Building grids faster: the backbone of the energy transition

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Energy Transitions Commission

Briefing Note

The Energy Transitions Commission (ETC) is a global coalition of leaders from across the energy landscape committed to achieving net-zero emissions by mid-century, in line with the Paris climate objective of limiting global warming to well below 2°C and ideally to 1.5°C.

Our Commissioners come from a range of organisations – energy producers, energy-intensive industries, technology providers, finance players and environmental NGOs – which operate across developed and developing countries and play different roles in the energy transition. This diversity of viewpoints informs our work: our analyses are developed with a systems perspective through extensive exchanges with experts and practitioners. The ETC is chaired by Lord Adair Turner who works with the ETC team, led by Ita Kettleborough (Director), and Mike Hemsley (Deputy Director). The lead authors for this document are Elena Pravettoni and Shane O'Connor.

This briefing note, *Building grids faster: the backbone of the energy transition*, was developed to outline the critical role of grids in the energy transition. It highlights the challenges faced with building grids at the pace and scale required to scale clean electrification, in order to limit warming to well below 2°C. This briefing note is part of the ETC's ongoing work on power systems transformation. Detailed reports on electricity networks, which will build on this note, and power systems balancing will be published in early 2025.

The ETC team would like to thank the ETC members, member experts and the ETC's broader network of external experts for their active participation in the development of this briefing note.

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Key messages

Clean electrification is the backbone of global decarbonisation. This means that power grids, which link the generation and use of electricity, will play a central role. Under net-zero scenarios, the total length of grids must grow by over 50% by 2050 – a $22.5 trillion investment.

The development of power grids should aim to optimise the system, reducing the total build required by deploying innovative grid technologies that increase the efficiency of power flows, increasing storage and flexibility and the use of long-distance interconnectors. **However, even full deployment of all optimisation routes will not eliminate the need to build new grids.**

Grids have been a "laggard" in the energy transition – slow to adapt to new needs. Increasing the rate of grid build requires a step-change for many countries, particularly in developed economies where the build rate in recent years has been stable or declining. **Yet, the world risks losing out on large volumes of cheap renewables for clean electricity if systems fail to build at the speed required.** Five times the amount of solar PV and wind capacity added in 2022 are now waiting in grid connection queues.[1] Furthermore, congestion payments – where grid operators pay renewable generators not to produce due to insufficient grid capacity – are rapidly increasing. Critically, the International Energy Agency (IEA) estimates that in a grid-delay scenario the world could miss out on 58 Gt CO_2 of cumulative emissions savings by 2050, equivalent to global power sector CO_2 emissions from the past four years and almost 30% of the remaining carbon budget for a 1.5°C scenario.[2]

Therefore, to fast-track grid build and deliver the transition at the pace and scale required, policymakers and industry must take action across four critical areas. They must:

1. Implement a strategic vision for grids and generation coordinated across key stakeholders and supported by clear data.
2. Address slow permitting and approvals, and grow societal acceptance.
3. Address skill, component and material gaps.
4. Reform financing structures and increase access to finance.

1 Note: not all projects in queues will turn into realised projects; some project applications for grid connection are speculative. See IEA (2023), *Electricity Grids and Secure Transitions*.

2 This is the carbon budget remaining for a 50% chance of staying within a 1.5°C scenario. See IEA (2023), *Electricity Grids and Secure Transition*; Forster et. Al (2024), *Indicators of Global Climate Change 2023: annual update of key indicators of the state of the climate system and human influence*.

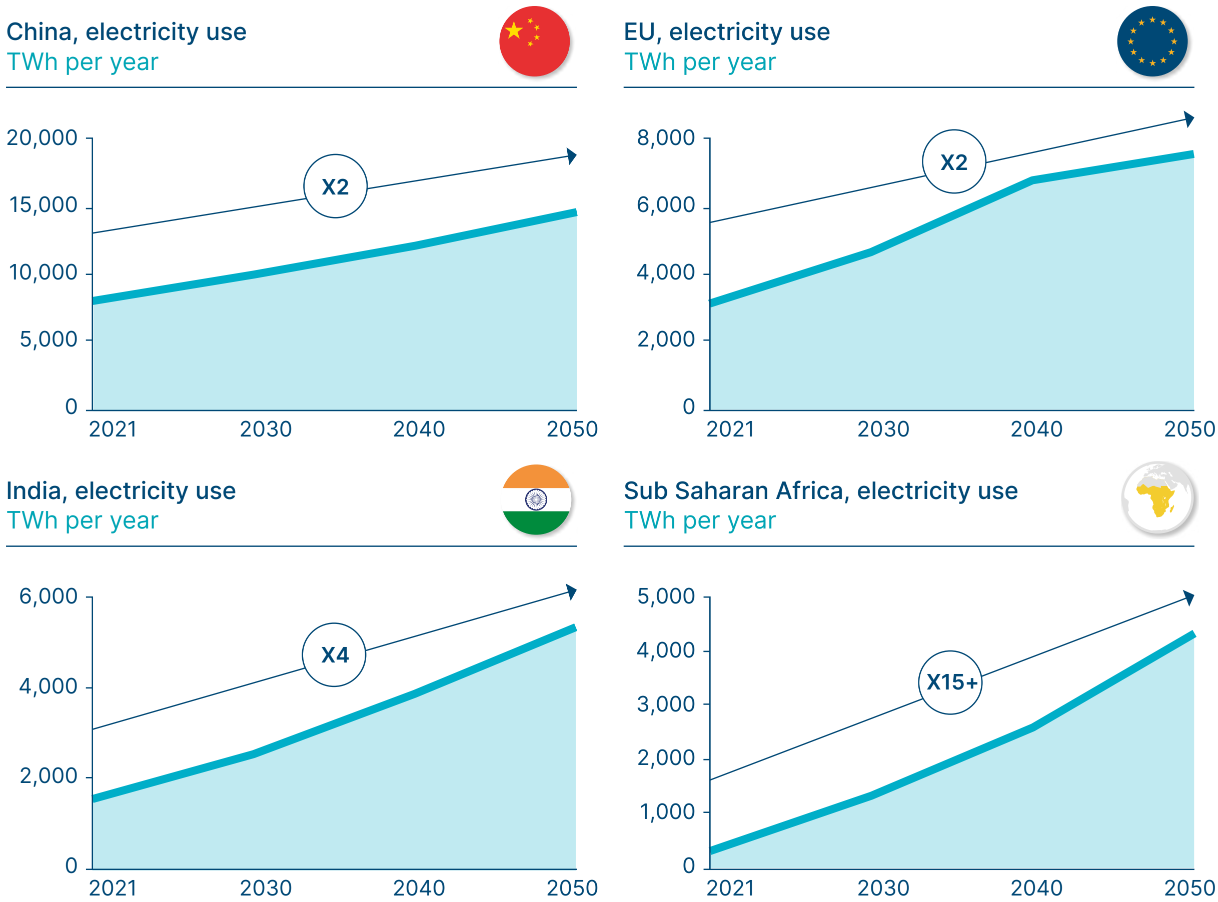
1. Grids as the backbone of the energy transition

The trajectory to net-zero will require significantly higher electricity use across the world to 2050.

The trajectory to net-zero aligned economies will be built on massive clean electrification. The ETC's latest scenarios show that electricity as a share of final energy demand will need to grow from around 20% today, to between 55–70%.[3] As a result, total direct electricity use will need to grow from around 28,000 TWh today to over 60–70,000 TWh.[4] This means at least a doubling of electricity use at the global level, with much steeper growth in some regions [Exhibit 1].

EXHIBIT 1

Electricity use 2021-2050 across key regions



Source: ETC (2023), *Fossil Fuels in Transition.*

3 Range is across the ETC's Accelerated But Clearly Feasible (ACF) and Possible but Stretching (PBS) scenarios. See ETC (2023), *Fossil Fuels in Transition.*

4 There could be a need for up to around 22,000 TWh of wind and solar generation to produce green hydrogen, although this may not require significant grid buildout if renewables are sited with electrolysers.

The way that electricity is generated and consumed is changing, moving to a more dispersed system.

There are two key forces driving a change in the "map" of networks around the world [Exhibit 2]:

- **A shift in power generation, with a greater role for wind and solar and reduced role for large thermal plants.** This shift will lead to a more dispersed generation system, with smaller-scale renewable generating assets spread across more – and new – locations.

- **Massive electrification across transport, buildings, as well as some industry, which will lead to new, and more dispersed, use of electricity.** As electric vehicles, heat pumps and industry electrification take off, these will often require new or upgraded connections across the network.

These evolutions are already underway; wind and solar now provide 13% of global power generation, and electric vehicles make up over 25% of new car sales in key markets.[5]

EXHIBIT 2

Key features of power systems

FROM…	TO…
Primarily thermal fossil-based generation	**Primarily variable renewables generation**
Concentrated (small number of large thermal plants, relatively closer to consumption) →	**Low cost dispersed** (geographically distributed wind farms & solar farms – electrons generated further away)
Limited behind-the-meter →	**Growing share behind-the-meter** (roof-top solar & on-site)
Continuous generation →	**Variable generation,** with system balancing challenge
Fossil meets majority of mobility & heating needs	Significant **economy wide electrification** requiring **wider web** of wires (e.g., road transport, home heat, low temp industrial heat)
Parallel gas, petrol & diesel, and electricity **networks**	**Capacity in new locations** – e.g., truck charging network & industrial connections
5,800 Mtce of coal, 4,200 bcm of gas, and **97 mb/d of oil** used each year (total demand)	**Changed demand profiles** – e.g., more post 6pm charging required (without mitigation)
	Increasingly **central role for electricity networks** and system management

Source: Systemiq analysis for the ETC.

5 Ember (2024), *Electricity Data Explorer*; IEA (2024), *Global EV Outlook 2024*.

Grids will become more central in a system dominated by clean electrification.

To deliver the required growth in electricity and accommodate the changing nature of power generation and consumption, countries will need to significantly expand and upgrade their grids. Both transmission grids (which support high-voltage, large-scale movement of electricity spanning larger distances) and distribution grids (which support lower voltage, connecting to end-use demand) will need to expand – as well as grow in complexity [Exhibit 3]. There are three main requirements around expansion and upgrade of the system:

- **Developing new grid connections,** such as new transmission corridors to connect new wind and solar generation (often sited in high resource areas with no previous access to grid connection and far away from key demand centres such as cities), and new distribution infrastructure to connect new loads, such as new electrified industrial demand, electrolysers for green hydrogen production, and domestic demand for electric transport and heating.

- **Replacing ageing assets to maintain the existing asset base,** which includes planned replacement schedules at the end of operational asset lifetimes. Needs for this are estimated to be somewhat reduced by the increasing digitalisation of the grid, which can improve information provision around maintenance needs.[6] These needs will also predominantly be in developed economies whose grid infrastructure is older on average.

- **Significant system reinforcements,** such as structural changes to existing grid infrastructure to enable higher complexity and flexibility in grids (e.g., enabling bi-directional power flows in distribution networks) as well as grid digitalisation (e.g., installing sensors and software for modelling higher complexity power flows).

6 BNEF (2024), *New Energy Outlook*.

Fossil dominated systems are linear. Clean, modern grids are more complex and flexible, with increased generation options and demand requirements

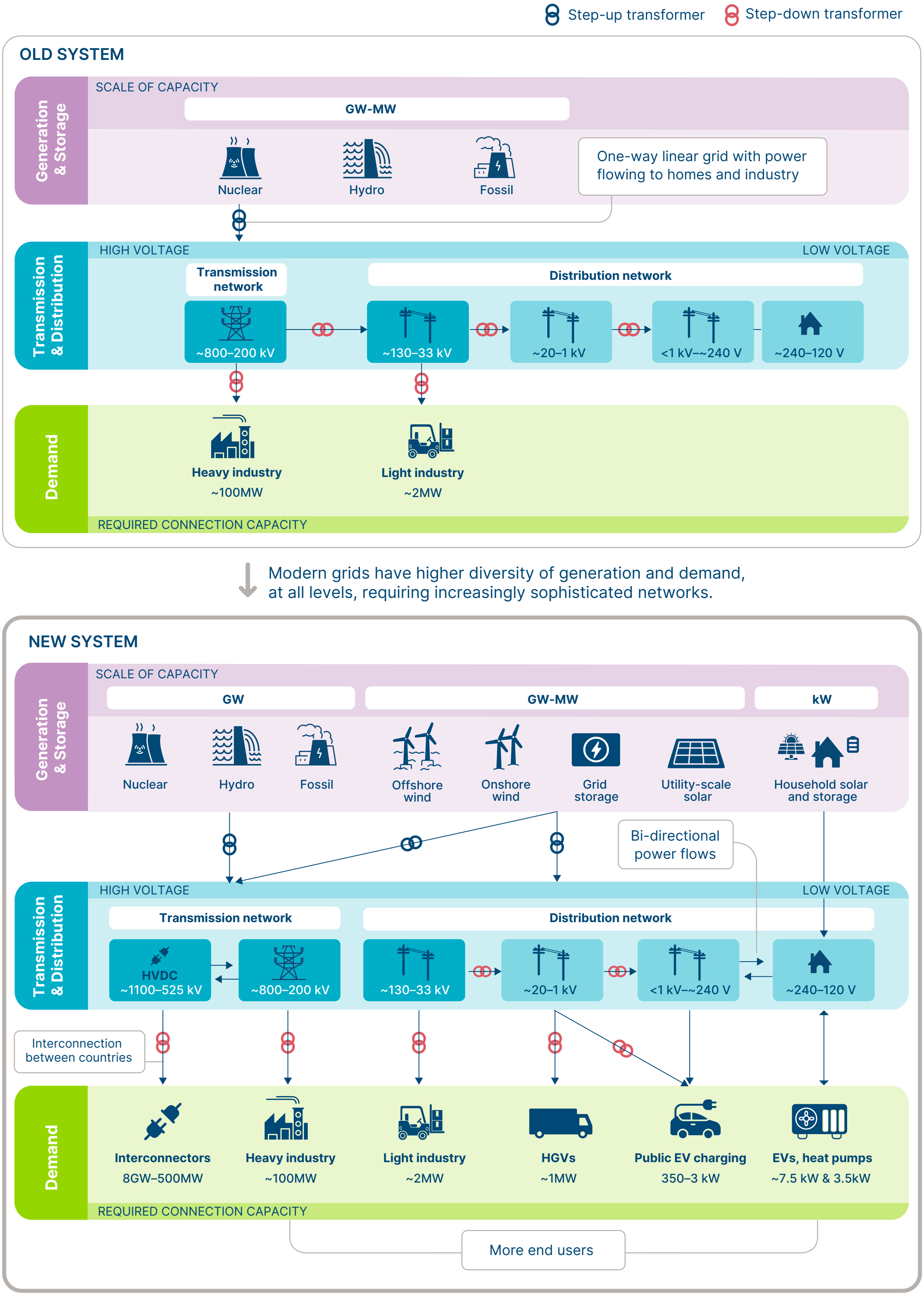


EXHIBIT 3

Note: The delineation between transmission and distribution grids is different between countries, in England and China the distribution grids operate at higher voltage levels, above and beyond 100 kV, whereas in Scotland and the United States, the maximum voltage on the distribution grid is around 35 kV.

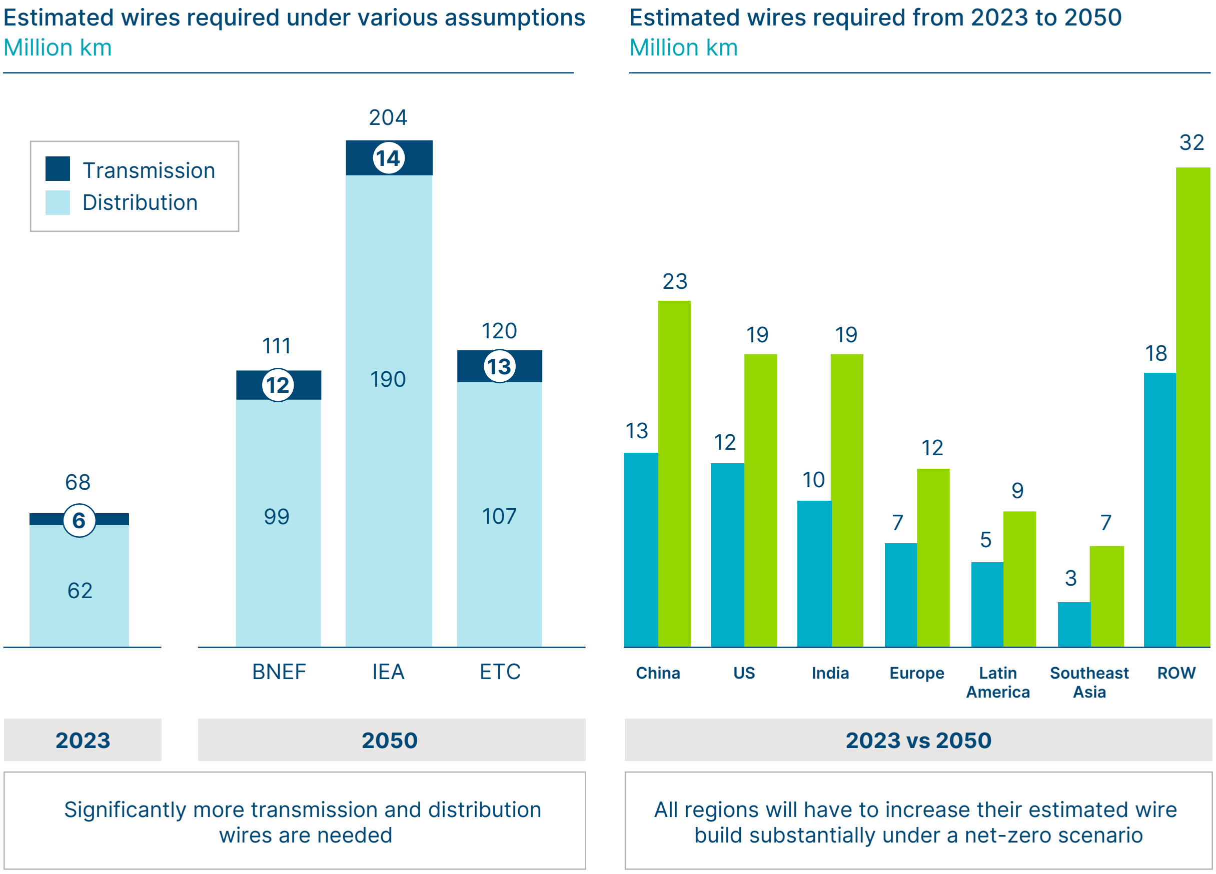
Source: Systemiq analysis for the ETC.

The size of the grid will need to grow by over 50% by 2050 to meet net-zero trajectories.

Estimates show that the size of grids must grow by more than 50% by 2050, growing from around 68 million km of grid in 2023, to a range of around 110–200 million km in 2050, with growth consistent across all regions [Exhibit 4]. Both transmission and distribution grids must be substantially scaled up in every region of the world. While optimising grid build – including via improving efficiency of power flows and optimising siting of generation and storage on the system – is critical, the scale of the grid build required remains significant.

EXHIBIT 4

Network build will have to increase dramatically across regions



Source: Systemiq analysis for the ETC; BNEF (2024), *New Energy Outlook*.

Grid investment needs to rise rapidly from ~$300 billion p.a. today to ~800 billion p.a. in 2050. Investment will be split across replacing and building new lines, as well as upgrading grid capabilities.

To deliver the required expansion of grids, annual investment in transmission and distribution networks needs to rise **to $800 billion per year, growing by over 2.5 times compared with today's levels [Exhibit 5]. Cumulatively, this would equate to over $22.5 trillion between 2022–2050.**

Investment into the grid is required to enable new connections, to replace ageing assets, and to provide reinforcements (structural changes to grid architecture), such as increasing the capacity of a substation. BNEF's estimates show that a significant investment focus is on system reinforcements, enabling the grid to provide the flexibility and capabilities required to run a more complex system [Exhibit 6].[7]

Grid investment must accelerate rapidly

Global annual power sector investment
USD billion per annum

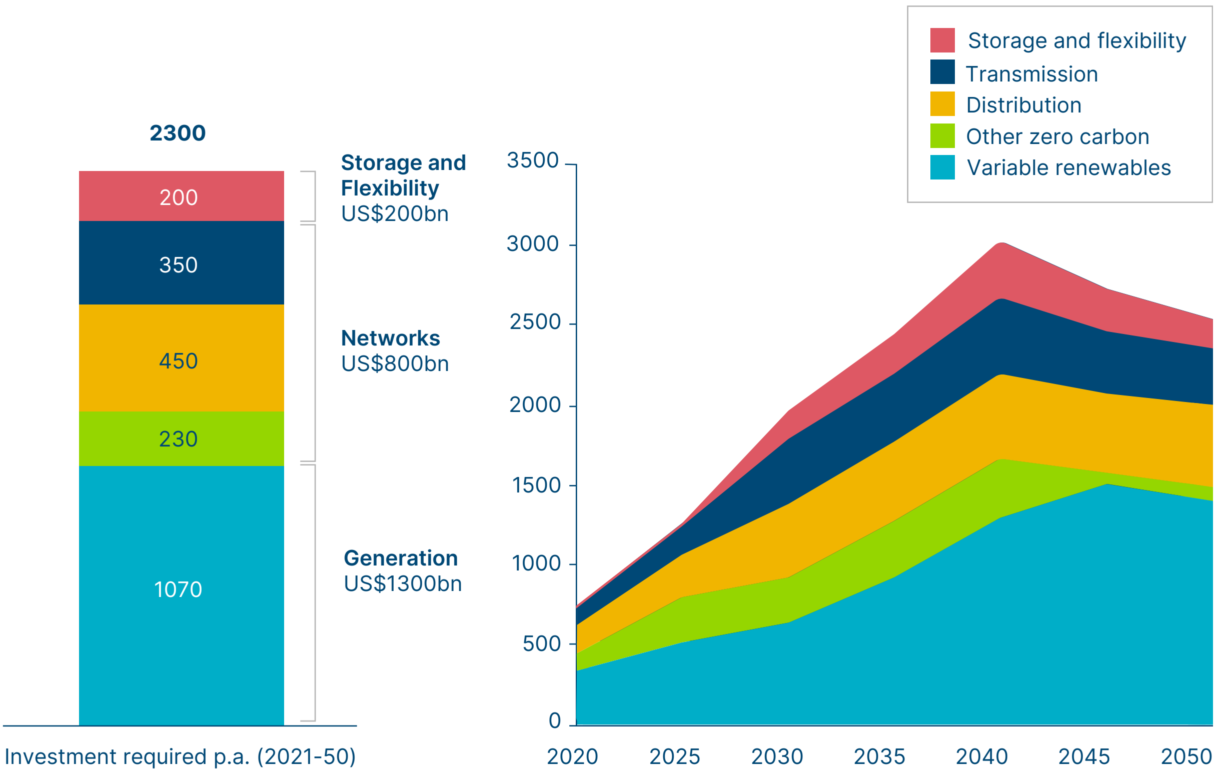


EXHIBIT 5

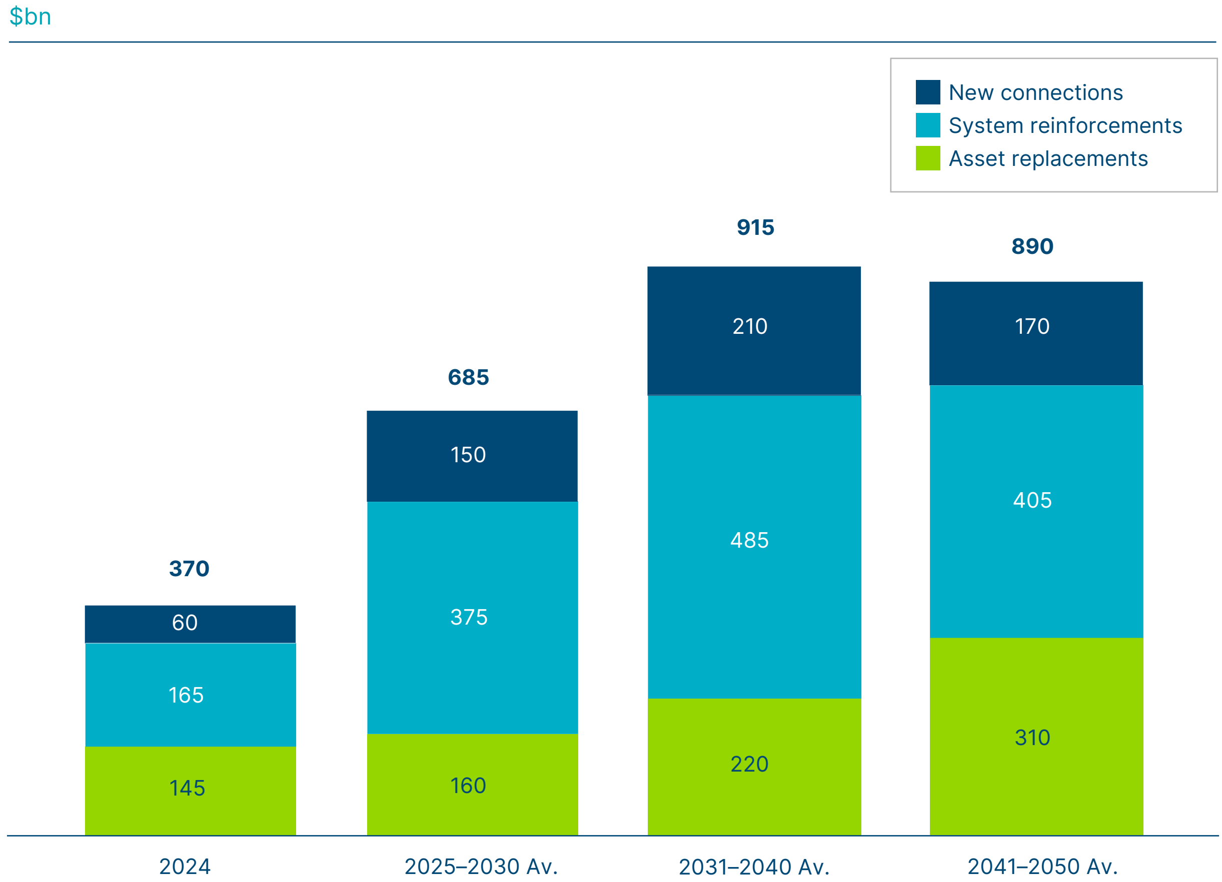
Note: Includes investment in clean electricity generation required to produce green hydrogen.

Source: Systemiq analysis for the ETC; BNEF (2022), *Energy Investment Trends*; BNEF (2023), *New Energy Outlook Grids*; BNEF (2024), *New Energy Outlook*.

7 Note: New connections refer to extensions of the existing grid to a new generation or load facility. Asset replacements refers to replacement of ageing assets that have reached end-of-life. Reinforcements refer to large projects that make structural changes to the grid architecture to improve reliability or market efficiency.

EXHIBIT 6

Breakdown of global annual grid investment required (2024–2050)



Sources: Systemiq analysis for the ETC; BNEF (2024), *New Energy Outlook*.

2. Grid optimisation can accelerate progress, but grid build will also be required

The scale of grid build needed can be partially offset by optimising grids – avoiding some overall build and buying time for wider reinforcements.

While the grid will need to substantially grow in size to 2050 under all net-zero scenarios, optimising flows of power across the system will be critical to ensure that grid build can be minimised where possible – and therefore reduce bottlenecks to the deployment of clean electrification. The transition to a power system which is flexible – where the demand for power is able to proactively react to meet primarily variable supply sources – is a critical shift that will be required. However, even with advanced optimisation, it is clear that the need to build new grids will not be fully eliminated. **Therefore, focus on the grid build challenge remains critical.**

There are several ways to optimise power flows across the grid, including innovative grid technologies, storage deployment, demand-side flexibility and long-distance interconnection.

Successfully deployed, these could significantly optimise power flows across the grid and reduce overall build needs:

- **Innovative grid technologies could materially improve the efficiency of power flows on to the system:**
  - *Via existing networks* ***with*** *changes to pylons and wires*: this would be, for example, by increasing the capacity for a given line, such as with advanced conductors, superconductors, voltage upgrades (with larger pylons), double circuiting (through adding another set of lines).
  - *Via existing networks* ***without*** *any changes to pylons and wires:* this would be through technologies such as dynamic line rating, to better understand actual line limits for current flow; advanced power control flow (APFC) or flexible AC transmission systems (FACTS) which dynamically control power flows on the grid; and better grid inertia measurements, which can increase the flow of renewable electricity on the system without putting inertia levels at risk.

A recent study estimated that innovative grid technologies have the potential to increase current capacity on the grid by 20–40%. Taking a more conservative view of a 10–20% grid capacity increase, deployment of these technologies could equate to gaining the equivalent of 4–8 years of new grid build.[8] This could be critical in unblocking connection queues for new generation and demand.

- **Deploying storage, demand side flexibility, and long distance interconnectors can reduce grid build needs:**
    - Storage deployment (in the right locations) can reduce the need for new wires by storing electricity until lines are unconstrained, or storing it at off peak times close to demand centres. This would be the case, for example, where there is a large regional disparity in where renewables are produced and consumed, such as between Scotland (higher wind production) and southern England (higher electricity consumption), and similarly between the north and south of Chile. Storage of electricity near production sites could minimise the need for new transmission lines, but still optimise renewables production.
    - Demand-side flexibility – or the ability to temporarily reduce/increase or shift load – could reduce peak consumption levels in local areas. The ability to shift load would reduce the need for new generation and new grid capacity needs, though in some cases it would require grid upgrades to enable more complex grid operation.
    - Deploying long-distance interconnectors where optimal, which can also reduce local transmission needs. Where there is a rationale (such as around costs, land constraints, and/or complementary generation patterns) to import significant electricity from a more distant region or country, long-distance interconnectors could optimise against the need to build new local generation and grid capacity which is less efficient for the overall system.

In the short-term, grid build should be optimised by considering an effective use of existing grid connections for new generation siting.

This could include developing new renewable generation in locations with available capacity where renewable resource profiles allow, such as at decommissioning coal plant sites which are already connected to the grid; or maximising the amount of generation capacity connected at any specific location, such as oversizing generation relative to grid connection (noting that often generation is below max output) and co-locating wind and solar to a single grid connection, though the business case needs to be evaluated on a location-by-location basis. However, given the scale of the new generation required, this is likely to only offer limited optimisation potential.

8 CURRENT (2024), *Prospects for innovative power grid technologies*.

3. Why action to accelerate grid build is critical

Building grids at the rate required will be a step-change for many countries.

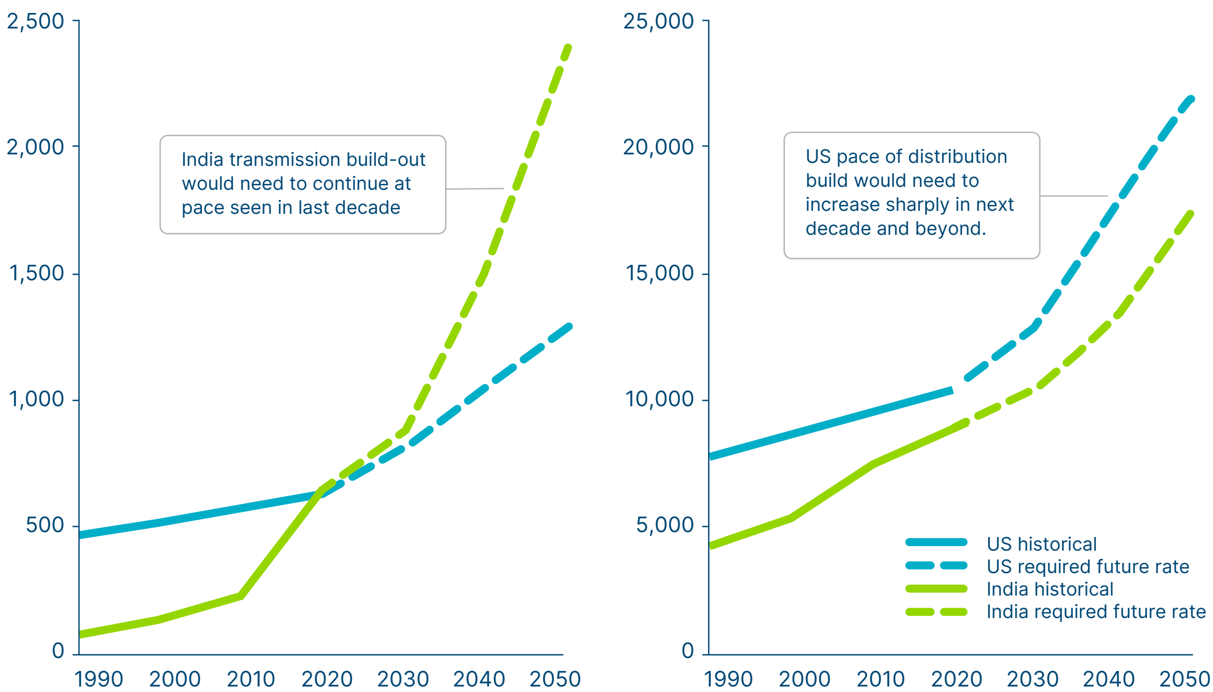
Grid growth in many developed markets (US, Europe) has been very slow for decades, whilst others (India/China) are building at record pace [Exhibit 7]. For countries where build rates have been more stable, the rapid expansion of grids requires a significant reset to regulatory and financing frameworks, as well as supply chains, in order to accelerate investment.

EXHIBIT 7

Recent grid growth varies across regions

Historical and forecast transmission build rate, US and India
Thousand km of wires

Historical and forecast distribution build rate, US and India
Thousand km of wires



Note: US historical build rate calculated on assumption of 1% grid growth in transmission and distribution per year from 1990–2022; Princeton modelling outlines that from 2013 to 2020 transmission lines have expanded at only 1% per year.

Source: Systemiq analysis for the ETC; BNEF (2021), *Power Grid Long Term Outlook 2021*; BNEF (2023), *New Energy Outlook Grids;* Princeton Zero Lab (2022), *Preview: Final REPEAT Project Findings on the Emissions Impacts of the Inflation Reduction Act and Infrastructure Investment and Jobs Act.*

In developed countries, where electricity demand has been fairly stable in the last few decades, or declining due to energy efficiency, grid growth has largely stalled. These countries will therefore need a significant step change:

- In the United Kingdom, for example, National Grid estimates that five times as much transmission will need to be built in the UK in the next 12 years than was installed in the past 30 years, based on an electricity demand growth of 50% by the same year.[9]
- In Europe, a recent study estimated that the required buildout needs to happen 20 times faster for the transmission network and three times faster for the distribution network compared to past buildout rates.[10]
- In developing countries, grid growth has in many cases been faster in recent years, matching growth in total electricity demand. In India, for example, in recent years network length has been growing at over 4% per annum, fast enough to meet net-zero build requirements if maintained (much faster than the US rate of around 1% per annum).[11]
- Finally, in some low-income countries, some national grids have not been growing at all. Around 600 million people in Sub-Saharan Africa live without access to electricity, and where connections to the national grid occur, supply is often intermittent and unreliable. In these instances, expanding the prevalence of minigrids (a set of small-scale electricity generators connected to a local distribution network) may be an important step before national grids can become widespread.[12]

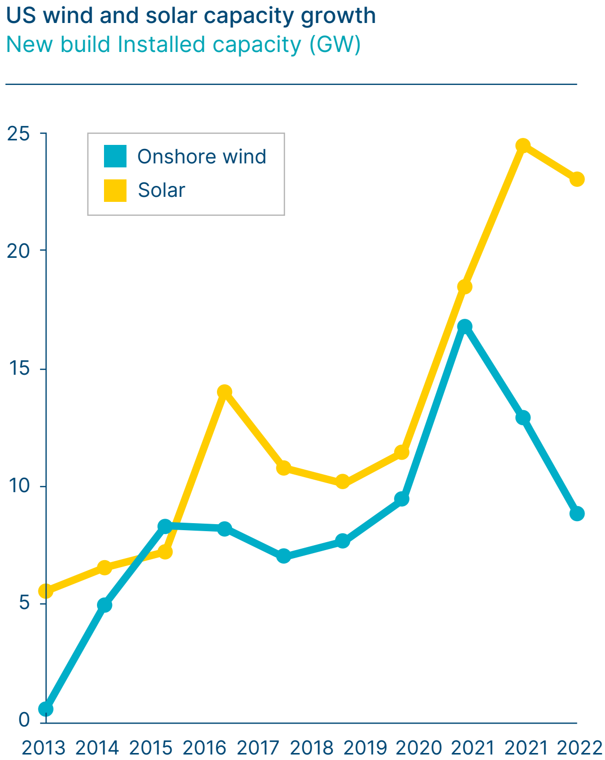
9 National Grid (2023), *Delivering for 2035.*
10 Compass Lexecon (2024), *Prospects for innovative power grid technologies.*
11 BNEF (2021), *Power Grid Long Term Outlook.*
12 CAMCO (2024), *Opportunities and risks in the African grid of the future.*

Grid growth has lagged the rapid expansion of renewables, with slow progress across the world.

Around the world, the deployment of wind and solar capacity has grown rapidly, reaching a new record of 560 GW of annual capacity additions in 2023 globally.[13] Yet, grid build has often not kept pace.

The contrast is particularly evident in the United States [Exhibits 8 & 9]. From 2013 to 2022, US wind and solar annual capacity additions have grown by 300% for solar and by 1400% for wind. Together, cumulative installed wind and solar capacity in the US has increased from 75 GW in 2013 to 290 GW in 2022.[14] In the same time period, US transmission line growth has slowed down almost 90% [Exhibit 8].

In the US, grid expansion is not keeping pace with renewable deployment



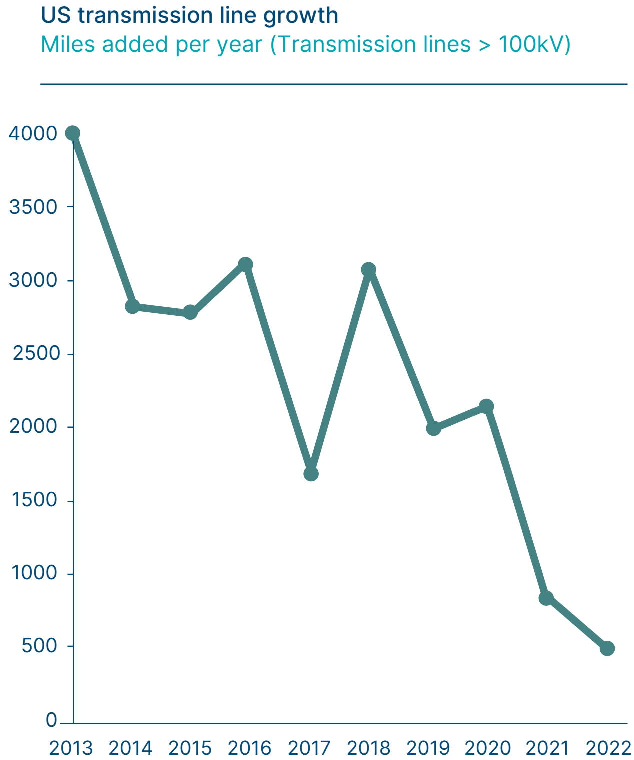


EXHIBIT 8

Note: Transmission lines > 100kV.

Source: BNEF (2024), *Global Installed Capacity*; J.P. Morgan (2024), *Eye on the market* | *14th Annual Energy Paper.*

13 BNEF (2024), *Global Installed Capacity.*

14 Ibid.

EXHIBIT 9

Construction times for clean energy infrastructure projects

Global average, Years to delivery

Source: Systemiq analysis for the ETC; ETC (2023), *Streamlining planning and permitting to accelerate wind and solar deployment*.

There are several drivers of slow grid build globally, including planning and permitting delays, regulatory issues around investment frameworks, public utility debt levels, and supply chain pinch points including lead times for key grid components (e.g., transformers). Transmission line construction times often far exceed both necessary build time, and the time taken to build new energy generation projects are vastly above the average; while the actual construction phase of transmission lines generally could only take 1–2 years, planning and permitting issues mean it commonly takes at least 10 years to complete construction – significantly longer than should be required even accounting for the fact that transmission lines cross more land.[15]

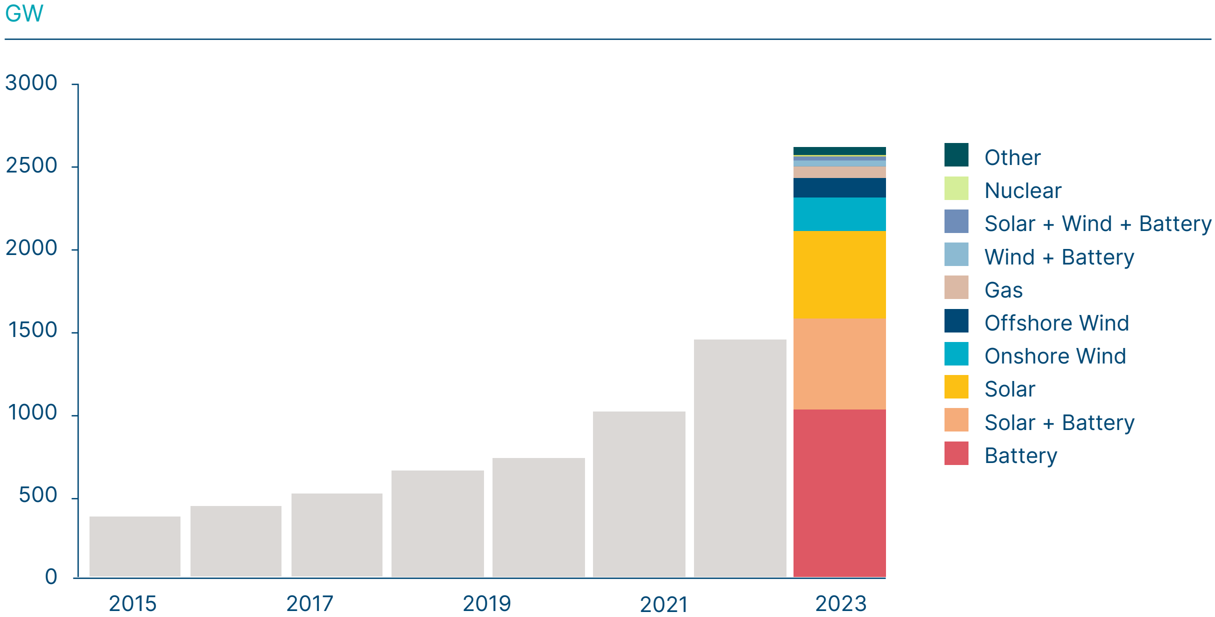
15 Permitting and building new transmission infrastructure often takes 10 years plus, but construction can be completed in two to three years. There are also significant non-build delays for renewable projects (i.e. offshore wind often takes 12 years of projct development time and only 2 years to build); however obtaining a grid connection often comes towards the end of renewable developments and adds further delays. See Systemiq analysis for the ETC; ETC (2023), *Streamlining planning and permitting to accelerate wind and solar deployment*.

Lack of sufficient grid capacity is having significant consequences, both by delaying new renewable project connections and by increasing system costs.

Grid connection queues for new power projects to connect to the system have grown significantly. At least 3,000 GW of renewable power projects, of which 1,500 GW are in advanced stages, are currently waiting in grid connection queues – equivalent to five times the amount of solar PV and wind capacity added in 2022.[16] While the issue is severe around the world, the scale of the challenge is particularly fraught in the US, where current grid queues have doubled compared to 2020 [Exhibit 10].[17]

EXHIBIT 10

US grid connection queue sizes (2015-2023)



Projects in queues are growing, in 2023 the US had 1450 GW of wind and solar capacity in queue (equal to 50% current global wind and solar capacity).

Source: Berkeley Lab (2024), *Queued Up: Characteristics of Power Plants Seeking Transmission Interconnection.*

16 Note: not all projects in queues will turn into realised projects; some project applications for grid connection are speculative. See IEA (2023), *Electricity Grids and Secure Transitions.*

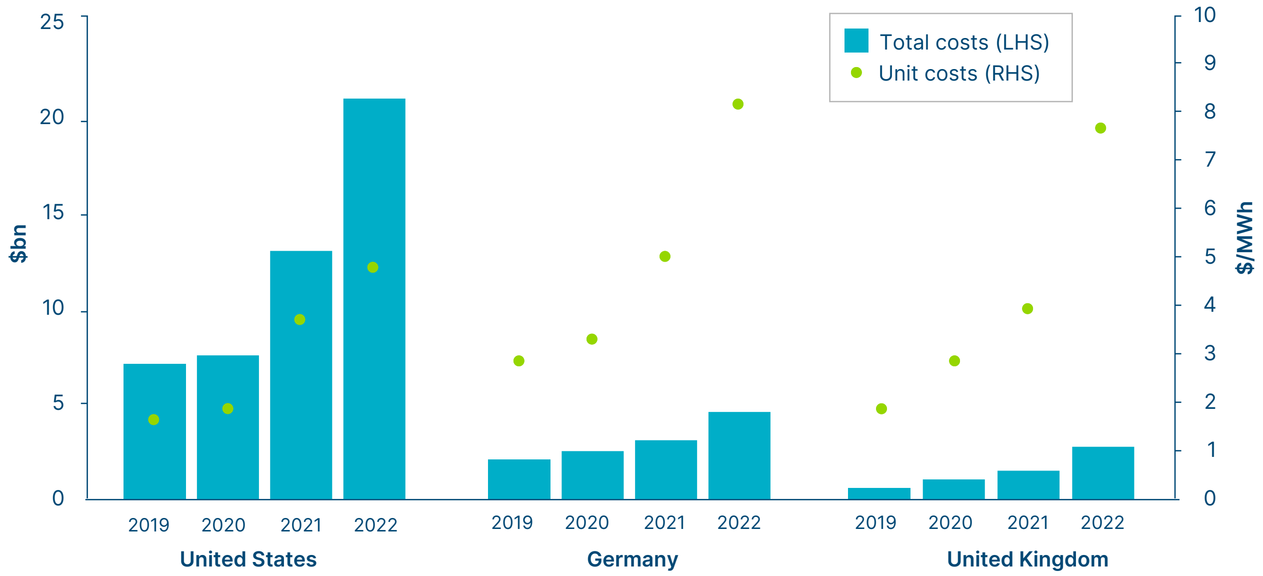
17 Ibid.

Congestion payments – where grid operators are paying renewable generators not to produce due to insufficient grid capacity – have grown rapidly. Congestion payments to curtailed renewables are totalling in billions for some regions, having risen significantly in the last two years [Exhibit 11].

EXHIBIT 11

Annual transmission grid congestion estimates in select regions

$bn and $/MWh



Source: IEA (2023), *Electricity Grids and Secure Energy Transition*.

Failing to build grids at the speed required will block large volumes of cheap, clean renewables coming online – locking in a higher emissions and higher cost trajectory.

The IEA estimates that in a grid-delay scenario, the world could miss out of a significant amount of cheap, clean renewable electricity, reducing the share of wind and solar of total power generation from around 60% to 44% by 2050. Under this scenario, the world would miss out on 58 Gt CO_2 of cumulative emissions savings by 2050, equivalent to global power sector CO_2 emissions from the past four years and almost 30% of the remaining carbon budget for a 1.5°C scenario.[18] As ETC scenarios assume an even greater role for wind and solar in the future power system (~75% in 2050), potential emissions at stake from a slow grid built out could be even greater [Exhibit 12].

Furthermore, analysis from *Transition Zero* highlights that a net-zero scenario where transmission lines are reinforced within and between countries could save nearly $3 trillion in the net-zero transition vs. a net-zero scenario with no transmission build, significantly reducing the amount of costly generation and storage.[19]

Delaying grid build will slow renewables adoption and delay emissions savings

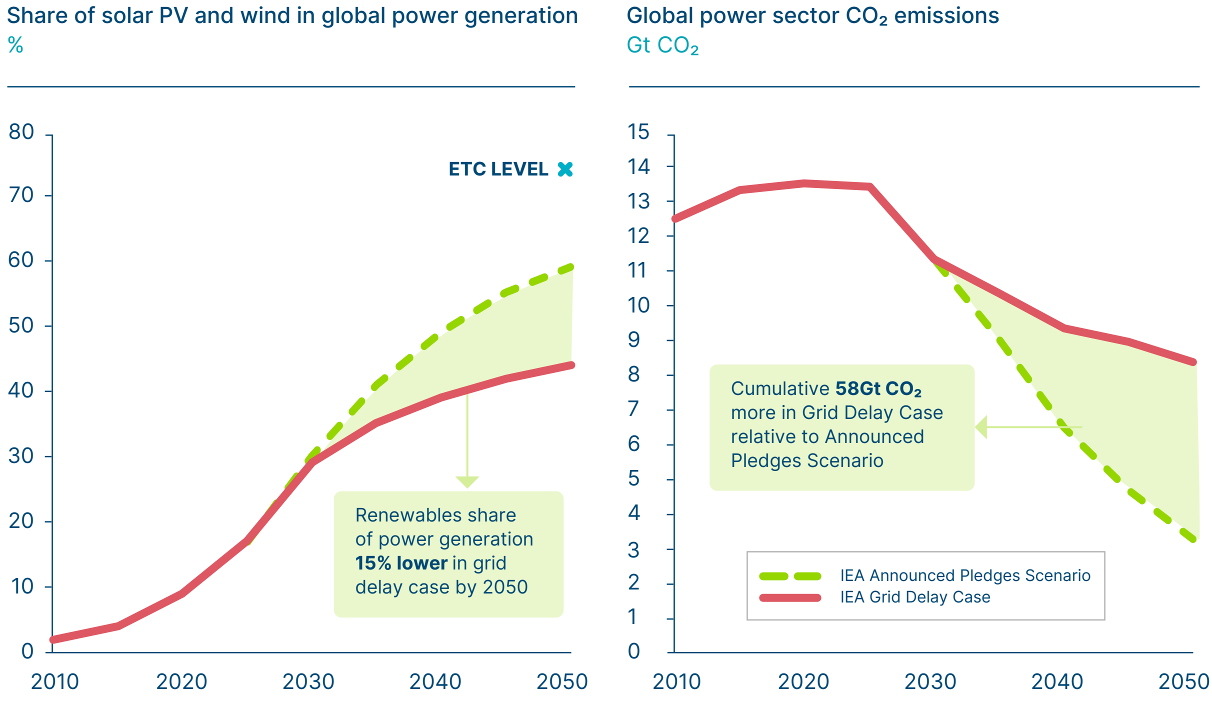


EXHIBIT 12

Note: Announced Pledges scenario (APS) shows the pathway corresponding with announced ambitions and targets, including all national announcements as of September 2022. The Grid Delay case is a variation on the APS showing a scenario where there is failure to modernise existing infrastructure and deliver new grid infrastructure in a timely manner.

Source: Systemiq analysis for the ETC; IEA (2023), *Electricity Grids and Secure Energy Transitions*.

18 IEA (2023), *Electricity Grids and Secure Transitions*; Forster et. Al (2024), *Indicators of Global Climate Change 2023: annual update of key indicators of the state of the climate system and human influence*.

19 Transition Zero (2023), *Cables to Change the World*.

4. Four major action areas to address the grid build challenge

Delivering the transition at pace and scale will require accelerating grid optimisation and build. Policymakers and industry must take action across four critical areas.

Policymakers and industry players must accelerate the build of new grids to deliver clean electrification at the pace and scale required. This should be in parallel to a major focus on optimising power flows across the system, increasing flexibility including via storage and demand-side response. To tackle challenges around building grids, policymakers and industry must [Exhibit 13]:

- Implement a strategic vision for grids and generation coordinated across key stakeholders and supported by clear data.
- Address slow permitting and approvals, and grow societal acceptance.
- Address skill, component and material gaps.
- Reform financing structures & increase access to finance.

EXHIBIT 13

Four areas to address grid build challenge

Area	Actions	Tx	Dx	Ix
		Greatest relevance		
i. Implement a strategic vision for network expansion by a future date	**Ensuring grid plans are:**			
	• Aligned with **decarbonisation targets** and **planning horizons.**	⊗	⊗	⊗
	• Integrated with plans for **generation siting**.	⊗	⊗	⊗
	• Developed across as **wide a geographic area as possible** (e.g., across regions, countries).	○	○	⊗
	• Targeted to develop a **coordinated expansion approach for distribution** networks.	○	⊗	○
ii. Address slow permitting & approvals and societal acceptance	• Regulatory and legislative reform to address **regulatory and administrative blockages** (e.g., slow consenting, multiple authorities in charge/lack of resources).	⊗	⊗	⊗
	• **Improve societal support** via actions to increase community buy-in and reduce opposition.	⊗	○	⊗
iii. Address skill, component and materials gaps	**Rapidly and sustainably scale up supply and coordination across key stakeholders for:**			
	• **Specific materials**, such as copper.	⊗	⊗	⊗
	• **Specific components**, such as transformers, subsea cables, and cable-laying vessels.	⊗	⊗	⊗
	• **Skills**, particular for linesmen; power engineers; planners etc.	⊗	⊗	⊗
iv. Reform financing structures & increase access to finance	• **Reform existing investment approach** to enable anticipatory investment ahead of need.	⊗	⊗	○
	• Improve routes to provide **sufficient financing for grid assets in developing countries.**	⊗	⊗	○

Note: Tx = Transmission. Dx = Distribution. Ix = Interconnection.
Source: Systemiq analysis for the ETC.

These actions build on previous in-depth work that the ETC has conducted as part of its *Barriers to Clean Electrification* series, on the issues of planning and permitting, supply chains, and materials and resources[20] reflecting a view of critical priorities that must be addressed to overcome barriers to building grids globally. While all of these actions are critical, the relative urgency of priorities will differ across countries. For example, in South Africa, the difficulty of financing new grid infrastructure given high levels of debt means that unlocking new financing mechanisms is critical,[21] and this has been the focus of recent policy announcements. This section is therefore intended as a comprehensive overview and global reference, with the understanding that the call to action for specific countries will reflect a different balance of these.

I. Implement a strategic vision for grids and generation coordinated across key stakeholders and supported by clear data. Policymakers should deliver this on multiple levels, including to:

- **Align grid expansion plans to power sector and economy-wide decarbonisation trajectories & include sufficiently long planning horizons** (e.g., at least 10–15 years ahead), for example, Chile's annual power sector long term planning processed, which was aligned with a 20-year national transmission plan, and aligned grid expansion plans with other relevant policies such as a ban on operating and installing new coal by 2025 and injecting fossil fuels into the power system from 2030.[22]

- **Include an integrated clear view of siting of generation & networks in grid expansion plans, agreed across key stakeholders (e.g., government, system operator/network companies, developers), supported by clear data.** An example is the UK's "Holistic Network Design" for offshore wind, which sets out a single, integrated design supporting large-scale delivery of electricity generated from offshore wind with efficient grid buildout, reducing the km of cables required compared to a piecemeal approach [Exhibit 14]. In the Netherlands, a dialogue across key stakeholders has been created to identify renewable locations and assess where grid capacity is and should be made available.[23] It is also important to align plans for new distribution infrastructure with generation and demand increases, to mitigate upcoming bottlenecks.

- **Ensure strategic visions are developed across as wide a geographic area as possible (e.g., across regions, countries) and supported by data sharing and integration to maximise benefits.** An example is the Political Declaration on energy cooperation between North Seas countries, which aims to improve offshore wind development via the building of a "meshed offshore grid" which connects national grids to each other, enabling power transfer between countries and offshore wind farms in the most integrated and cost-effective manner.[24]

20 ETC (2023), *Streamlining planning and permitting to accelerate wind and solar deployment;* ETC (2023), *Better, Faster, Cleaner: Securing clean energy technology supply chains;* ETC (2023), *Material and Resource Requirements for the Energy Transition.*

21 Blended Finance Taskforce (2023), *Better Finance Better Grid.*

22 IEA (2023), *Electricity Grids and Secure Energy Transitions*; REGLOBAL (2022), *Chile Decarbonisation Plans: Focus on grid modernisation and digitization.*

23 Regionale Energie Strategie (RES), *Dutch National Programme Regional Energy Strategies*. Available at: https://www.regionale-energiestrategie.nl/english/default.aspx

24 European Commission (2023), *The North Seas Energy Cooperation.*

UK offshore wind network development models

The UK created a **'Holistic Network Design'** setting out a single, integrated design supporting large-scale delivery of electricity generated from offshore wind with efficient grid buildout.

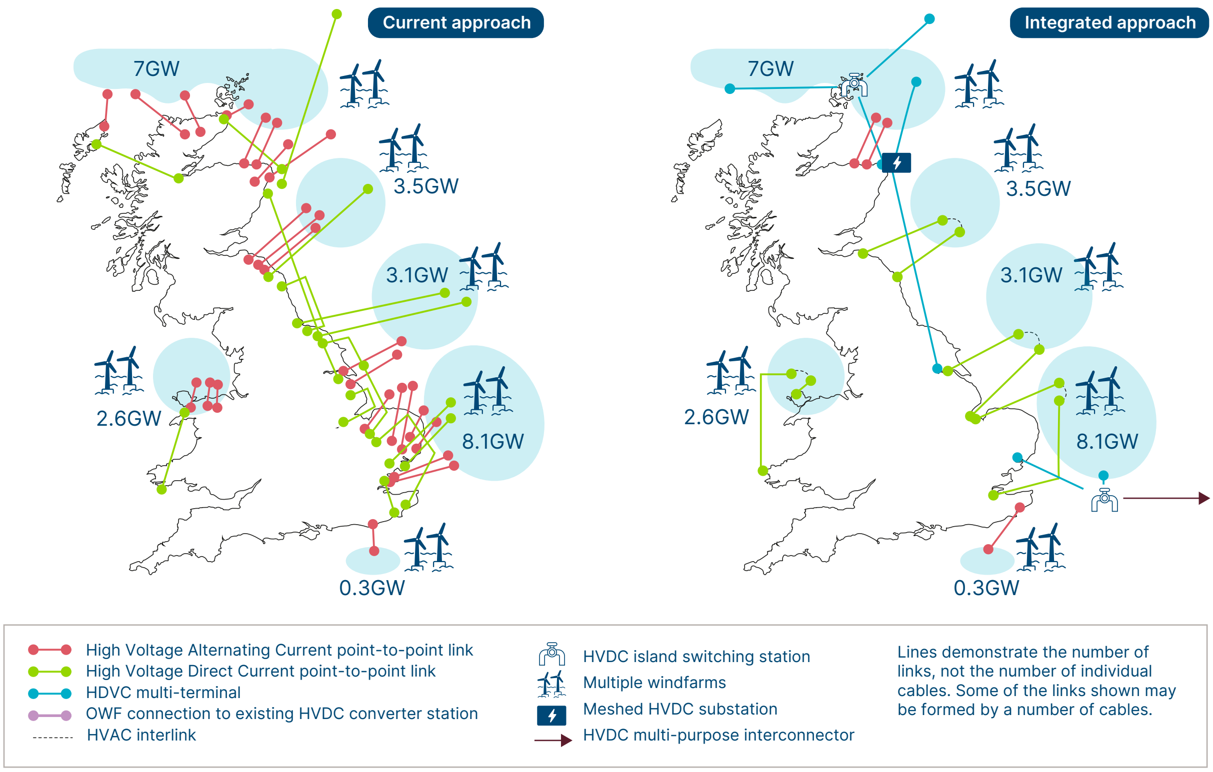


EXHIBIT 14

Source: National Grid ESO space (2020), *Offshore Coordination Phase 1 Report*.

- **Improve coordinated approach for expansions in the distribution network,** accounting for higher challenges due to higher volume of assets, new use cases, and lack of underlying data on network capacity. For example, new EU regulation requires member states to have at least one charging hub on every 60–100 km of road to accommodate scale up in electric trucks; it is important to designate where these are and plan to build as early as possible to plan for the required increases to wider distribution network capacity.

II. Address slow permitting, approvals and grow societal acceptance, including to:

- **Address regulative barriers,** such as slow consenting processes; lack of dedicated land; lack of regulatory priority and clarity; complex regulation; adverse legal systems; land ownership issues. Examples include streamlining permitting in dedicated areas, such as via "Competitive Renewable Energy Zones" in Texas to connect wind resource in Western Texas via transmission lines to demand centres in the East.[25]

- **Address administrative barriers,** such as multiple authorities in charge of permitting; lack of capability and resources; lack of digital permitting infrastructure. Examples include enabling one-stop-shops for permitting so that one government department is responsible, as in Denmark regarding offshore wind and transmission.[26]

25 ETC (2023), *Streamlining planning and permitting to accelerate wind and solar deployment, Solution Toolkit: Actions for national/ regional governments and policymakers.*

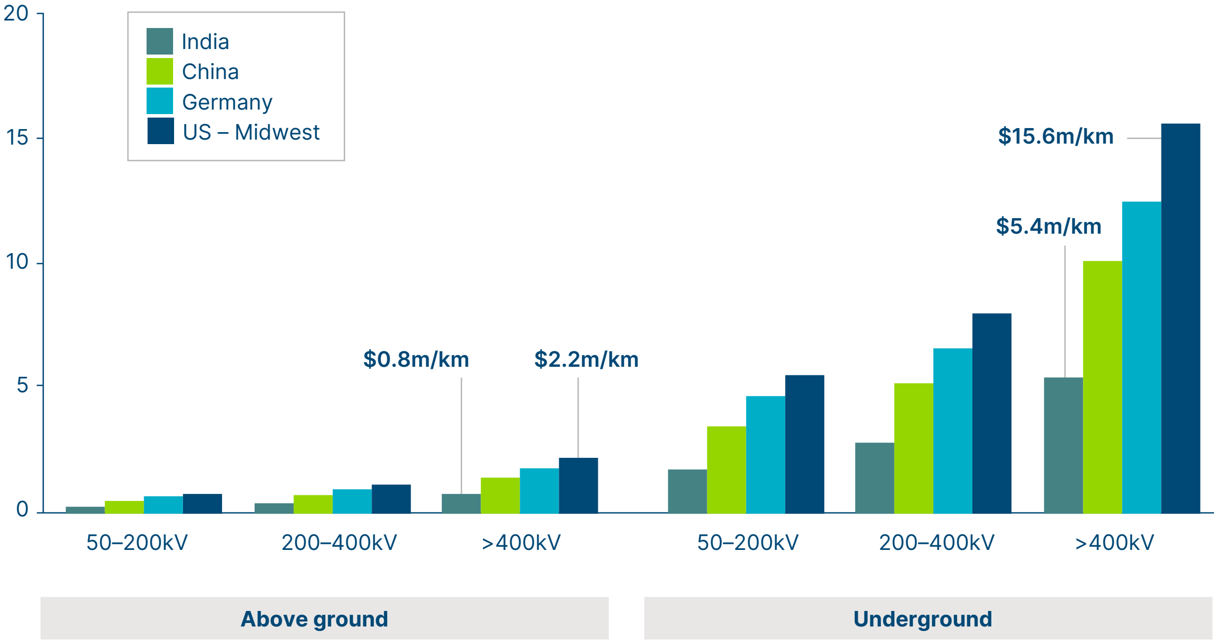
26 Ibid.

- **Build societal support,** such as taking actions to increase community buy-in and reduce opposition to build on environmental, aesthetic and safety grounds. Given the scale of the build required, pursuing strategies to enable societal acceptance are vital. Key routes include:
  - **Building less new infrastructure,** by using innovative grid technologies either via existing rights of way (with changes to pylons and wires) as well as via existing pylons and wires, as discussed above.
  - **Building infrastructure in a more holistic way,** such as via undergrounding power lines (though accepting higher costs) and integrating vegetation management via green transmission corridors which are actively managed to support local habitats, such as the Life Elia-RTE project in Belgium and France, which has revived plant and animal species alongside transmission corridors. From a cost perspective, undergrounding lines would be around 7 times more expensive [Exhibit 15].[27]
  - **Increasing public awareness and education around the importance of grids for climate change.** Local authorities, civil society and media should increase awareness of the benefits to communities from the energy transition, the necessary magnitude of grid infrastructure scale up and potential trade-offs. Ensuring local grid build pro-actively benefits local communities should also be considered (e.g., through community benefit schemes).

EXHIBIT 15

Cost of constructing power lines

$ m/km, 2024 nominal costs, total project capex



Note: Representative grid costs based on BNEF's GridVal model, based upon 500 km projects with MW capacities of 25, 250 and 2,500 respectively for wires at voltage levels of ~70 kV, ~230 kV, and ~500 kV. Excludes substation costs.
Source: Systemiq analysis for the ETC; BNEF (2024), *Grid Capex Cost Model (GridVal V1.0)*.

27 BNEF (2021), *Power Grid Long-Term Outlook 2021*; Elia (2023), *Elia and Eco first share their experience in managing ecological corridors under high-voltage lines*.

III. Address skill, component and material gaps.

This requires rapidly and sustainably scaling up supply in areas where demand could be likely to outpace current supply outlooks in the near-term, including for:

- **Key material inputs to grids,** such as copper, which is used extensively in underground and subsea power cables. In its in-depth 2023 *Material and Resource Requirements for the Energy Transition* report, the ETC concluded that while there are plenty of resources in the ground to meet energy transition needs, there are concerns around the ability to scale up annual copper supply rapidly enough due to long mining timescales, project delays and declining ore grades.[28]

- **Key components,** particularly transformers, subsea cables, F-gases and cable-laying vessels, where supply chain and market issues and regulatory constraints are posing existing and potential pinch points. For example, there are concerns around the production of subsea cables given a very concentrated market (three main producers covering 75% of the awarded length since 2016) and booming demand; since 2018, lead times between award of contract and start of installation has doubled.[29]

- **Skills,** including for linesmen and women, as well other power engineering technicians. In some cases (e.g., power engineers), long training lead times could lead to short-term bottlenecks of skilled workers; for example, training to become a journeyman line worker can take up to seven years. High percentages of older workers in the sector also leads to additional pressure.[30]

While there are no inherent barriers to scaling materials, components and skills to underpin supply chains for grids, there are several actions that governments and industry need to take to ensure supply can keep pace with demand, some of which are cross-cutting across all barriers to clean electrification. These include: setting clear decarbonisation targets; streamlining planning and permitting for strategic mining and manufacturing projects; developing clear offtake agreements across industry to de-risk investments in new supply capacity.[31]

28 ETC (2023), *Material and Resource Requirements for the Energy Transition.*

29 Spinergie (2023), *New challenges lay ahead as demand for offshore cables increases*; ETC (2023), *Better, Faster, Cleaner: Securing clean energy technology supply chains.*

30 In the UK there are currently 200 trained linesmen and 1,400 will be needed to deliver the Accelerated Strategic Transmission Invesment projects by 2030.

31 ETC (2023), *Material and Resource Requirements for the Energy Transition*; ETC (2023), *Better, Faster, Cleaner: Securing clean energy technology supply chains.*

IV. Reform financing structures and increase access to finance. This includes primarily two actions:

- **Reform existing investment approach to enable anticipatory investment ahead of need.** Regulatory frameworks must shift from models aiming to keep costs low for consumers, to models which allow grid operators to make significant investments into capacity required to enable rapid electrification [Exhibit 16]. This includes increasing the planning cycles for grid operator investment plans, allowing for socialisation of costs beyond rate-payers, and more closely coordinating investment plans across other system needs. Furthermore, many grid investment frameworks are currently weighted to incentivise capex rather than opex spend.[32] This fails to incentivise investment in upgrades into existing grid infrastructure, which as discussed above are an important part of the grid network build.

- **Improve routes to provide sufficient financing for grid assets via alternative financing models including through higher private sector participation.** This includes differentiated financing instruments beyond the main grid operator balance sheet, such as green bonds for specific grid infrastructure, and/or via the creation of project finance structures such as independent transmission projects (ITPs), which allow for different forms of ownership and control structures by the transmission company and require minimal regulatory change. These mechanisms are particularly relevant where capital levels are constrained, for example, South Africa due to high debt levels of the state utility and transmission company.[33] Overcoming bottlenecks relating to currency and exchange rate risk via additional financing guarantees also remains paramount.

EXHIBIT 16

Key framework elements for grid investment approaches

CURRENT STATE		FUTURE NEEDS
• **Shorter term planning cycles** (e.g., 5–7 year windows agreed in advance with regulator) • **Costs typically charged to beneficiary or existing customers,** leading to no/limited pro-active investment	→	• **Longer term planning cycles** • **Socialisation of costs** of unsolicited network upgrades across user • **Whole-system planning approaches** and cost-optimisation
Low risk, but no capacity for anticipatory investment Lower risk system, but sub-optimal choices made from long term system perspective (e.g., incremental decisions which postpone more significant grid upgrades), generally designed for cost efficiency over flexibility and scale	→	**Higher risk, but can enable anticipatory investment** Increased tolerance for risks which enable decarbonisation, even if elements are not later fully utilised and costs for consumers/taxpayers therefore rise; critical to avoid network bottlenecks

Source: Systemiq analysis for the ETC.

32 The typical model in Europe is revenue-cap-and-cost-plus-model, where opex is subject to efficiency requirements, while capex is passed through to consumer with additional return for utility.

33 Blended Finance Taskforce (2023), *Better Finance Better Grid*.

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