Morgan Stanley

INVESTMENT MANAGEMENT

BEYOND WIRES:

Why the Great Grid Upgrade is the next Multi-Decade Opportunity

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For much of the last century, electricity grids in Europe and US quietly underpinned economic growth, industrial productivity, and rising living standards. Designed around connecting large, centralised generation assets with relatively predictable pockets of demand, these systems delivered power so reliably and at such low cost that, for decades, electricity transmission and distribution networks (together, the "grid") attracted little public scrutiny.

That era seems to be coming to an end.

Today, grids in Europe and the US are capacity-constrained, complex to operate, costly to upgrade, and vulnerable not only to extreme weather but also to physical sabotage and cyberattacks. And this at a time when the consequences of failure have rarely (if ever) been so severe. Part 1 of this paper will discuss the most significant pressures faced by grids in Europe and the US, Part 2 explores the technologies available today that promise to resolve these issues and Part 3 explores how capital providers and stakeholders can work together to catalyse the roll-out of these technologies.

PART 1: A System Under Strain

Power grids today face a convergence of structural pressures that individually might be manageable but together are pushing the system towards a tipping point. Aging infrastructure is being asked to perform at its original design parameters despite being well beyond its rated operating life. Weather-related disruptions are becoming more frequent and more severe and cause significant economic and social costs. Electricity demand is rising unpredictably after decades of stagnation. Finally, the rapid expansion of cheap, distributed renewable energy is fundamentally changing how electricity is produced and consumed, creating unprecedented complexities for grid operators to grapple with.

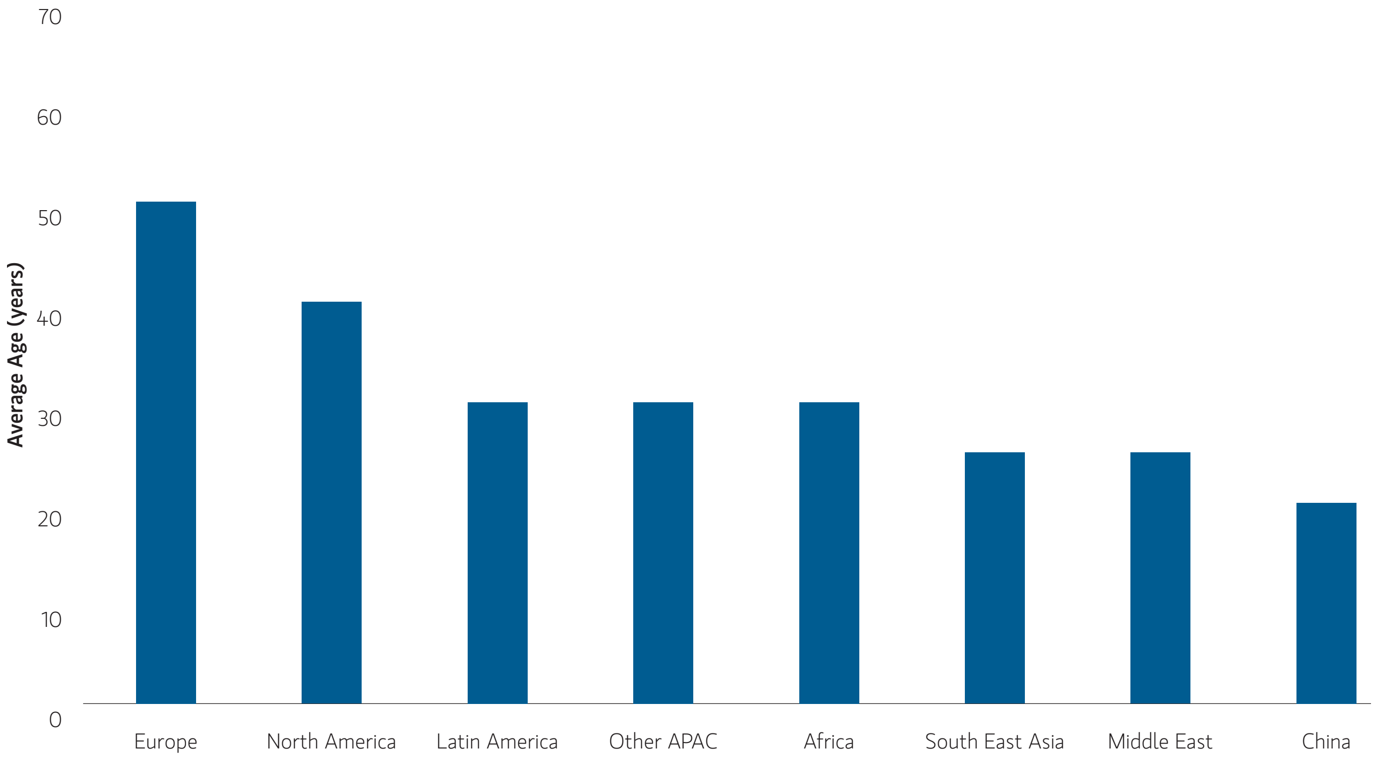
PROBLEM 1

Grid Infrastructure is Operating Well Beyond its Design Life in an Ever More Challenging Environment

Much of the physical backbone of today's electricity grid was built between the 1950s and 1980s. Critical electricity transmission infrastructure in Europe and the US is today operating close to its original design life. As shown in **Figure 1,** the aging of infrastructure is a particularly acute issue in the US and some European countries. Indeed, by 2050, some 90% of European power lines are expected to be over 40 years old. In addition, key components such as transformers, substations, and circuit breakers were typically designed with an operating life of 30-40 years. Many, if not most, are well beyond that threshold today – the hardware upgrade cycle is long overdue.

FIGURE 1

Average Age of Power Grids Across the World[1]



[1] Goldman Sachs, Europe Needs $3.5 Trillion of Power Investment Through 2035, 12-Sep-2025

For instance, large power transformers – key nodes in networks that step voltage up or down at every interconnection point – are operating close to their design life, as shown in **Table 1** below. Some 70% of all transformers on the US grid have been in service for more than 25 years,[2] and as these transformers operate beyond their design life, their rate of failure increases correspondingly.[3] Other critical grid assets (e.g., conductors, switchgear, circuit breakers, and substations) are also operating well beyond design lives. Many of these were installed during large-scale network-building capital expenditure campaigns 50-75 years ago and have only received incremental upgrades since.

TABLE 1

Average Age of Critical Grid Hardware in the US[4]

HARDWARE COMPONENT	AVERAGE AGE IN THE US	TYPICAL SERVICE LIFE
Large power transformers (≥100 MVA, bulk transmission)	■ **~38-40 years**	■ **~40 years** design lifetime commonly cited by DOE
Distribution transformers (service transformers <34.5 kV)	■ **~55% of in service units are >33 years** (approaching end of life)	■ **~33+ years** (depends on loading/thermal aging)
Overhead transmission lines (≥100 kV)	■ **~70% of transmission lines are >25 years old** ■ Indicative: ~40 years average for installed base	■ **50-80 years** typical life
Substations	■ **>40 years**	■ **40-60 years** typical life
Substation circuit breakers (transmission level)	■ **~60% are ≥30 years old**	■ Varies, though many utilities plan replacements in **~30-40+ year** window
Underground power cables (T&D)	■ (No national average)	■ **~20-40 years** typical
Utility poles (distribution and transmission structures)	■ (No national average)	■ **Wood:** ~30–50 years ■ **Steel/Composite:** ~80 years ■ **Concrete:** ~60 years

Under-maintenance of these aging assets has contributed to blackouts and outages. For example, the 2025 North Hyde (Hayes) substation fire near Heathrow Airport in the UK was ultimately caused by moisture ingress into the 'bushing' (i.e., the insulation around high-voltage connections) in a transformer. This then caused a short-circuit that eventually led to the transformer catching fire, and ultimately forced the airport (one of the world's busiest) to be shut for ~16 hours, disrupting more than 1,00 flights and affecting more than 200,000 passengers. A subsequent review has found that moisture ingress was first detected in July 2018, but the issue was not resolved at that time and further maintenance scheduled for 2022 was likewise deferred. Multiple further attempts were made to schedule maintenance, but none went ahead.[5]

Aging power grid infrastructure has also amplified the risk of wildfires. When a hook manufactured in 1924 failed and dropped a live power line to the forest floor, it sparked the deadliest wildfire in California's history: the 2018 "Camp Fire" wildfire.[6]

Due to the interdependence of grid assets, failures of individual pieces of equipment can quickly spiral into full system-wide failures. A phase conductor failure on transmission line V411 in the Czech Republic led to cascading outages across the country. Over 1 million consumption points were affected and critical infrastructure like hospitals and transport systems were disrupted.

As grid assets continue to operate well beyond their design lives, equipment-related disruptions to any segment of the power system are likely to have cascading effects downstream, ultimately jeopardising the reliable supply of electricity that end-users have come to rely on.

While these case studies and statistics about grid assets operating beyond their design lives are alarming, it is important to emphasise, however, that age alone does not guarantee failure – age combined with stress does.

[2] US Department of Commerce Bureau of Industry and Security Office of Technology Evaluation, The Effect of Imports of Transformers and Transformer Components on the National Security, 2020
[3] US Department of Energy (DOE), Large Power Transformers and the US Electric Grid, Jun-2012
[4] Table compiled using information from the following: DOE, Large Power Transformers Resilience Report, 2024; National Renewable Electrical Laboratory (NREL), Distribution Transformer Demand Factsheet, 202 ; DOE Grid Deployment Office (GDO) Explainer, 2023; US Energy Information Administration (EIA), Today in Energy: Major utilities continue to increase spending on U.S. electric distribution systems, 20-Jul-2018; DOE, Enabling Modernization of the Electric Power System: Technology Assessments – Transmissions and Distribution Components, 2015; DOE and Lawrence Berkley National Laboratory (LBNL), Undergrounding Transmission and Distribution Lines: Resilience Investment Guide, 2024; DOE, Utility Pole Resilience Guide, 2024
American Society of Civil Engineers, 2025 Infrastructure Report Card, 2025
[5] BBC News, Five things we now know about the fire that shut Heathrow down, 2-Jul-2025
[6] California Public Utilities Commission, Incident Investigation Report, 8-Nov-2019

EXTREME CONDITIONS ACT AS A FORCE MULTIPLIER

Adverse weather- and climate-related events are now more frequently exerting pressure on grid infrastructure at a frequency and intensity that was never anticipated in original designs. Since 1980, the United States has experienced approximately 400 weather and climate disasters that have each caused damages in excess of $1 billion (almost $3 trillion in aggregate).[7] However, almost half of these events and economic losses have occurred since as recently as 2015.

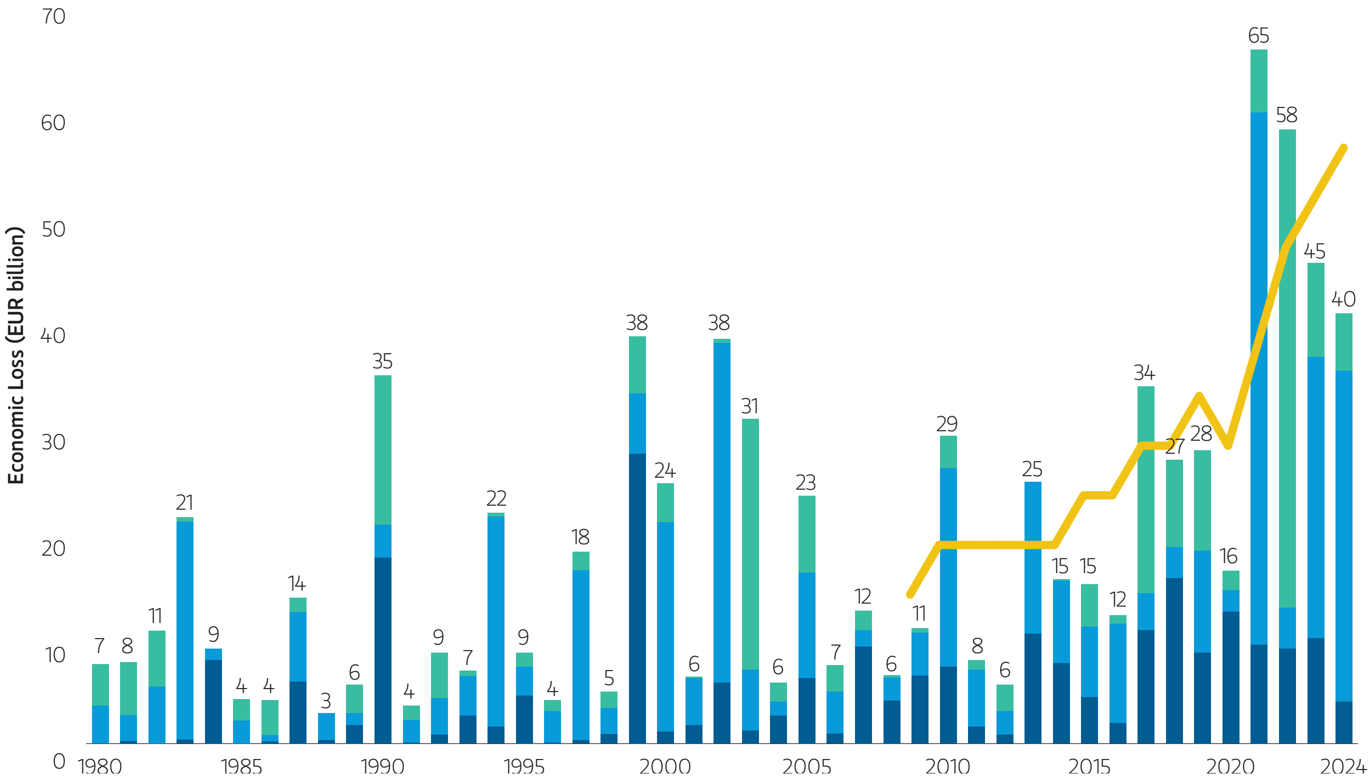
A frequently cited example is Winter Storm Uri in 2021, during which extreme cold caused generation and grid assets in Texas to fail simultaneously. At its peak, the Electricity Reliability Council of Texas (ERCOT) introduced rolling blackouts as 40% of the grid's capacity went offline, leaving more than 4.5 million households and businesses without power for extended periods with – some for more than 3 days. Post-event analysis suggested that the system came within five minutes from an indefinite blackout that could have lasted weeks.[8]

In addition to demonstrating the fragility inherent to an isolated grid with limited interconnections to neighbouring networks, the event exposed structural and system-wide vulnerabilities related to under-maintenance of grid assets that were insufficiently winterised.[9] The financial consequences of this are clear: power industry experts posit the value of lost load (VOLL) for the 70.5 hours of load shed during the blackouts at $4.3 billion – well in excess of the Federal Reserve Bank of Dallas's estimates of the costs of winterisation.[10]

Likewise in Europe, extreme weather events are occurring at an increasing frequency, with growing economic consequences as shown in **Figure 2** below. In Sweden, analysis of grid operations from 2007-2021 has found that some 26% of outages were due to adverse weather – primarily, snow, storms, and high winds.[11] Wildfires in southern Europe, storms in north-western Europe, and heat-driven demand spikes have all stressed aging infrastructure.

FIGURE 2

Annual Economic Losses Caused by Weather- and Climate-Related Extreme Events in EU Member States[12]



[7] National Oceanic and Atmospheric Association (NOAA) National Centers for Environmental Information (NCEI), U.S. Billion-Dollar Weather and Climate Disasters, 2025, DOI: 10.25921/stkw-7w73

[8] Reuters, Fact check: the causes for Texas' blackout go well beyond wind turbines, 19-Feb-2021

[9] University of Michigan at Ann Arbor, 2021 Texas Power Grid Failure – a preventable disaster, 27-Dec-2024

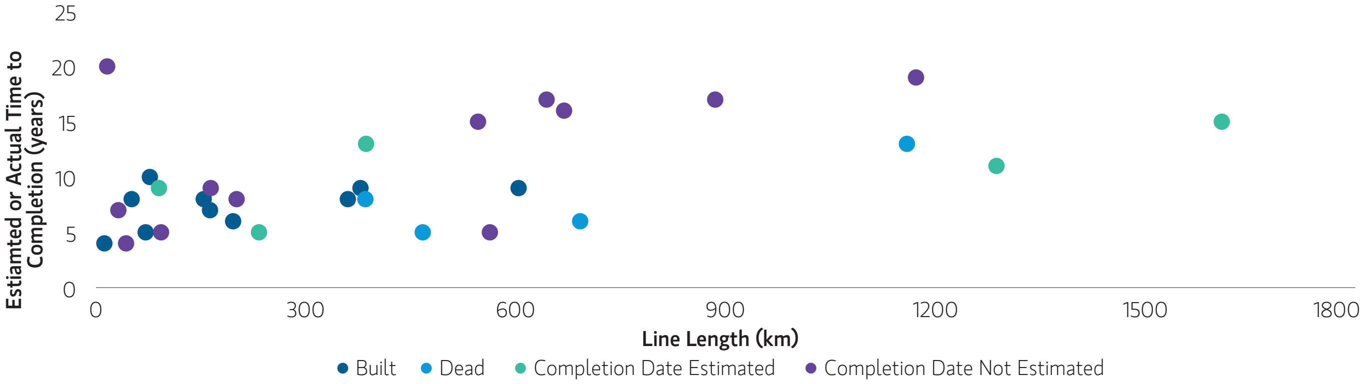
[10] Federal Reserve Bank of Dallas, Cost of Texas' 2021 deep freeze justifies weatherization, 15-Apr-2021

[11] Duvnjak Zarkovic, S. and Messori, G., Impact of Climate Extremes on Power Systems, European Geosciences Union General Assembly 27 Apr-2 May 2025, 14-Mar-2025 https://doi.org/10.5194/egusphere-egu25-8932

[12] European Environment Agency, Economic losses from weather- and climate-related extremes in Europe, 14-Oct-2025

FIGURE 3

Relationship between Transmission Line Length and Completion Time in the US[13]



Multi-year studies show that heatwaves, high winds, and heavy precipitation increasingly interact, creating 'compound' extreme weather events. In the US, heatwaves and high-wind events are dominant drivers of grid outages, with compounding factors acting as tipping points.[14] The North American Electric Reliability Corporation's long-term risk assessment in 2024 highlighted that most grids in North America are at elevated risk levels of disruption due to extreme weather.[15]

When we think of the physical resilience of the grid, therefore, we need to raise the bar from 'storm-hardening' individual assets to 'climate-proofing' the system, with rapid recovery built-in by design.[16]

SLOW REPLACEMENT CYCLES AMPLIFY RISK

Extensive asset replacement programmes are one way of upgrading networks. However, even if grid operators were to suddenly stumble upon huge sums of capital and steadfast support from their regulators to spend this capital solely on upgrading infrastructure (both of which scenarios are distinctly unlikely, as will be further explored in Part 3 of this paper), grid expansion is not simply a case of laying thousands of kilometers of copper wire. Electricity grids require thousands of grid assets such as transformers, switchgear, HVDC components, and inverters. Replacing these critical grid components is neither fast nor easy. Demand far exceeds supply with the inevitable consequence that lead times for critical hardware are lengthening. For instance, lead times for large power transformers are now two to four years at best.[17] Moreover, European and US grid operators predominantly source their grid assets from a handful of suppliers operating across the globe across complex supply chains.

Building capacity to manufacture these components domestically in Europe and the US is a significant challenge that is beyond the scope of this paper. But if such capacity were to materialise in a dramatically short space of time, these newly minted manufacturers would be exposed to further upstream supply constraints themselves. For instance, large power transformers require grain-oriented electrical steel (GOES) for their cores. The US Department of Energy specifically highlighted in 2022 that domestic GOES production as "a major weak link" in the US large power transformer supply chain, with no domestic steel mill producing a price-competitive product. As a result, the US imported more than 80% of all transformers in 2019 – a ratio that is unlikely to change even in the medium-term.[18]

Finally, as geopolitical pressures continue to disrupt trade flows unpredictably, constraints, and bottlenecks in the supply of critical metals and minerals (e.g. copper, lithium, graphite, rare earths) are widely recognised as major hurdles to grid upgrade and expansion programmes.[19]

Thus, even while large-scale infrastructure upgrade campaigns are now being promoted by stakeholders across Europe and North America, it will be an unprecedented challenge to simply make like-for-like replacements quickly enough. Indeed, in the US, transmission lines take, on average, 10 years to build with only a weak relationship between line length and time to completion **(see Figure 3 above)**.[20] As will be discussed further in Part 3 of this paper, grid operators are working closely with their regulators on policy and procedural reforms that aim to expedite network build-out, but these will take time we do not have to be implemented. In the short term, therefore, the stage is set for the adoption of some of the most promising technologies and solutions discussed in Part 2.

[13] Moch, J. M., "Review of transmission lines since 2005", 2022; A list of the reviewed transmission lines with accompanying data and sources can be found at: https://doi.org/10.7910/DVN/MDQ6ME
[14] Saki, S. et al., A multi-year analysis of the impact of heatwaves and compound weather events on power outages, Nature Scientific Reports 15 30846, 22-Aug- 2025 https://doi.org/10.1038/s41598-025-15065-x
[15] North American Electric Reliability Corporation (NERC), 2024 Long-Term Risk Assessment, Dec-2024
[16] IRENA, Enhancing resilience: Climate-proofing power infrastructure, Dec-2025
[17] National Infrastructure Advisory Council, Addressing the Critical Shortage of Power Transformers to Ensure Reliability of the US Grid, Jun-2024
[18] DOE, Large Power Transformer Resilience Report, Jul-2024
[19] IEA, Global Critical Minerals Outlook 2025
[20] Moch, J. M. and Lee, H., The Challenges of Decarbonizing the U.S. Electric Grid by 2035, Harvard Kennedy School Belfer Center for Science and International Affairs, Feb-2022

PROBLEM 2

Demand Growth Supercharges the Race to Modernise the Grid

For much of the late twentieth and early twenty-first century, electricity demand in advanced economies grew slowly, if at all. Efficiency gains largely offset population growth and economic expansion. That pattern is now reversing.

Across Europe and North America, electricity demand is expected to grow meaningfully over the coming decade, driven by a set of reinforcing trends:

- Electrification of transport and heating, as electric vehicles and heat pumps replace fossil-fuel alternatives
- Industrial reshoring, particularly of energy-intensive manufacturing, motivated by supply-chain resilience and industrial policy[21]
- Rapid expansion of data centres, driven by cloud computing and artificial intelligence workloads

Even conservative forecasts suggest that electricity demand in the United States could rise by 35–50% between the mid-2020s and early 2030s, with similar upward pressure expected in Europe.[22]

The operative question for grid operators, regulators and other stakeholders is how to integrate these facilities, which require large, continuous, highly reliable power supplies and often seek connection in regions where grid capacity is already constrained. And they must find a solution quickly.

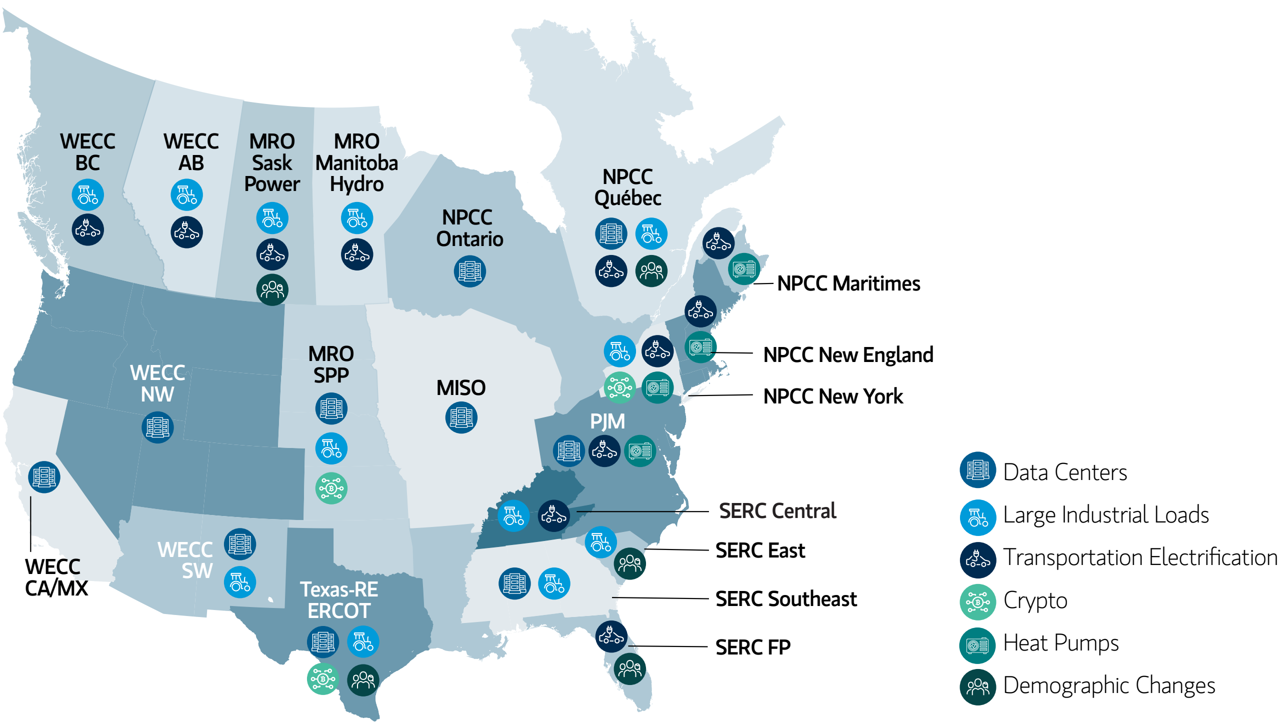
LARGE, INFLEXIBLE LOADS

Data centres illustrate the challenge particularly well. In 2023, data centres accounted for roughly 4% of US electricity consumption. Some projections place that figure between 7-12% by 2028 – that is to say, a doubling or tripling in just five years.[23,24] The sheer volume of power that will be needed for new data centres, particularly AI data centres is staggering: the IEA have estimated that a typical AI-focused data centre consumes as much electricity as 100,000 households, while the largest ones under construction today will consume 20 times as much.[25]

Accordingly, grid connection timelines are lengthening across the board in the US – a trend exacerbated by the concentration of new large loads in particular regions **(see Figure 4 below)**.[26] Congestion is particularly severe in advanced manufacturing corridors and 'data centre hubs' such as Virgina's 'Data Centre Alley' where new >100 MW connections can face waits of up to seven years as utilities need to reinforce networks before integrating such load profiles.[27]

FIGURE 4

NERC's Assessment of Primary Drivers of Load Growth by Region[28]



[21] Reshoring Initiative, 2023 Annual Report
[22] American Clean Power, U.S. National Power Demand Study, Mar-2025
[23] DOE LBNL, 2024 Report on U.S. Data Centre Energy Use, 20-Dec-2024
[24] DOE, DOE Releases New Report Evaluating Increase in Electricity Demand from Data Centers, 20-Dec-2024
[25] IEA, Energy and AI, 10-Apr-2025
[26] Rand, J., et al., Characteristics of Power Plants Seeking Transmission Interconnection as of the End of 2023, 2024
[27] IEA, Energy and AI, 10-Apr-2025
[28] Federal Energy Regulatory Commission (FERC), NERC Seeks to Address Reliability Impacts from Large Load Integration, 17-Apr-2025

European grid operators are also grappling with interconnection queues of unprecedented magnitude **(see Table 2 to the right)**.In the Netherlands, for example, favourable incentive schemes have accelerated the roll-out of large numbers of distributed energy resources as well as large-scale green hydrogen production.

Integrating these loads on the existing network while ensuring system-wide stability has proven such a challenge that by May-2025, some 12,000 companies were waiting for a new or expanded electricity connection.[29] Wait times for data centre connections in the Netherlands are currently 10 years (and counting), with some market analysts now pointing to an "effective ban on new data centres" in the country. It is increasingly becoming clear that data centre developers and owners are 'voting with their feet': European countries that have managed to minimise interconnection queues (e.g., Norway,) have correspondingly seen stronger growth in data centres.[30]

TABLE 2

Transmission Interconnection Queues vs Peak Load (2024) in Europe and the US[31]

COUNTRY (GRID)	QUEUE SIZE/2024 PEAK LOAD[i]
Finland	30x
UK	15x
Italy	12x
Netherlands	6x
US (SPP)	5.5x
Belgium	4.5x
US (ERCOT)	4x
Germany	4x
US (NYISO)	4x
US (MISO)	3.5x
US (CAISO)	2.5x
US (PJM)	1.5x
France	0.75x

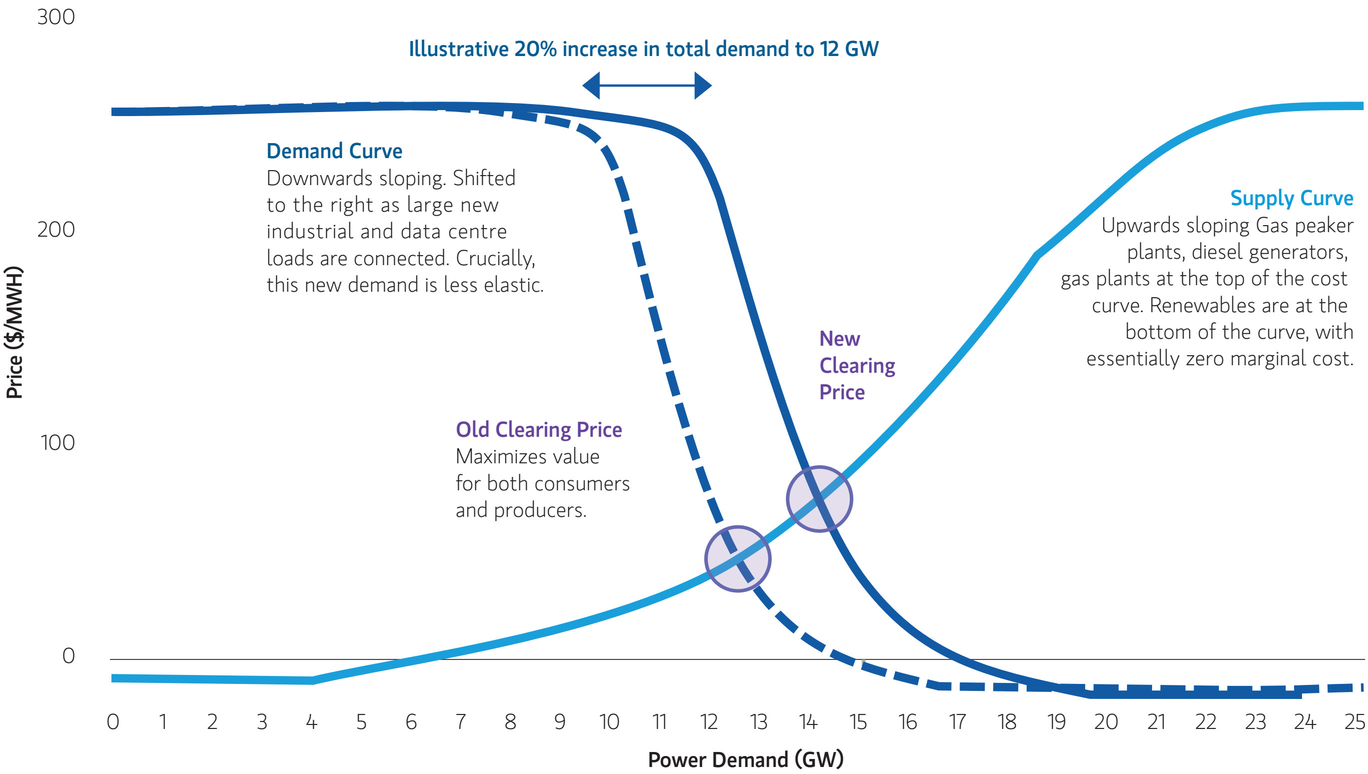
[29] Taylor Wessing, Grid capacity in the Dutch energy sector, 9-May-2025
[30] Ember Energy, Grids for data centres: ambitious grid planning can win Europe's AI Race, 19-Jun-2025
[31] Boston Consulting Group, Mind the queue connection reform for the electricity grid, 4-Sep-2025

System operators are scrambling to integrate the sheer volume of these new connection requests by implementing new reliability guidance and expedited permitting frameworks, as will be further discussed in Part 3 of this paper.[32] Nevertheless, there is growing pressure from stakeholders to cut these connection queues quickly not least because costs associated with grid congestion are directly impacting consumers. For instance, the Dutch transmission system operator (TSO), TenneT, spent six times more on congestion management in 2022 vs 2020[33], while in Germany, similar costs rose three-fold between 2020 and 2022 to more than €4 billion, with the majority of these costs passed on to end-users via 'network charges.'[34] For instance, in the Netherlands, consumer electricity tariffs are expected to rise at 4.7% annually until 2034 to cover the majority of the required upgrades to the electricity network.

Lastly, demand for power from these new, larger loads is expected to be round-the-clock and price inelastic, likely leading to escalating wholesale power prices for all as the demand curve shifts upwards **(see Figure 5 below)**.[35] In the absence of reforms to power market design or roll-outs of enabling software and hardware (discussed further in Part 2), it is unlikely that data centres will embrace the load-shifting that is required to avoid wholesale power prices rising for all ratepayers.

FIGURE 5

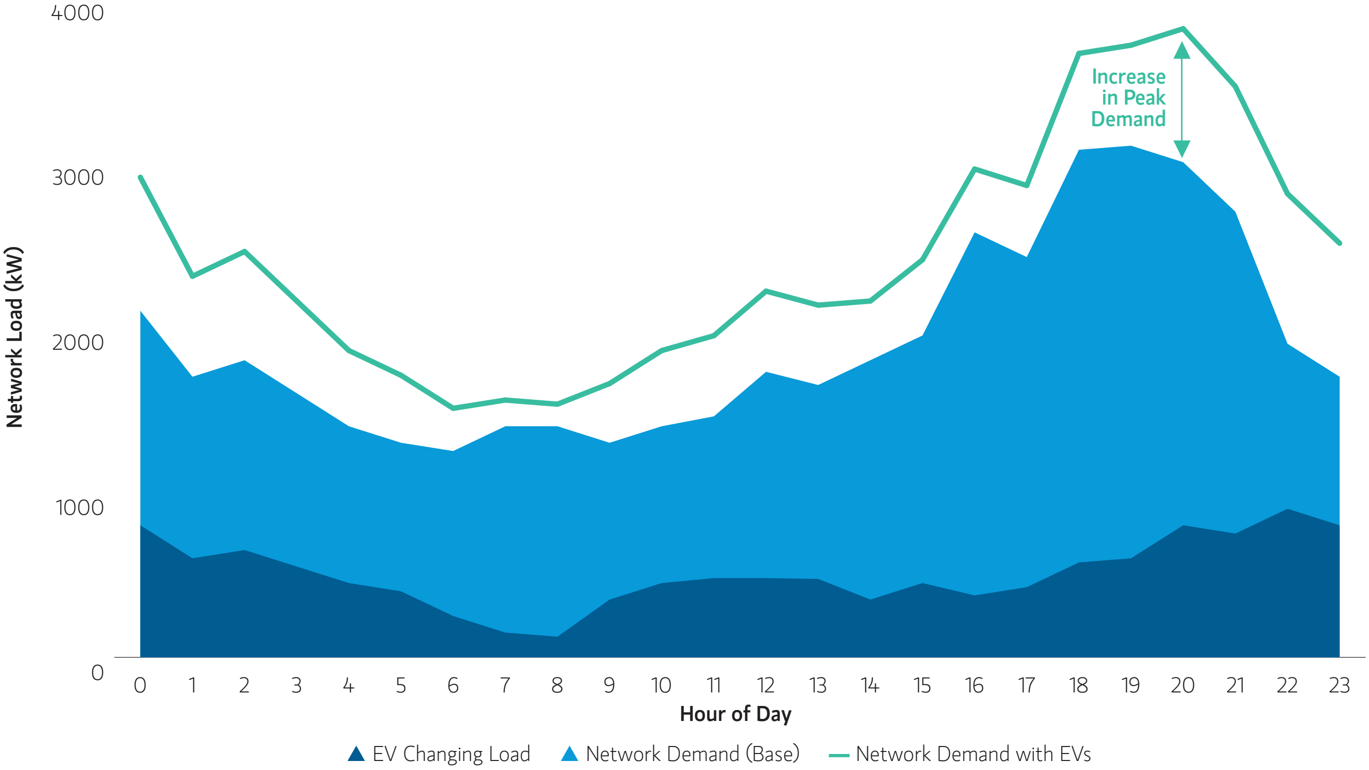
Illustrative Impact of a 20% Increase in Power Demand from Always-On Data Center Demand[35]



[32] FERC, NERC Seeks to Address Reliability Impacts from Large Load Integration, 17-Apr-2025
[33] TenneT, Annual Market Update 2023, 17-Jul-2024
[34] IEA, Grid congestion is posing challenges for energy security and transitions, 25-Mar-2025
[35] Thunder Said Energy, Wholesale power markets: classical economics, 3-Nov-2025

FIGURE 6

Illustrative Network Demand Profile for a Medium-Density Urban Network of 1,264 Households[36]



MORE VOLATILE DEMAND PATTERNS

In addition to the aggregate load on the grid increasing, the shape of electricity demand is changing too. Large, round-the-clock demand for data centres is just one piece of the puzzle. The electrification of transport and heating is also expected to change consumption patterns in profound ways.

By 2040, electric vehicles (EV) and electric heating systems are expected to account for 10% and 3% of total energy demand, respectively. Consumers tend to charge EVs and use heating/cooling systems immediately as they get home in the evening, amplifying spikes in demand for electricity. As shown in **Figure 6,** even at modest EV penetration rates, electricity demand peaks are expected to rise dramatically, posing further supply-demand balancing challenges to grid operators.

For grid operators in the US, the consequences of overall peak load increasing almost 50% to 1,200 GW in 2050[37] are far-reaching: more volatile demand profiles will require more granular planning, monitoring and control of the grid, as well as the incorporation of flexible power generation sources, emergency power dispatch services, and load-shifting incentive programmes.

However, absent the toolkit of flexibility solutions (which will be discussed in Part 2 of this paper) to address these implications, grid operators face a costly choice today: over-build for rarely-used peak demand or accept the financial and reputational consequences of network congestion and outages.

PROBLEM 3

Renewable Energy is Cheap to Build but Difficult to Integrate

While aging power grid infrastructure can eventually be replaced and disruption risks from adverse weather events can be mitigated by better use of existing grid technologies and better network planning, US power grids today face a more fundamental challenge: the structural transformation of electricity supply and demand patterns. In the US, renewables accounted for 26% of electricity generation in 2025, up from roughly 12% in 1990.[38] Europe has seen a similar, and in some countries faster, transition. In 2024, 47.5% of gross electricity consumption in Europe came from renewable sources vs ~16% in 2004. In Germany, this was 54% in 2024 vs 9% in 2004.[39] As hardware costs continue to compress, ~45% of US electricity supply in 2050 is expected to come from renewables, which, in turn, will intensify the challenges grid operators are already struggling with.[40]

[36] Nutkani, I., et al.: Impact of EV charging on electrical distribution network and mitigating solutions – A review, IET Smart Grid. 7(5), 485–502, 2024 https://doi.org/10.1049/stg2.12156
[37] ICF, America's Growing Electricity Demand, 12-Sep-2024
[38] US Energy Information Administration (EIA), Electricity Explained: Electricity in the United States
[39] Eurostat, Share of energy from renewable sources, 2026 https://doi.org/10.2908/NRG_IND_REN
[40] EIA, Today in Energy Newsletter, 18-Mar-2022

This shift brings enormous long-term benefits: lower marginal costs, reduced emissions, and improved energy security.[41,42] But it also challenges many of the assumptions on which legacy grid infrastructure was designed.

FROM CENTRALISED TO DISTRIBUTED

Traditional grids were built around a small number of large, centralised power plants predictably feeding electricity one-way through transmission and distribution networks to end-users. Renewable generation, by contrast, is often smaller-scale, geographically dispersed, and variable in output.

On the supply side, this increases the number of generation points and introduces greater network planning complexity given the power output is inherently intermittent and variable. On the demand side, distributed energy resources such as rooftop solar and behind-the-meter batteries turn once passive consumers into "prosumers," both drawing power from and injecting it back into the grid. In the United States, the number of customers exporting electricity back to the grid increased thirteen-fold between 2011 and 2020, reaching approximately 2.4 million.[43]

FROM PREDICTABLE AND STABLE TO COMPLEX

Wind and solar output fluctuates with weather conditions, and inverter-based resources do not provide the stabilising system inertia that was traditionally delivered by large rotating generators in fossil fuel power plants. As the penetration of renewables rises, maintaining stable frequency and voltage becomes more challenging for grid operators – especially during disturbances.

These issues have already constrained renewable deployment in some regions, with grid operators curtailing output or delaying interconnections due to stability concerns. In practice, this has also contributed to the continued reliance on expensive gas-fired "peaker" plants that can ramp quickly to support the system, despite operating for only a small fraction of the year.[44]

As power systems become more complex, the ability to see, predict, and respond in real time is becoming just as important as physical capacity. Many legacy grids still rely on static ratings, limited sensor coverage, and manual intervention – approaches ill-suited to today's operating environment. Improved digital visibility can help operators detect equipment stress, forecast congestion, and isolate faults before they cascade into large-scale outages. As will be further explored in Part 2 of this paper, improved visibility and controls can also enable more precise use of existing assets – postponing costly physical upgrades or potentially avoiding them altogether.

The need for better control is not limited to physical risks. Cyber threats are also rising in prominence. Between January 2023 and January 2024, global critical infrastructure reportedly experienced hundreds of millions of cyber-attacks, underscoring the importance of secure, modern control architectures. The ongoing digitisation of the grid and proliferation of small-scale distributed energy resources and other Internet of Things-(IOT-)enabled devices has in effect expanded the attack surface for cyber-attacks.[45] Physical attacks on grid infrastructure have also markedly increased. Even if only a fraction of the 2,800 attacks on US electricity facilities in 2024 directly caused an outage, stakeholders now recognise the persistent threat to grid infrastructure from such acts of sabotage.[46] Indeed, the North American Electric Reliability Corporation now ranks cyber- and physical security as 'top-tier reliability risks' in their 2025 Reliability Risk Priorities report right alongside extreme weather events and grid transformation.

Conclusion

The pressures outlined above are not transient or policy-driven anomalies. Aging infrastructure, accelerating electricity demand, rising climate and cyber risks, and the rapid growth of renewable and distributed energy are structural features of the modern grid.

Critically, the response to these challenges cannot rely solely on traditional, capital-intensive grid expansion. New transmission lines, substations and other grid assets remain essential, but they are increasingly constrained by long permitting timelines and supply chain bottlenecks. As a result, there is a widening gap between what grid operators need in the near- to medium-term and what conventional infrastructure investment models can deliver. The promising technologies that will be evaluated in Part 2 of this paper offer a faster, more capital-efficient complement to traditional built-out of grid assets. They can help extend asset life, unlock latent capacity, improve network resilience, and enhance operational visibility, directly addressing the significant challenges discussed earlier.

This dynamic underpins the investment thesis for grid technology. Commercially proven, mission-critical hardware and software solutions can deliver measurable economic value by deferring capital expenditure, reducing outage risk, accelerating interconnections, and improving utilisation of existing assets. As will be explored in Part 3, for investors and other stakeholders alike, this matters because these forces create a sustained requirement for capital deployment and innovation across transmission, distribution, and grid operations – independent of short-term political cycles.

Grid failures are no longer niche, technical events. They impose real economic costs, undermine public confidence, and create political and regulatory fallout for utilities and policymakers alike.

The challenge is clear. The tools exist. What remains is to deploy them at scale.

[41] Lazard, Levelized Cost of Electricity 2024, Jun-2024
[42] DOE LBNL, New study refocuses learning curve analysis on LCOE, 31-May-2022
[43] Smith, K. et al., Regulating net metering in the United States: A landscape overview of states' net metering policies and outcomes, Mar-2021 DOI: https://doi.org/10.1016/j.tej.2020.106901
[44] Lazard, Levelized Cost of Energy 2024, Jun-2024
[45] EEPower, Grid Cyber Threats a Rising Concern in 2025, 21-Jan-2025
[46] NERC, 2025 ERO Reliability Risk Priorities Report, 22-Jul-2025

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