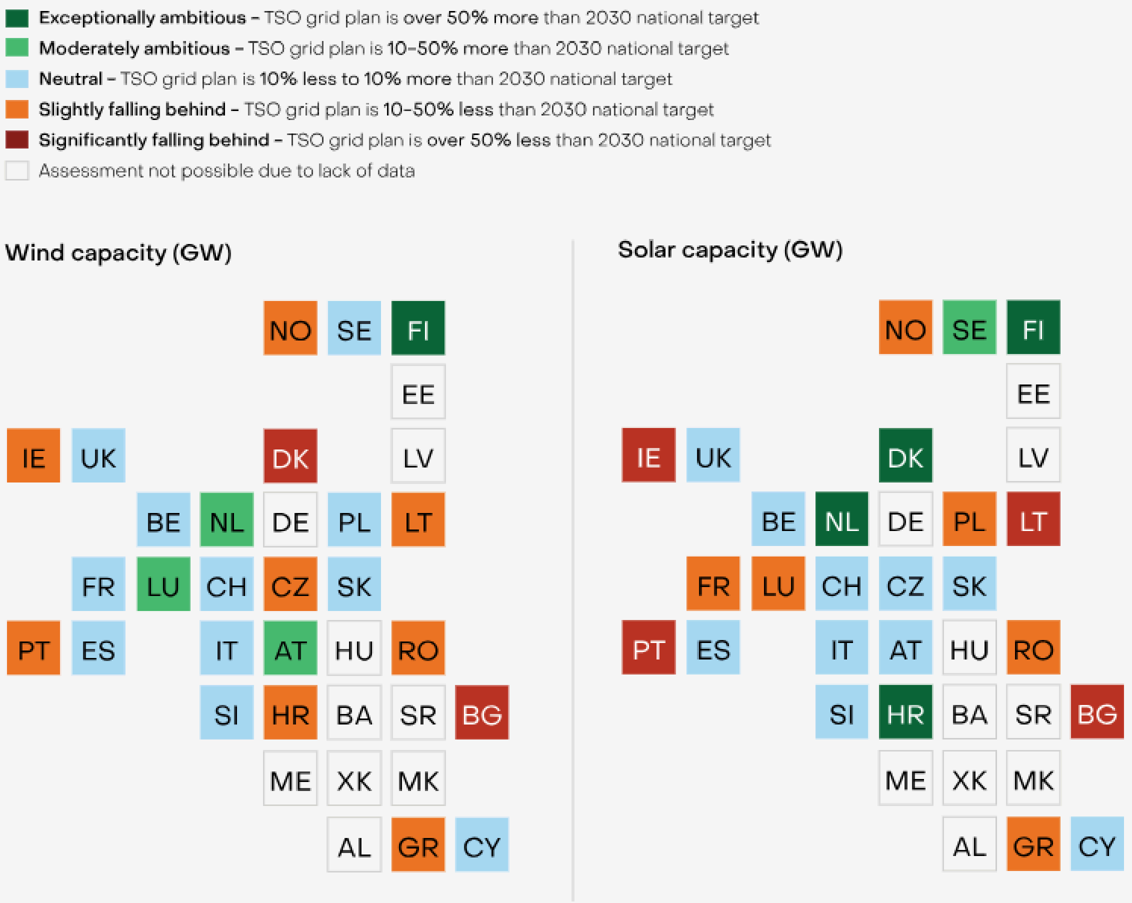
Close alignment with national wind and solar targets should be expected in TSO grid plans, since national legislation related to grid planning often requires TSOs to abide by existing energy policies targets when preparing their plans. However, analysis shows that this is not always the case, with some plans significantly undershooting the national targets.

Wind and solar capacities from the 26 grid plans with adequate data available were compared to their respective 2030 country targets. Of these, ten use scenarios with lower ambition than targets. Among the rest, 13 grid plans were found to be well aligned, and four use more ambitious scenarios.

Of the ten of 26 grid plans that are based on scenarios where the combined capacity of wind and solar is lower than established national policy; the total difference is 65 GW. This is equivalent to about 8% of the total capacity targeted by these countries. While that may not seem significant at a pan-European level, the divergence at national level in certain countries is concerning. For instance, Bulgaria's grid development plan assumes 4.1 GW wind and solar in 2030 but the country's policy target is more than 11 GW, a difference of 63%.

Comparing TSO grid plans to national policy targets reveals cases of misalignment, risking insufficient network development

TSO grid plans vs. 2030 national targets



Source: Ember analysis of Transmission System Operator (TSO) plans, Draft updated NECPs, 2030 Global Renewable Target Tracker
Certain countries could not be assessed due to lack of data or, in the case of Germany, because the data corresponds to the grid plan's target years 2037 and 2045, and not 2030. Countries examined in this report include EU27, Norway, Switzerland, UK and the Western Balkans. Kosovo (XK): This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.

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When TSOs' assessments of future infrastructure needs are based on under-ambitious scenarios, it is likely that new investments necessary to support policy targets will be overlooked and their development delayed. This means that, instead of playing an enabling role, transmission grids in a number of countries risk being unprepared to support the wind and solar roll-out expected by national policy, creating a physical barrier to the transition.

However, this is not universally the case. The four plans based on scenarios with higher capacities for wind and solar include Croatia, Denmark, Finland, and the Netherlands. The scenarios used by most of these TSOs are significantly more ambitious than existing targets, ranging from 50% higher for Denmark to 200% higher for Finland.

Across these four countries, the grid plans are preparing for 81 GW more wind and solar than national policy targets. This is a sensible approach that better prepares transmission networks to accommodate potential future step ups in national ambition levels. Indeed, the Finnish TSO notes its scenarios tend towards more positive outcomes as scenarios limited in ambition will not challenge Finland to prepare for the energy transition, but could only guide it to resolve short-term challenges. These more ambitious scenarios also better reflect the accelerated state of the energy transition, such as in the case of the wind and solar capacities used by the Dutch and Croat TSOs which are similar to the market outlooks for these technologies.

Solar tends to be more underestimated

To understand how grid planning is tracking against overall targets, combined wind and solar shortfall is a useful indicator. However, considering them separately shows that in some plans one or the other may be more significantly out of step with national policy. The split between wind and solar is an important factor when planning a transmission grid, as their installations are likely to be built in different locations according to the distinct resource potential for each energy source. This would impact the locations where grid investment is required to address local geographical imbalances between production and consumption. Therefore, considering misalignment by source reveals where grid issues could be more likely to emerge.

Solar tends to be more affected by misalignment, with solar's capacity underestimated by 60 GW across 11 countries. The same number of countries use wind capacities which are lower than national targets, but the discrepancy results in a relatively smaller difference of 27 GW.

This bias towards underestimating solar is also reflected at the country level. The greatest absolute difference in solar capacity is between the energy scenarios used by the French TSO RTE (35 GW) and France's national solar capacity target (54 GW), a difference of 19 GW in 2030. The largest difference is between the scenarios used by Denmark's TSO Energinet (8.25 GW) and national targets (17.2 GW), an underestimation of 9 GW. That being said, in terms of combined wind and solar capacity, Denmark's grid plan remains more ambitious than the national target as it includes a much higher solar capacity of 35.5 GW, compared to 11.7 GW.

Aligning targets and infrastructure planning
It is likely that the observed misalignment between grid plans and policy targets stems from a time lag between the establishment of national policy and the development of grid plans. In most cases, underestimates in grid plan capacities match more closely with previous, superseded policy targets.

Grid plans are based on energy scenarios that trail national targets for 2030 wind and solar

Wind and solar capacity in 2030 (GW)

Source: Ember analysis of Transmission System Operators' (TSOs) grid development plans
Countries examined in this report include EU27, Norway, Switzerland, UK and Western Balkan countries. Old targets refer to 2019 national energy and climate plans (NECPs). New targets refer to latest announced policy targets.

The common requirement for TSOs to abide by established national targets when planning their grid, while logical in principle, is causing grid plans to persistently lag behind the latest level of ambition.

The process of transposing political targets into national legislation (which often takes about two years), and subsequently incorporating them into grid plans creates a sequential time lag. This means that grid planning, despite its cyclical nature, is often unable to keep up with the widespread increases in EU and national ambition levels, particularly over the last five years. The EU's 2030 targets for renewable energy were initially increased from 27% to 32% in 2018, and subsequently raised further in 2022 to 42.5-45% in response to the gas crisis.

Additionally, targets themselves often lag behind other external conditions, making it difficult for grid plans to keep up with the fast evolution of the energy landscape and therefore better reflect and prepare for reality.

Grid plans require approximately two years to be developed, owing to their complexity, and the energy scenarios that form the basis of these plans are largely fixed at the start. This means a grid plan published in 2023 would be using scenarios developed in or before 2021, which is based on a political target that was likely set in 2019.

Power networks should be ready to facilitate renewable and clean technology deployment, but this will not be achieved if grid plans remain exclusively rooted in targets established in national legislation at the start of the planning cycle. This is especially important as grids typically take much longer to build than renewable generators. Additionally, latest member state targets for wind and solar build out are not yet sufficient to deliver on REPowerEU commitments and will need to be stepped up further. This implies that even those grid plans well aligned with recent policy targets risk inadequate preparation of the infrastructure necessary for REPowerEU ambitions.

A number of countries provide insight on how this issue could be avoided. The Finnish TSO Fingrid appears to use high level political targets, such as climate neutrality in 2035 and EU climate neutrality in 2050, to guide its scenarios, rather than being tied to set medium-term policy trajectories. The German TSOs have taken a similar approach, using a scenario framework that considers a time horizon until 2045, the target year for achieving climate neutrality in Germany. In this way, the resulting infrastructural plans ensure that the electricity transmission network will be prepared to deliver and support a climate-neutral energy system.

Grids risk being unprepared for the upcoming solar surge

While many grid plans already lag behind policy commitments, market trends in some clean technologies are outpacing both. Clean technologies are accelerating so swiftly that they surpass even the most ambitious EU policy targets. Comparing the 2030 wind and solar capacities foreseen in grid plans to market outlooks from WindEurope and SolarPower Europe reveals that many grid plans do not account for the recent acceleration of clean energy technology deployment across Europe, a trend anticipated to persist.

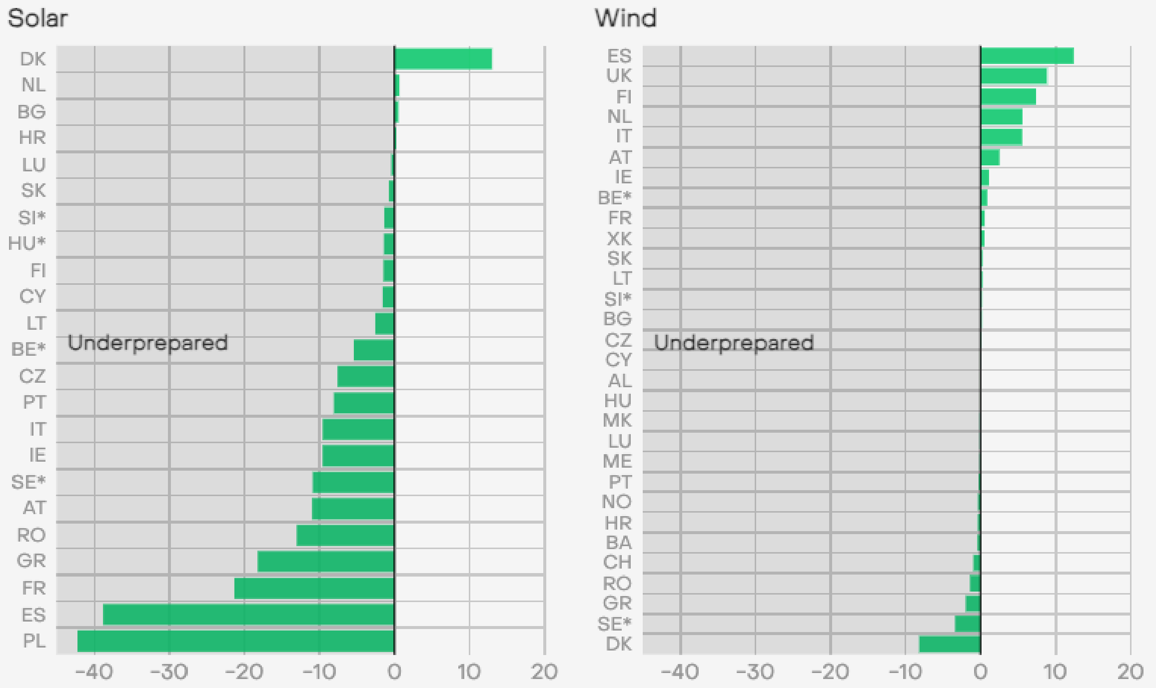
Solar, in particular, is consistently underestimated in grid expansion plans compared to market outlooks. Out of the 23 plans that could be assessed against solar industry outlooks, 19 were found to be significantly lower than the 2030 market forecasts, between 12-82% below expected capacities. Across the 23 plans, a total of 205 GW less capacity is being planned for in grid developments than the market expects.

This disconnect from on-the-ground trends implies, unless remedial actions are taken, grid congestion may worsen in the short-term and larger volumes of solar capacity may become stuck in grid connection queues. While this issue is more often discussed for distribution grids as the majority of solar installations are connected to lower voltage levels, a coherent grid planning system for the transmission network should take into consideration expected deployment at all voltage levels.

The situation for wind is less obviously misaligned, likely due to more stable outlooks for the sector, but there is still evidence of disconnect. Out of the 31 grid plans that could be compared to WindEurope market outlooks, ten were found to use lower wind capacities (13-80% lower) than those expected by the industry in 2030, underestimating wind installations by a total of 17 GW. In contrast, 12 grid plans use higher capacities for wind (13-100% higher or more), a positive difference of 44 GW. This indicates that grid preparations in these countries are being made to integrate a larger wind fleet than that expected by WindEurope. This is a positive finding as it means transmission networks will be ready to integrate more wind installations, should these be pursued by developers.

205 GW of solar could get held up as grid plans underprepare for the expected solar surge

Difference in 2030 capacity forecasts between TSO grid plans and market outlooks from SolarPower Europe and WindEurope (GW)



Source: Ember's analysis of TSOs' grid development plans. Market outlooks are based on the business-as-usual forecasts from, WindEurope's Outlook for 2024-2030, and SolarPower Europe's EU Market Outlook 2023-2027
Certain countries could not be assessed due to lack of data or, in the case of Germany, because the data corresponds to the grid plan's target years 2037 and 2045, and not 2030. Solar values are reported in AC, according to the authors' assumptions. *In the case of grid plans based on more than one scenario, the difference in capacity is based on the most ambitious TSO scenario.

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This disconnect between TSO plans and on-the-ground trends extends across fast developing clean technologies. There is also evidence that the rapidly evolving trends in battery storage may have been overlooked by some TSOs when planning future grids. Twelve grid plans provide figures for future battery storage deployment. This is despite a forecast of exponential growth in the sector, taking Europe's grid-scale battery storage from 7 GW today to over 50 GW by 2030. Ireland is currently a leading market, and Eirgrid's latest grid plan foresees 3.2 GW by 2030. Yet, recent research reveals an existing project pipeline of 6.3 GW, of which 4.7 GW have been approved (in addition to 1.3 GW already in operation). Conservative assumptions such as this may be leading TSOs to underestimate the degree of flexibility available on their future networks, leading to an over-reliance on conventional fossil sources.

While grid plans are not specifically designed to take market trends into account, they should be forward-looking enough to adapt to the evolving investment landscapes. This is especially important as clean energy technologies can be deployed much faster than the time required to build or upgrade transmission lines.

Grid development plans show promise, but must be stepped up

TSO plans reveal a trend of increasing grid expansion over the coming decade, alongside network refurbishments and upgrades. However, higher or front-loaded investments are likely to be necessary in countries where grid plans lag behind existing energy policy.

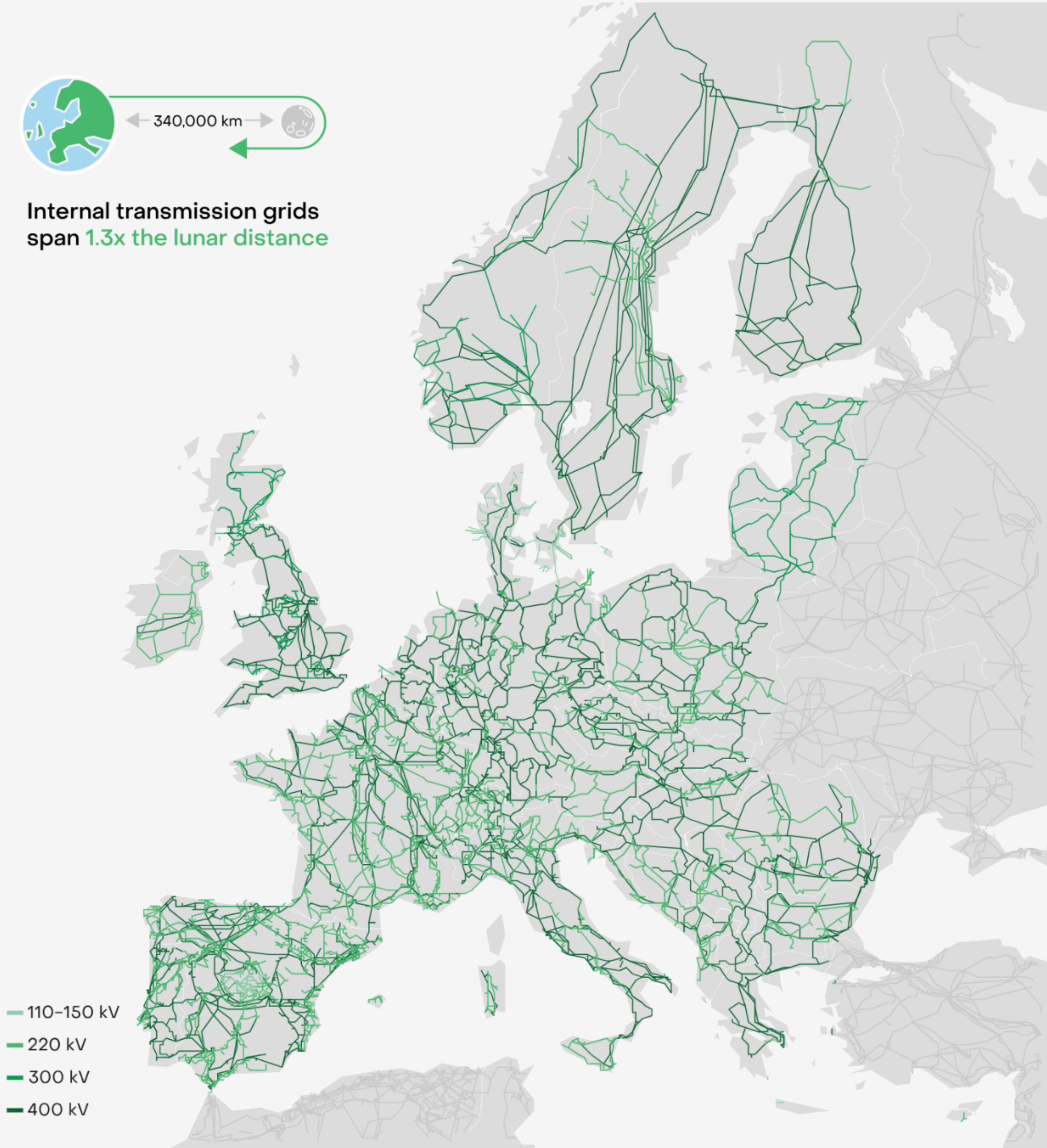
Europe's extensive grid system is already helping enable decarbonisation. But as the rollout of wind, solar and other clean technologies accelerate, grids need to be prepared to avoid turning from an enabler to a bottleneck. Ember's analysis of grid plans suggests that developments may not keep pace with the accelerating energy transition.

However, various examples from TSOs show that there are an array of options to make up this shortfall and accelerate grid developments. With some changes in approach, transmission networks could lead the way on delivering towards the objectives of a clean, secure and affordable energy future.

Europe's energy transition will be powered through its enormous grid

The scale of Europe's grid system is enormous. Europe's national transmission networks today consist of approximately 500,000 km of lines between voltages of 110-400 kV, based on data Ember has compiled from Transmission System Operators (TSOs). This length exceeds the average distance from Earth to the Moon.

Transmission lines within countries create a network which extends almost half a million kilometres long



Lengths of national transmission grids in Europe (in thousand kilometres)

Source: ENTSO-E (map data), Ember (length data)
The data presents line lengths of transmission networks as at end 2022, excluding cross-border lines. Where this data was unavailable, data for other historic years are used, none of which date back further than 2019. Line lengths are presented in terms of circuit length not geographic route. Countries include EU-27, UK, Norway, Switzerland and the Western Balkans. Borders of Kosovo: This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.

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The extensive connections within and between countries are an enormous asset in enabling Europe to rapidly decarbonise, providing the necessary infrastructure to accommodate higher volumes of electricity from increasingly distributed generation sources in new geographic locations — wind and solar. However, as the previous section showed, grid planning will need to become more nimble to match the increasing ambition and need for renewables across Europe.

Aligning grid capacity

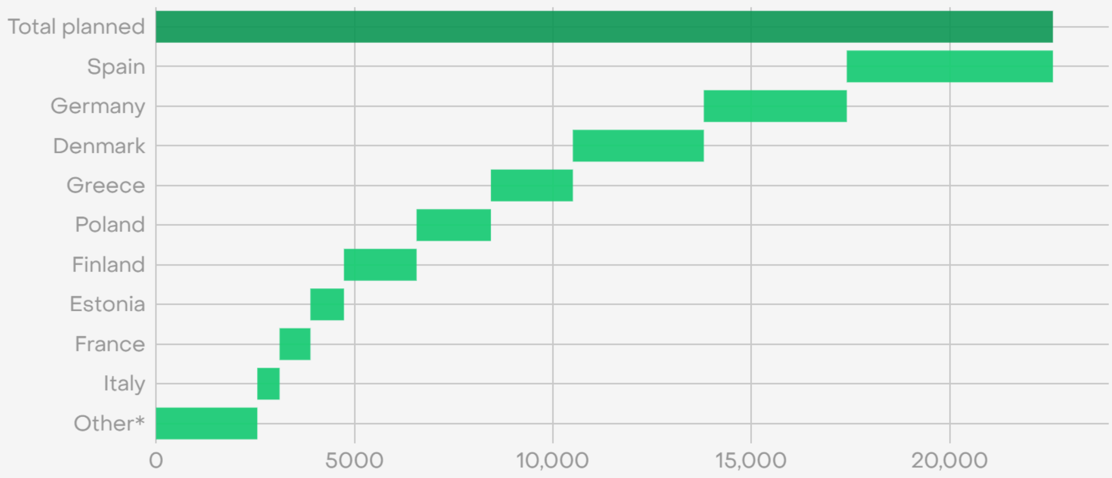
Lack of grid capacity can be addressed in two ways. Firstly, by physically expanding the capacity. This is done by adding new power lines to existing routes and establishing new routes. Secondly, by maximising the use of the existing networks through refurbishment of existing lines, digitalisation, and greater utilisation of demand flexibility and storage. These actions are complementary and both indispensable in tackling the grid challenge.

While there are concerns that TSOs are incentivised to favour new build over other solutions, it should be noted that maximising the use of the existing infrastructure alone will not be sufficient. Expanded infrastructure will still be needed to accommodate growing electricity demand and reach the new locations of renewable generators.

Network expansion outlook
According to grid plans from 35 countries, over 25,000 km of new lines are planned between now and 2026, increasing the total length of national transmission networks by 5.3%. This would bring the total length to approximately 523,000 km by the end of 2026.

European countries plan to add over 25,000 km internal transmission lines by 2026, led by Spain

Total new lines to be added between 2023 and 2026 (km)

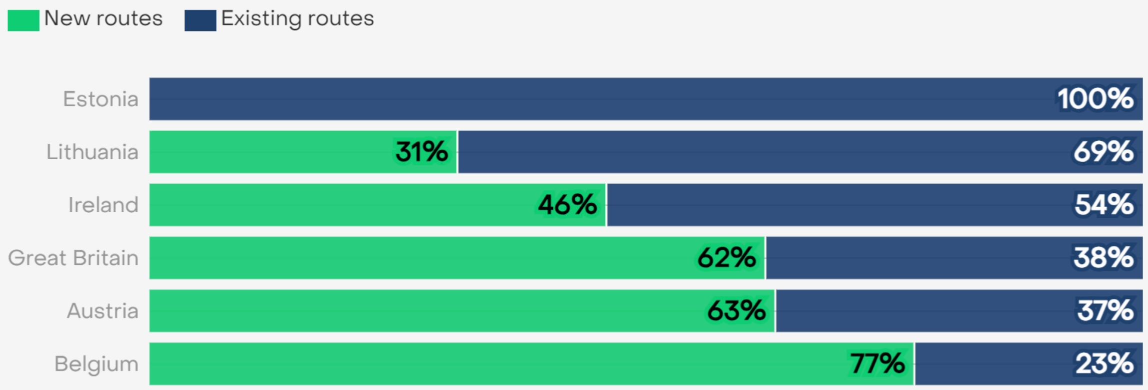


Source: Ember
Countries include EU-27, UK, Norway, Switzerland and the Western Balkans.
*The category "Other" covers those countries that do not publically report planned line lengths. It is estimated based on the average growth reported by the other countries, which account for more than 90% of total line lengths in 2022.

New lines can either be developed along existing land corridors or as an entirely new route, according to the potential locations of new supply and demand patterns.The use of new or existing land corridors is a decision that can affect the speed and efficiency of expanding network capacity. In some cases, the use of existing corridors can reduce the need for additional permitting including environmental impact assessment. On the other hand, there may be a strong need to expand the physical footprint of the high voltage grid, for example to connect new areas of high renewable potential to the network, making new corridors unavoidable. Six TSO plans provide insight into the different development patterns of planned lines, showing that approaches may vary according to existing transmission routes and the projected location of future needs.

The use of existing line corridors for new grid projects varies substantially between countries

Estimated percentage of high-voltage transmission line projects using existing versus new land corridors



Source: Ember
Estimated from information published about individual line projects commissioned between 2021 and the end of the planning period (typically early 2030s). Countries that are shown provided high quality data with sufficient granularity. Only line projects of 220kV or above are included. Includes transmission lines that are entirely new or are to be increased in voltage of capacity. Refurbishments at the same voltage level are not included.

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Is network expansion accelerating?
Limited historical data makes it difficult to identify whether current network expansion plans constitute an acceleration compared to historical development. Out of the ten TSOs that report both historical and planned line lengths, five expect growth rates between 2023-2026 that exceed historical rates between 2015-2022, while the other five foresee slower expansion. In addition to data availability, it may be difficult to identify a clear trend due to a single project having significant impact on line lengths, or TSOs focusing investments more on refurbishing existing lines or other grid components.

Despite this, there is a clearly evident trend that grid expansion is expected to ramp up in the subsequent four years after 2026. In the 25 plans with sufficient data, the total transmission line length will expand by 3.8% between 2023-2026 and then by 8.1% between 2027-2030. These figures indicate TSOs foresee a continuing need to physically expand their networks over time and accelerate the rate at which new lines are laid down.

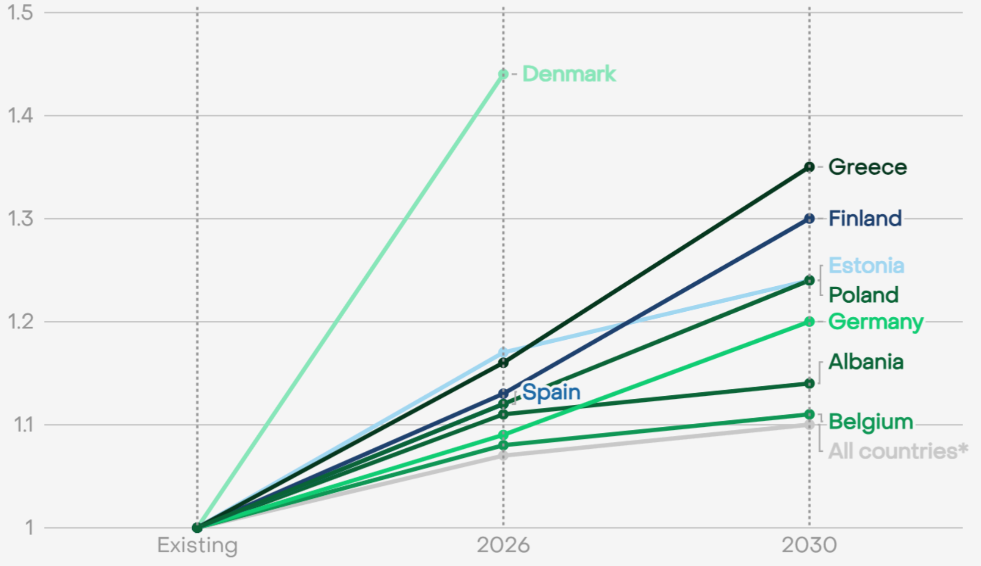
It is likely that network expansion plans will need to go further than these positive signs, given the gaps identified between the scenarios used and national policy commitments. However, it is difficult to assess the scale of the necessary increase due to the variety of national circumstances and the complex analysis involved in network planning. To improve identification of potential investment gaps before they present problems for grid capacity, the process of national grid planning could benefit from increased scrutiny and oversight from a centralised perspective. Similar processes are already in place for other components of power system planning, such as the collaborative assessment of optimal cross-border needs (TYNDP) which is undertaken by ENTSO-E and approved by the European Commission following an opinion by ACER.

Accelerating network expansion is feasible

Several TSOs are planning significant grid expansion over the near term, indicating that a significant scale up can be feasible within a short timeframe. For instance, investment plans published by Danish TSO Energinet earlier this year reveal that the TSO will expand its grid by 3,300 km between 2023 and 2026, an enormous expansion compared to the existing 7,440 km grid. This would put the annual rate of growth at 7.6% for the next four years, compared to 3.6% between 2015-2022.

At least 10 European grid operators are targeting rapid network expansion, led by Denmark

Growth in internal transmission networks (index, 1 = existing line length)



Source: Ember's analysis of Transmission System Operators' grid plans
*Includes EU-27, UK, Norway, Switzerland and the Western Balkans.

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Ambitious grid development objectives call for coordination among grid operators and manufacturers to secure supply chains. The Grids Action Plan highlights improved visibility of grid project pipelines as a measure that can avoid bottlenecks in supply chains and facilitate investments in manufacturing capacity. Mechanisms to deliver this should be established by Q4 2024. ENTSO-E called for clear long-term commitments from the industry, in turn, to invest in manufacturing and supply chain organisations.

Another concrete example is provided by the Baltic synchronisation project, which aims to synchronise the electricity grids of the Baltic states with the Continental European Network via Poland, thereby reducing dependence on Russia. Originally scheduled for completion by the end of 2025, this major infrastructure project was brought forward by ten months following Russia's invasion of Ukraine. The infrastructure works required are substantial: 670 km of new transmission lines are to be built and 660 km of existing lines replaced. This shows that with the political will and the right support in place, grid developments can move rapidly.

Not just growth: Upgrading existing infrastructure is equally important

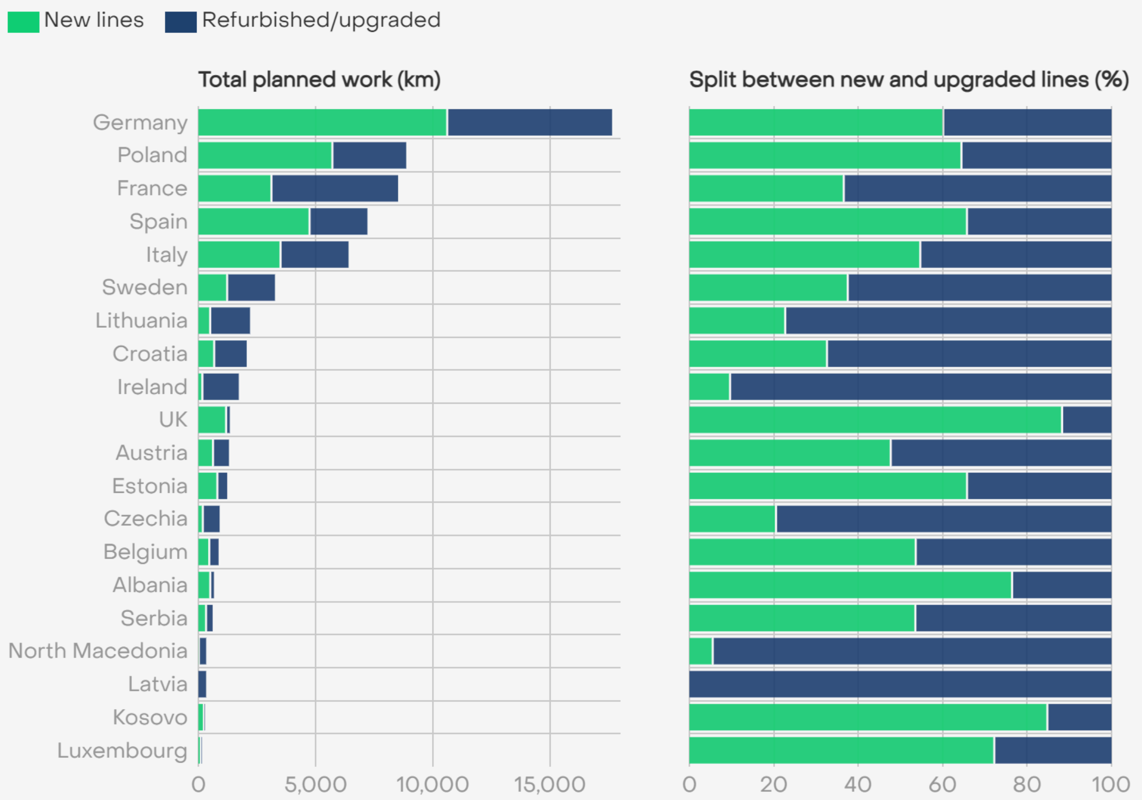
Europe not only needs to expand its electricity grid, but also modernise its ageing infrastructure. Development of much of the high voltage networks took place from the 1950s to the 1980s, making some lines up to 70 years old today, impacting their capacity and performance. Replacement investments have thus become a priority for many TSOs, crucial for both reliability of supply and for Europe to achieve its 2030 targets. Upgrading transmission lines can increase their capacity to handle higher loads, necessary as energy demands grow over time. Modernising and digitalising grids enables the integration of smart grid technologies, creating a more flexible grid that can efficiently accommodate higher shares of renewable energy.

Of the grid plans examined, 20 provide insight into the balance between building new lines and upgrading or modernising existing ones. Approximately 30,000 km of existing lines will be modernised over the coming decade, alongside 34,100 km of the new lines to be built in these countries.

Looking at individual countries reveals significant divergences in this relationship. For instance, the UK places more than 7 km new lines for each kilometre modernised, while Latvia appears to be exclusively planning line upgrades. Different priorities drive grid investment, according to the condition of the infrastructure and TSO outlooks on the future energy system.

Europe's grids will need to be expanded and modernised to unlock the energy transition

Line lengths (km) additional to the existing network (new) and line lengths refurbished/upgraded between 2023-2032



Source: Ember
The line lengths - new and/or refurbished/upgraded - represent the total planned works between 2023-2032. This was selected as it aligns with the period covered by many of the current grid development plans; however certain country plans cover a longer period (such as Germany, until 2045) or shorter period (such as Spain, until 2026).

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Non-wire solutions can rapidly address grid capacity scarcity

The need for additional grid capacity in the near-term may be greater than what can be delivered in the form of new lines in some countries, as already acknowledged by some TSOs. TSOs are therefore increasingly incorporating alternative approaches that can more swiftly (and cheaply) alleviate the problems of a lack of grid capacity.

So-called 'non-wire solutions' can be employed to increase grid capacity as an alternative to new or upgraded network infrastructure. They are also often faster to deploy. A solution commonly referenced in grid plans is dynamic line rating, which increases transmission capacity by allowing lines to operate closer to their thermal limits, rather than implementing fixed values.

Load flexibility constitutes another non-wire solution; smoothing out fluctuations and lowering peaks can alleviate pressure on grid capacity as grids are dimensioned according to the expected peak load. The Dutch TSO TenneT, for instance, has proposed initiatives for large companies and major consumers to use less electricity at peak times to alleviate pressure on its grid, with financial incentives also providing benefits to consumers.

TSOs are already required to take full account of the potential of demand response, energy storage or other resources as alternatives to system expansion when designing their network plans. This obligation is likely to be reinforced through the reform of the electricity market which requires EU Member States to perform biennial assessments of flexibility needs at the national level, based on the input of transmission and distribution system operators.

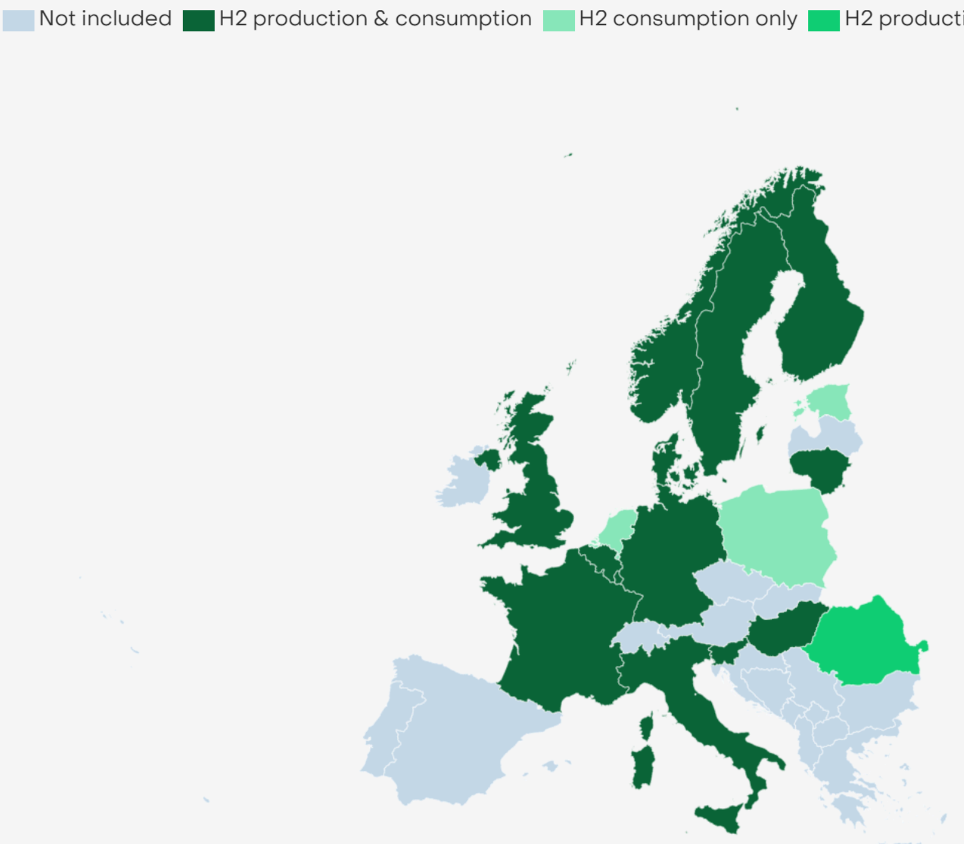
Integrating hydrogen in grid planning is necessary

Hydrogen production and consumption, which is receiving increasing attention following the publication of REPowerEU, has significant implications for the power grid. Electricity TSOs are thus progressively incorporating these considerations into their grid plans, although some only consider one side of this equation.

Integrating the structural effects of hydrogen demand and supply in electricity grid planning is also necessary for both electricity and gas TSOs to analyse the optimal sizing of grid infrastructure. For instance, strategic deployment of electrolyser plants could reduce bottlenecks in the electricity transmission grid and lower the need for grid expansion. However, this is contingent on proximity to the existing natural gas network or planned hydrogen network, which may not be the case as locations of high energy demand and sites of large renewable generators are often different. This implies hydrogen pipelines or storage solutions would have to be newly built, significantly increasing overall system costs.

Europe's grid plans will need to account for the impact of hydrogen strategies

Indicator of whether grid plans include consideration of hydrogen, electrolysis, both or neither



Source: World Bank (boundaries)
Countries include EU-27, UK, Norway, Switzerland and the Western Balkans.
Borders of Kosovo: This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.

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Financing the future grid

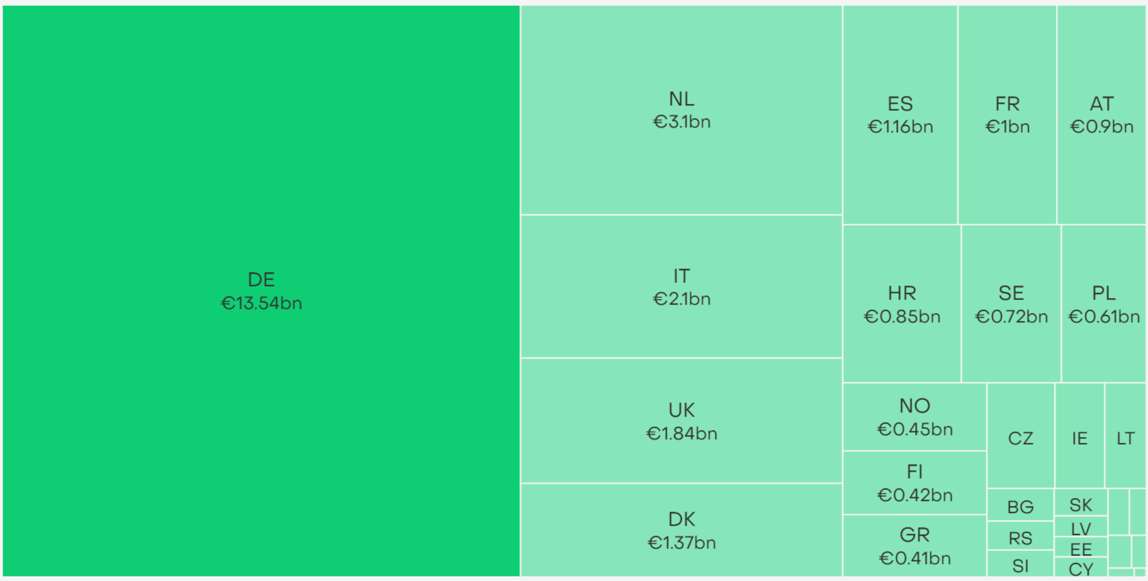
Grid plans provide an estimate of the necessary funding to cover the proposed grid investments (reported by 31 out of the 35 plans examined). Cumulatively, these represent an average spending of just over €30 billion euro each year.

While substantial, failing to address grid issues will be more expensive, and already constitutes a substantial cost for many countries. In 2023, managing its already constrained grid cost Spain [€2.04 billion](), actually exceeding its investment in the transmission grid, an average of €1.16 billion. In 2022, Germany spent more than €4 billion on congestion management alone. This is about 30% of the €13.5 billion average annual investment earmarked for the transmission system.

Historical investment data for internal transmission grids is not reported by all countries, making it difficult to gauge whether Europe's average annual spending on transmission grids represents increased investment, although trends in network expansion indicate this is likely.

At least €30bn is earmarked for national transmission grids in Europe, with a huge push from Germany

Planned investment in national transmission grids, average annual over plan timeframe (in billion euros)



Source: Ember
The investment data is presented as an annual average to account for the different planning horizons used by different countries. In most cases, the investment data corresponds to the projects proposed by the national TSO(s) and not the final budget approved by the government. Investment data represented here covers 31 countries out of the 35 covered by the scope of this report. It does not include those that do not or have not yet published their investment plans: Albania, Belgium, Switzerland, Hungary.

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These investment figures allow us to create a more complete picture of current grid spending by EU member states. Approximately €28 billion is earmarked for annual investment in the transmission grid, and spending on the distribution grid in 2022 reached €35 billion. This amounts to a total annual investment of approximately €63 billion, surpassing the figure put forward by the European Commission of €58.4 billion annually. This underestimates both the total amount of money already being invested into grids in EU Member States, as well as that which is necessary to make them "fit-for-purpose" for the energy transition. It is likely that investment in transmission systems will need to be increased or the investment front-loaded in those countries where grid plans lag behind existing energy policy. BloombergNEF estimates that 2022-2030 grid investments in the EU-27, UK, Norway and Switzerland should reach approximately €106 billion each year under their Net Zero Scenario.

Estimated investment needs for power grids in the years after 2030 indicate that current spending will need to be stepped up to an average of €85 billion per year. This need for increasing investment is already foreseen by a number of TSOs. For instance, the grid plan by France's TSO RTE notes its current average spending of €400 million per year will need to rise to an average of €650 million per year between 2020-2035, doubling after 2035 to reach approximately €1.3 billion per year.

Recommendations

Preparing the grid for the clean energy transition

Expansion of national transmission networks is accelerating but grid plans are struggling to keep pace with increasing ambitions.

The success of Europe's energy transition critically relies on developing enough grid capacity. Constraints are already evident in the form of grid connection queues and congestion, incurring significant costs and risk holding back the accelerating energy transition.

Our analysis shows that expansion of the internal transmission grid in European countries is expected to accelerate over the next decade, indicating a shift in the right direction. However, grid plans do not adequately consider the demands of evolving policy targets, such as increased renewable deployment and rising electricity demand, and diverge significantly from recent market outlooks for clean technologies, particularly for solar. This risks grids becoming obstacles rather than facilitators of the transition, and presents a significant delivery risk for 2030 energy targets.

Grids cannot be used as an excuse for missed targets or justification for low renewable energy ambition. Rapid grid acceleration in some Member States, plus the expedited plans for Baltic synchronisation, show that it is feasible to deliver grid infrastructure projects quickly, given the political will. The ongoing political debate constitutes a crucial opportunity to tackle the obstacles hindering adequate grid development, enabling it to keep pace with the rapid growth of clean technologies.

Key recommendations

Political prioritisation of grids
The critical role of power grids for achieving EU energy and climate goals should be firmly embedded in the political agenda. This would enable strengthened political support and financing, as exemplified by the Biden-Harris administration in the US and the Dutch

government. This is particularly important given that more funding than that originally estimated by the European Commission is needed for grid investment. It would also allow for the acceleration of ongoing and planned projects, as illustrated by the compressed timeline of the Baltic synchronisation project. The Grids Action Plan, published in November 2023, is a strong step in this direction.

Regulatory frameworks must be revised to allow timely planning and investment
National legislation in many countries mandates that TSOs base their network planning on energy scenarios that are in line with the energy targets enshrined in legal documents. This mandate should be revised to encourage TSOs to use energy scenarios that better reflect ongoing policy discussions and market trends of key technologies, even where these developments mean binding national targets will be exceeded. Political targets should only be retained to define the minimum ambition level of scenarios, not the maximum.

Allowing TSOs to plan using forward-looking materials will help in addressing the sequential time lag between policy discussions and the formal update of targets in legislation. It will also facilitate future-proofed planning, ensuring that grid investments will be sufficient to deliver on updated ambitions. This is key to enabling anticipatory grid investments: it is clearly impossible to identify such investments if grid planning is restricted to the boundaries of current or outdated policy.

Increased oversight and scrutiny of network plans
Given the central role of grids in providing energy security and facilitating the energy transition, their planning and development would benefit from additional oversight. The reform of the electricity market provides impetus for national regulators to provide such scrutiny, stating they “will play a central role in ensuring that sufficient investment is provided for the necessary grid development, expansion and reinforcement”. This would require regulators to assess the adequacy of grid plans and their proposed investments to support the timely decarbonisation of the energy system. This could also be accomplished through assigning the responsibility of a net zero mandate to the regulator in countries with such targets, such as in the case of the UK.

Reporting transparency and standardisation
TSOs should be required to regularly publish data on key indicators, including but not limited to grid connection queues, available grid capacity and planned investments. The reform of the electricity market and the Grids Action Plan make important steps in this regard, but fall short in terms of data that will allow assessment of alignment between planned grid investments and power system targets. Grid operators should be required to publish the energy scenario(s) used for identifying necessary grid investments in an accessible and standardised form, to allow better scrutiny and monitoring.

Place clean power at the core of grid planning to enable anticipatory investments
The EU's commitment to limit global heating to 1.5C requires the development of a predominantly clean power system across Europe by 2040. To ensure adequate preparation of electricity infrastructure, future scenarios used to plan the grid must fit such a vision. This is reflected in Action 2 of the Grids Action Plan, which states that TSOs and Member States should ensure sufficient electricity transmission projects to fulfil the infrastructure needs by 2030 until 2050. This should not only be taken to refer to interconnection but also preparing national transmission networks.

Some TSOs already take this into account, implementing “Target Grid” strategies which look ahead to the task that awaits beyond typically five to ten year planning horizons. This enables TSOs to take early action and also feed more explicitly into policy making, shedding light on the trade-offs associated with different political decisions.

Supporting Materials

Methodology

Definitions

National transmission grid
For this report, "national transmission grid" refers to electricity grid infrastructure above 110 kV, and excludes cross-border connections. There are cases where TSOs own lines with voltage levels below 110 kV but these are not included in the data of this report for reasons of consistency.

Line length
Line lengths are reported as single circuit lengths, not geographic routes. For the reporting of line lengths, the double circuits of a power line are considered as different lines, unless otherwise indicated, i.e. a double circuit line of 10 km is reported as a single circuit of 20 km. This approach was adopted to better illustrate the development of grid capacity; the capacity of a line can be increased by adding another circuit, even though this will not increase the length of the geographic route. That being said, we recognise the importance of reporting geographic line lengths to convey the reality of grid expansion, that is, whether TSOs are creating a new route or simply adding capacity to an existing route.

Planned line length refers to the expected change in the length of the national transmission grid based on projects proposed in the TSO grid plan. It should be noted that proposed projects and those approved by the national government are not necessarily the same. However, data availability and transparency presents an issue in reporting the latter.

Planned total line length is calculated as the net change in line length, taking into account additions (both new and existing routes), referred to as "new lines" and decommissioning. In cases where annual data is not available, Ember annualised the reported changes to lines. Plans for refurbishment or upgrade of existing lines are recorded, but not considered to change the total line length unless involving the decommissioning and reconstruction of an existing line. In such a case, the line lengths decommissioned and reconstructed are recorded under "decommissioned" and "new", respectively.

Investment figures
It should be noted that the annual investment volumes largely relate to the grid developments proposed by the TSOs, and may be different to the final list of projects

approved by the government. These investment figures are not always made publicly available.

Data sources

Grid development plans

Grid development plans published by Transmission System Operators (TSOs) constituted the primary source of information, along with data published in their websites. The editorial deadline was set at 31 December 2023. New plans or updates published after this date could not be taken into account.

Where no English version was available, these were downloaded in their original language and translated to English using Google Translate. There may be some cases where the data is not precise as it had to be extracted manually from charts in reports as data is often not made available in accessible formats. Links to the grid development plans can be accessed here.

Data from the grid development plans was collected by Ember in a standardised format, and shared with TSOs prior to publication to allow time for review and correction where required. Ember extends its gratitude to the many TSOs that actively participated in the consultation process.

TSOs from the following countries kindly provided feedback on the data collected by Ember: Albania, Belgium, Cyprus, Germany, Spain, Finland, France, Italy, Lithuania, Luxembourg, Montenegro, North Macedonia, Norway, Portugal and Kosovo.

No data input was received from TSOs of the following countries: Austria, Bosnia Herzegovina, Bulgaria, Switzerland, Czech Republic, Denmark, Estonia, Greece, Croatia, Hungary, Ireland, Latvia, the Netherlands, Poland, Romania, Serbia, Sweden, Slovenia, and Slovakia. The 2024 report published by SeeNext on *Renewable Energy Industry in Southeast Europe* was used to validate data for Bulgaria, Croatia, Greece, Romania, Serbia and Slovenia.

National policy targets

Latest national policy targets represent the most recent political commitments. These are sourced from Ember's Live NECP Target Tracker and 2030 Global Renewable Target Tracker. Old national targets are based on 2019 National Energy and Climate Plans (NECPs).

Further notes

- Inconsistent data availability meant that only selected countries could be assessed across all categories, including capacity planning and targets, market outlooks, length of planned new and modernised grid lines and investment.
- The energy scenarios underlying Germany's grid development plan could not be benchmarked against national policy targets or market outlooks as 2030 capacity figures for wind and solar were not available. These are published for 2037 and 2045.
- Malta is not included in the list of European countries as it does not have a transmission system, except for one 220 kV AC interconnector to Sicily.
- Solar capacity can be reported as DC or AC rated capacity. However, capacity figures from TSO plans, national policy targets and market outlooks rarely specify which style of reporting is used. Assumptions were made by the authors in an attempt to compare like with like in this report. These assumptions are clearly stated in the datasheets.
- Comparisons between energy scenarios from TSO grid plans and market outlook from SolarPower Europe are based on AC capacity, in line with the authors' assumptions. Any DC capacity figures were converted to AC assuming a 1.2 AC to DC conversion rate, the same used by SolarPower Europe.
- Seven countries do not report planned network expansion in kilometres. The lines added in these countries between 2023 and 2026 was estimated by applying the average percentage increase of the 28 other European countries. These countries represent over 90% of the total current line length of national transmission grids.
- In benchmarking data from grid plans and market outlooks, there were a few instances where reported data diverged by one year. For instance Finland's grid plan reports capacities for 2029 while SolarPower Europe provides outlook figures for 2030. The reference years for energy scenario data from grid plans is indicated in the datasheets.

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