Global Grids Index

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Global Grids Index

This index measures and compares how prepared 10 major energy markets are in constructing the electricity grid of the future.

Building powerful connections

Power grids have been a success story since they were first constructed 150 years ago. Today, grids face an unprecedented challenge as they must support most of the effort that the energy transition will require. Grids will be greener, increasingly digital and more decentralized, enabling consumers to generate their own renewable power and distribute it back to the grid. By 2050, a 152-million-kilometer supersized grid—enough cable to stretch all the way to the Sun—and an investment of $21.4 trillion is needed to support a net-zero trajectory, according to BloombergNEF. It also requires stable regulatory frameworks, attractive revenues and digitalization at all levels.

So, which countries are most prepared to connect the renewable energy future? Bloomberg Media's proprietary algorithm, created in partnership with Iberdrola, from the latest available data collated in 2023 measures who's leading and who's lagging.

Index Scores

10 leading renewable energy markets have been scored using BNEF's Net Zero Scenario (100 = on track), using the following criteria:

Renewable Connections
- Generation mix 20%**
- Connection speed 20%*

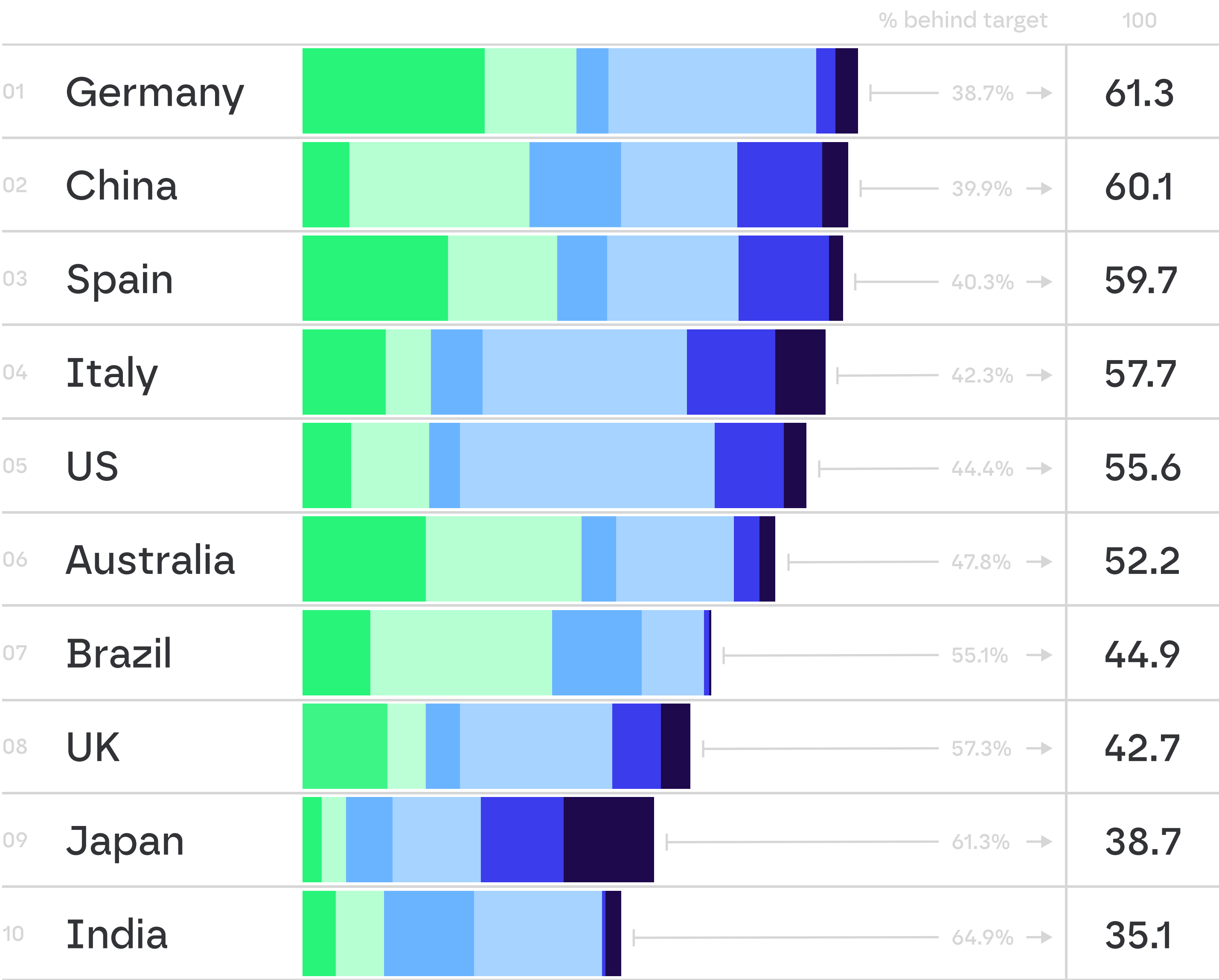
Network Development
- Network scale 10%**
- Combined grid investment 30%*

- Digitalization 10%**

- Energy Storage 10%**

*Situational KPIs: parameters calculated using available data for the period 2020-2023.

**Structural KPIs: parameters calculated using available data as of 2022-2023.



Germany leads the Global Grids Index, but needs to get smarter about digital meters.

Renewable Connections	Network Development	Digitalization	Energy Storage	Index Score
75%	**67%**	**21%**	**24%**	**61.3**

Germany, the Global Grids Index's top performer, is also Europe's largest energy market, with the most experience connecting renewable energy capacity as it works toward a net-zero future. However, ambitious renewable targets and a phasing out of fossil fuels means large-scale investment is required.

Renewable Connections

Germany was the first country to implement renewable energy installations at scale—in 2022, its cumulative installed wind and solar capacity was about 133 GW—and it has many years' experience linking projects to the grid.

To achieve net zero, however, the amount of new renewable generation capacity connecting to the grid each year will need to more than double to about 24 GW by 2025 from the 10GW installed in 2022, then increase to 31 GW by 2030, according to BloombergNEF (BNEF).

The Bundesnetzagentur (Federal Network Agency), the electricity industry regulator, has reported that onshore wind power awards increased between 2022 and 2023. Germany needs to triple its current clean energy capacity to meet its goal of generating 80% of its power from renewables by 2030.

Network development

Germany is set to be Europe's largest grid investor, spending $278 billion between 2022 and 2035 in BNEF's Net Zero Scenario. Germany's 2021 Network Expansion Plan shows total network investment of around $140 billion by 2035, with $89 billion to be invested in onshore and offshore transmission grids, and at least $50 billion invested in lower-voltage distribution grids through 2032.

While much of the nation's future clean energy will be generated by offshore wind farms in the North Sea off the northern coast of Germany, and at onshore wind farms mainly located in the north of the country, many of its key centers of demand are in the industrialized south.

Transporting power from the North Sea to Germany's southern industrial regions will require significant amounts of new infrastructure. BNEF estimates that the amount of underground transmission cables in Germany will triple to 21,665 kilometers in 2050, including more than 8,000 km of undersea cables.

Another challenge could be the country's fragmented distribution market. While only four companies own and operate Germany's transmission system (TenneT, 50Hertz Transmission, Amprion and TransnetBW), there are almost 900 distribution system operators, which makes it difficult to manage congestion on the network. However, Germany scores highly on network development in this index, with a high rating for the amount of investment in the grid relative to its current scale.

Germany is one of the largest energy consumers in Europe, and still significantly dependent on fossil fuels. The nation has launched a support scheme for energy-intensive industries such as pulp and paper, steel, chemicals and cement production, to switch to more climate-friendly production processes. Its Carbon Contracts for Difference program compensates energy-intensive industries for the difference in cost between low-carbon production methods and traditional fossil-based production.

The government has mandated that the vast majority of homes must switch to climate-neutral heating systems within the next 20 years. It has a target to install 500,000 heat pumps a year, and could reach an installed base of 6 million by 2030, although uncertainties remain around support schemes for the technology.

The electric vehicle market is growing by 14.49% a year and is projected to reach sales of 1.7 million a year by 2028. The number of charge points is predicted to almost double from 1.4 million in 2024, to 2.4 million on the same timeline.

High demand for cloud computing services, 5G and smart city applications, as well as stringent rules on data security is driving growth in the data center market of 6.5% a year to 2028, from 1.72 GW in 2024 to 2.36 GW in 2028.

Digitalization

Despite Germany's top score, digitalization is one area where the country lags behind, it is among the least developed markets for smart meters. Given its leading position in the index, this suggests that the German grid has the potential to become significantly more efficient.

At the start of 2023, the German government adopted a law to accelerate the rollout of smart metering. Utilities are now installing smart meters, and they will become mandatory in 2025, with a target of almost complete coverage of homes and small businesses by 2030; major energy consumers must have smart metering installed by 2032. The law also makes it easier to develop and install the meters, while shifting more of the cost onto network operators and away from consumers.

From 2025, all electricity suppliers must offer dynamic tariffs that vary depending on demand. Currently, only those utilities with more than 100,000 customers must offer dynamic tariffs with smart metering.

Energy storage

Germany's energy storage capacity is low, but it is expected to grow rapidly through 2030. In 2019, TransnetBW the operator of the electricity transmission system in Baden-Württemberg, and energy storage provider Fluence Energy GmbH announced Netzbooster (Grid Booster) a 250 MW battery energy storage system (BESS) that claims to be the world's largest energy storage-as-transmission project. Due to come online in 2025, the system will reduce the need for new transmission lines by releasing or storing power as required to facilitate the flow of electricity and balance the system.

With 5,300 GW of energy needed by 2050, **China's** electricity network will be stretched to its limit.

Renewable Connections	Network Development	Digitalization	Energy Storage	Index Score
63%	**57%**	**95%**	**28%**	60.1

Like all elements of its economy, China's grid is huge. Its vast network of ultra-high-voltage cables has set the benchmark for delivering renewable energy at speed. But with large volumes of solar and wind capacity slated to be connected every year, its grid will need to expand tremendously.

Renewable Connections

China's 735 GW of cumulative wind and solar capacity (as of 2022) and average annual installations of 120.5 GW from 2020 to 2022 dwarf the figures of any other nation and reflect the speed at which it is installing renewable capacity.

In the BloombergNEF (BNEF) Net Zero Scenario, wind and solar are predicted to grow to 15x and 13x 2021 levels by 2050, adding an average of 233 GW of capacity each year between now and 2050. Total electricity consumption will rise to 17,183 TWh by 2050, more than double current levels, wind and solar responsible for 75% of total power generation. Despite this high rate of renewable capacity growth, it appears that China's investment in the grid is keeping pace with this massive expansion of clean power.

The result of this investment is that China scores highly when it comes to connections. Although its energy mix remains carbon-intensive, it is connecting renewable capacity to the grid fairly rapidly

Network Development

At more than 12.4 million kilometers, China's power grid is the world's largest. With thousands of kilometers of ultra-high-voltage (UHV) cables providing around 200 GW of transmission, it delivers renewable power from remote regions such as Inner Mongolia to the coastal cities that are the key centers of demand. UHV power lines can transfer up to 12 GW of electricity—four times the capacity of extra-high-voltage (EHV) power lines.

China continues to invest record amounts in its grid infrastructure, and it is predicted to spend an unprecedented $3.8 trillion on its transmission and distribution grid through 2050, a figure only the US will come close to matching according to BNEF's Net Zero Scenario. In 2022 alone, it spent $75 billion on the grid, according to the China Electricity Council—more than any other market in history.

China's transmission grid is set to double in size to 3.5 million km by 2050, including 42,000 km of submarine cables that must be connected to the grid as it installs 315 GW of offshore wind capacity by mid-century, in BNEF's Net Zero Scenario. The HVDC transmission network will grow to 95,000 km, and there will be 51,000 km of UHV transmission to accommodate renewable assets.

Around half of China's grid assets are less than 10 years old and 85% are less than 20 years old, but after 2040, the Chinese market will be characterized by a heavy rate of investment to replace aged grid assets, comprising 45% of total grid investment in 2050, up from around 28% in 2020.

China has a target of reaching carbon neutrality by 2060. This will result in a huge increase in renewable energy generation and electricity demand across the economy, implying an overall electrification rate by 2060 of around 65%, with a breakdown of industry at 60% buildings 70% and transportation 55%. The goal is for 83% of its generation capacity to be from non-fossil sources by the same date.

Heat represents two-thirds of all energy demand in China's industrial sector, and there is a significant opportunity to switch to electric heat, with the biggest impact in industries such as ammonia, recycled plastic and steel production.

For transport, according to the State Grid Corporation of China, there could be 50 million electric vehicles on the road by 2030, leading to an annual electricity demand of 200 TWh for EV charging.

The proliferation of IoT, AI, and 5G technologies has led to a surge in demand for data centers in China, with high computational power from internet services propelling the growth of the tech sector. Power consumption from digital infrastructure in China is on track to grow 289% between 2020 and 2035, accounting for 5-7% of China's total power consumption, compared to just 2.7% in 2020.

China accounts for more than one-quarter of global heat pump sales, and in 2023 sales grew 12%. For China to meet its carbon neutrality target 100 GW of heat pumps need to be installed every year to 2050.

Digitalization

The State Grid Corporation of China's “Ubiquitous Power IoT” strategy aims to digitalize all internal operations and 90% of external services by 2024. As a result, China will account for one-quarter of global spending on digital grids between 2022 and 2050, at $1.3 trillion.

In doing so, it will be building on its already substantial efforts. For example, State Grid, one of the country's two major utilities, develops most of its software in-house and recently produced a digital 3D model of its 100,000-km grid in Jiangsu Province, using satellite imagery and artificial intelligence.

At a more granular level, 90% of the country's properties already have smart meters, and China continues to heavily invest in smart grid technology that allows it to distribute electricity efficiently and reliably. Advanced metering systems, automated control systems and real-time monitoring and management systems are among the technologies employed by the nation's smart grid infrastructure.

Energy Storage

China is set to become the global leader in energy storage, with 175 GW of storage expected to be installed by 2030, overtaking the US. BNEF increased its forecast for the country's energy storage market by 66% after the publication of new targets for provincial governments.

This will support significant new capacity, along with targets for 5% to 20% of renewable asset capacity to be paired with energy storage. Between January 2022 and March 2023, 26 provincial governments released development plans for energy storage projects with a total capacity of 70 GW by 2025, more than double the national 2025 target of 30 GW.

Spain needs to work on its regulatory framework and grid development to meet planned electrification demand, and deploy additional renewable energy generation.

Renewable Connections	Network Development	Digitalization	Energy Storage	Index Score
70%	**50%**	**99%**	**16%**	**59.7**

Alongside the work Spain needs to do on its regulatory framework and grid development—to ensure there is enough network capacity to meet planned demand for electrification and to deploy its additional renewable energy generation—the current total investment cap of 0.13% of GDP needs to be removed, while regulatory returns should be enough to guarantee that investments are made to meet energy transition objectives.

Despite being a global leader in renewable energy and smart meter deployment, the rapid growth of renewables has strained Spain's grid . Future renewable deployment will require grid expansion and improved connection capacity, which will be difficult to achieve under the current regulatory framework, which constrains companies from investing in the grid.

Renewable Connections

When Spain first started deploying renewables, the grid was capable of integrating all the capacity that required connections, but a lack of investment and the regulatory framework have hampered progress. Although the country has made efforts to connect new renewable capacity, grid development is not adequately reflected in plans for the electrification of the economy. Spain has high levels of wind and solar capacity seeking grid connection—around 176 GW in March 2023—in a market that has a wind and solar power target of just 160 GW by 2030.

Network Development

Spain's grid development is currently insufficient to meet the challenges of connecting the additional renewable capacity, and new sources of power demand that are growing rapidly. For example, there are currently 97 data centers requests in Spain, more than half of them in Madrid and Barcelona. Interest from the industrial sector in the electrification of processes is already increasing rapidly. Additionally, the expansion of the hydrogen industry is expected to boost electricity demand in the medium term, while the installation of heat pumps has more than doubled in the past decade. As a result, there is a real need to expand and reinforce high- and medium-voltage networks.

Low-voltage networks will also require significant investment in the upcoming years to accommodate the incremental power flows derived from electric vehicles. Passenger EV sales grew by 47.6% in 2023, comprising 12% of the total car market, according to the country's National Association of Motor Vehicle Dealers (GANVAM) and the e-mobility association AEDIVE. While the country’s 30,345 public charging points available at the end of the fourth quarter of 2023 already meets its 2024 target, Spain will need over 183,900 EV chargers to meet the EU’s Alternative Fuels Infrastructure Regulation objectives by 2030.

The current Transmission Network Development Plan (TNDP) 2021–2026 aims to prepare the transmission grid to connect and integrate more renewable energy in the coming years, and meet its target of 67% of electricity generation originating from renewable energy sources by 2026. The future TNDP 2025-2030 must be driven not only by the need of connecting and integrating more renewable energy, but also by the increase of capacity at a distribution level, which is expected to grow significantly to meet electrification demand.

Spain’s Integrated National Energy and Climate Plan (NECP) 2023-2030 called for a €308 billion ($333 billion) investment in the nation’s energy transition to drive renewable energies, distributed generation and energy efficiency at local level, as well as provide significant opportunities for investment and job creation. Almost a quarter of the investment, €53 billion ($57 billion), has been earmarked for spending on the network and electrification, to both reduce CO2 emissions and accommodate more renewable power generation.

Digitalization

Spain has the highest level of smart meter penetration of any country in the index. It is well placed to introduce demand-side management measures, such as variable tariffs, vehicle-to-grid operations and the use of smart appliances that can be powered down at times of limited supply or stress on the grid. The initial wave of installations started in 2010, and those meters are set to be replaced with the latest communications technology, significantly reducing network maintenance time, with less equipment and lower labor costs. Smart meters will become increasingly important as on-demand requests increase and new services are offered by utilities, such as variable tariffs and the integration of new services or renewables in the grid.

Energy Storage

Government subsidies are encouraging an increase in energy storage and supporting plans to achieve economic viability. The nation has set storage targets, including 2.5 GW of utility-scale batteries and more than 1 GW of small-scale batteries, as well as 3 GW of pumped hydro storage.

In December 2022, the Spanish government announced $164 million of subsidies that BloombergNEF estimates will drive around 375 MW of storage capacity by 2025. Energy storage projects must co-locate with renewables to be eligible. The subsidies will cover between 40%–65% of the capital expenditure for the storage portion of these projects.

Can **Italy's** billion-dollar “hypergrid” scheme help meet the north-south energy transmission challenge?

Renewable Connections	Network Development	Digitalization	Energy Storage	Index Score
35%	**71%**	**98%**	**55%**	**57.7**

Most of Italy's generation capacity is based in the south, while most of its energy demand is in the north, but its planned hypergrid scheme will double the power that can be moved around the country.

Renewable Connections

Italy's national energy and climate plan aims to source 40% of its total energy consumption and 65% of its electricity generation from renewable sources by 2030.

The country had cumulative installed wind and solar capacity of 37.2 GW in 2022, but it has significant grid connection queues, with both solar and wind projects facing waits of three to five years to join the network. However, in the BloombergNEF (BNEF) Net Zero Scenario, Italy is set to spend $496 billion on its grid infrastructure between 2022 and 2050, with spending rising from $5.6 billion in 2022 to around $20 billion a year up to 2050.

Italy scores well on the Global Grids Index, both in the amount of investment in renewable capacity and in investment compared to the size of the network. This suggests that it is sufficiently investing enough to create a grid that can cope with the 62 GW of solar and 13.5 GW of wind capacity that BNEF expects to be installed by 2030.

Network Development

The Italian network faces a key geographic challenge: Much of the country's generation capacity is based in the south, while most of its demand is in the north. At the end of 2021, 92 GW of connection requests were made in the southern half of the country, compared to just 7 GW in the north, according to Terna, the Italian transmission network operator. Italy needs improved transmission capacity to transport more electricity from south to north, and to clear the connection backlog.

In March 2023, Terna announced that it would invest more than $23 billion in the next 10 years to hasten the energy transition and increase Italy's energy security by reducing the amount of energy it needs to import. One of the central pillars of its investment plan is a $12 billion “hypergrid” scheme to install five new electricity backbones that will increase the amount of power that can be transported from south to north to 30 GW, double current levels. The initiative will include both undersea and overhead high-voltage direct current (HVDC) connections.

The hypergrid could allow Italy to increase its renewable energy capacity by around 85 GW. It is also seeking to create links across the Mediterranean with Algeria and Egypt, in addition to an already-approved underwater interconnector with Tunisia due to be completed by 2028 as part of the hypergrid. These links would allow it to become a southern European energy hub.

According to BNEF, almost three-quarters of Italy's investment is needed to improve the distribution grid, replace aged assets and integrate 60 GW of small-scale solar and 120 GW of utility-scale solar, which require grid upgrades.

The large amount of distributed resources on the network has created a need for more local solutions, and Italy aims to tackle congestion by introducing flexible markets that reduce the need for grid investments. Meanwhile, under BNEF's Net Zero Scenario, the transmission network is set to double in length to over 150,000 kilometers by 2050, including 3,000 kilometers that will handle the electricity from 8 GW of offshore wind capacity.

In terms of future energy demand, sales of electric vehicles are set to increase by 10% a year over the next four years, although sales are lower than in many other European countries as buyers await the introduction of a $1 billion government incentive plan.

The government has spent around $750 million to finance the installation of more than 21,000 fast and super-fast charging points by 2025, adding to the more than 37,000 devices already installed. Private companies are also installing significant numbers of chargers.

Italy is one of the largest markets for heat pumps in Europe, thanks to its Superbonus scheme, under which the government pays 110% of the cost of installing more energy efficient devices. However, sales have dropped due to a delay in the publication of the EU's Heat Pump Action Plan, which was due to be published early in 2024.

The country has also become one of the fastest-growing markets for data centers, thanks to its links to Africa via submarine cables. It currently plays host to 168 facilities, most around Milan, and the sector is expected to grow by 5.78% a year to 2028.

Digitalization

Italy scores well on digitalization because it recognized the benefits of smart metering early on, and made installation of smart meters mandatory in 2006; almost every customer has one. Enel, Italy's largest utility, has installed around 30 million devices, and is replacing the first meters with second-generation devices. The company set up an innovation lab in 2022 and collaborates with startups to develop AI, robotics and sensors for power plants and grids.

Energy Storage

Italy has enthusiastically embraced energy storage. In 2022, it was the biggest market in the world for residential storage, thanks to the Superbonus scheme. While residential installations will ease off as the program scales back, a large pipeline of utility-scale batteries is planned in the next five years. The nation also has 7.7 GW of pumped hydro storage capacity, providing the network with a large degree of flexibility. Energy storage is expected to provide ancillary services and energy shifting, with a significant amount of storage capacity being co-located with solar projects to increase their efficiency and economic viability.

The **US** needs fast-track approvals and grid investment to add 380 GW of clean energy to its aging power grid.

Renewable Connections	Network Development	Digitalization	Energy Storage	Index Score
35%	**79%**	**77%**	**23%**	**55.6**

By 2030, as much as 380 GW of new transmission capacity is slated to come online in the US, according to BloombergNEF (BNEF). Decarbonization policies alongside laws such as the Inflation Reduction Act (IRA) and the US Infrastructure Investment and Jobs Act (IIJA) are helping, but there is still much to do, especially from a distribution perspective.

Asset replacement should be a priority since 50% of grids in the US network date back over 20 years, according to the International Energy Agency (IEA). Grid resilience needs improvement in order to make networks more climate-proof to cope with more frequent and increasingly extreme weather events, while digitalization and network automation are not common in many suburban and rural areas, affecting quality of supply.

Renewable Connections

Current plans to increase the amount of renewable energy capacity could accelerate development of interstate transmission capacity, bringing forward the investment that was previously due after 2040. The best wind and solar resources in the US are not evenly distributed. The states between the Rocky Mountains and the Mississippi River are wind and sun havens, accounting for 88% and 56% of the country's wind and solar PV potential, respectively. The future US energy system will utilize these resources, so a strong power grid that can shuttle power out of this region will be imperative.

BNEF research shows that in 2021, in the US and Canada, 36% of transmission line projects were delayed, up from 16% in 2016. Transmission grid congestion costs more than tripled from over $6 billion in 2019 to almost $21 billion in 2022, according to the IEA—equivalent to about 18.52 GW of new solar PV capacity. BNEF modeling shows that US grid investments of $3.8 trillion from 2022–2050, the same level as China, will lead to the US grid doubling in length by the middle of the century. However, grid spending is still significantly lower than investment in renewable energy capacity, despite initiatives such as the IRA and IIJA, which means renewables will not be able to connect to the grid unless more investment is allocated to the power network.

Network development

The US grid operates without any single unifying entity that directs all investments or makes plans at the federal level. However, the government has placed transmission at the top of its agenda, with transmission lines such as TransWest Express, Champlain Hudson Power Express and SunZia receiving fast-tracked permitting approval over the past year.

The US Federal Energy Regulatory Commission (FERC) is looking to improve the speed of connections to the grid through a number of changes, including a switch from a “first-come, first-served” system to a “first-ready, first-served” approach and penalties for grid operators if they take too long to consider requests.

With $150 billion a year earmarked to be spent on grids by the end of the decade, according to BNEF estimates, more than half of spending is going toward asset replacement.

However, there will also be significant spending to build transmission capacity to move energy across the country and to upgrade power lines to accommodate higher consumption, as large parts of the economy are electrified and the number of electric vehicles on the road increases.

US electricity use is predicted to rise 27% from 2022 levels by 2050, to 5,178 TWh, driven by increased demand for space cooling and an increase in the number of electric vehicles. The volume of electricity purchased for transportation will increase between 900% and 2,000% by 2050, according to the US Energy Information Administration.

In the US, heat pumps overtook gas furnace sales in 2022, after years of almost equal growth. In 2023, 25 states belonging to the US Climate Alliance, which also account for 60% of the US economy, agreed to promote policies to speed up the installation of heat pumps in their states. From 4.7 million installations in 2023, the Climate Alliance wants to see that total grow to 20 million by 2030.

Switching the industrial processes used to make products such as concrete, chemicals, steel and vehicles to run on clean electricity could increase annual electricity demand by 6,000 TWh to 10,000 TWh, more than current total national demand of 4,300 TWh. Within the tech sector, the US currently hosts more than 2,500 data centers across 50 states, led by Virginia, California, Texas, Ohio and Nevada.

To move power from renewable energy sites to load centers will require existing interstate transmission capacity, currently optimized for the fossil fuel and nuclear fleet, to be expanded. The transmission capacity between the Western Interconnection and Eastern Interconnection is slightly above 1 GW, for example, despite there being over 1,000 GW of generation capacity between the two systems.

A study by the National Renewable Energy Laboratory shows that strengthening connections between the Eastern and Western interconnected grids would generate more than $2.50 for every dollar invested and save customers approximately $3.6 billion a year by 2038. These savings come from sharing low-cost wind and solar resources in addition to improving regional flexibility.

Digitalization

According to BNEF, 77% of the US market has smart meters, which allow users to voluntarily reduce household energy demand during periods of grid strain. In 2022, more than 15 million US homes and businesses took part in these energy-saving programs.

The Edison Institute for Electric Innovation projects that 135 million smart meters will be installed by 2025—85% of all homes and businesses. Coverage, however, is very uneven. Five states had penetration of less than 15% in 2021—Hawaii, Massachusetts, New Jersey, New Mexico and Utah—while 11 states had coverage of between 15% and 50%.

The US accounts for 22% of global digital spending on grids this decade in BNEF's Net Zero Scenario, with spending boosted by laws such as the IIJA, which steers investment to digitalization for grid flexibility and resilience. BNEF figures show that the IIJA and the IRA allocated $29 billion to initiatives related to the power grid, which is expected to stimulate $83 billion in grid investment through 2030.

Energy storage

Although the US has seen project delays due to the rising cost of batteries, the energy storage market is growing rapidly, led by a pipeline of large-scale projects in the Southwest, California and Texas. Developers plan to add another 15 GW in 2024 and around 9 GW in 2025, according to the IEA. Much of the capacity, predicted to reach 123 GW by 2030, is paired with solar for system reliability.

FERC is looking at ways for utilities to increase their visibility of the real-time condition of power equipment, using solutions such as smart sensors and dynamic line ratings (DLR). This visibility allows utilities to safely increase power line capacity to connect more renewables; more efficiently balance supply and demand to reduce congestion; and improve resilience by reducing outage response time. More than 15 US utilities already use DLR.

Australia has the longest interconnected grid system in the world, but it needs to almost double in length by 2050.

Renewable Connections	Network Development	Digitalization	Energy Storage	Index Score
77%	**42%**	**30%**	**17%**	52.2

All Australian states, territories and the federal government have committed to achieving net-zero targets with varying levels of ambition (from 2030 to 2050), and electricity networks will play a crucial role in supporting cost-effective decarbonization.

The country will require more investments in new transmission infrastructure in the next few years to reach its ambitious targets for renewables. The acceleration of smart meter deployment as part of network digitalization is also an important factor.

Renewable Connections

Much of Australia's electricity is generated by a fleet of aging coal-fired power stations, and as those assets retire, they will increasingly be replaced by wind and solar. If Australia is to reach its 2050 net-zero target, the share of generation from wind and solar will need to grow to 97%, up from 26% today. Stronger transmission networks will be needed to move this power around the country.

In 2022, the Queensland government set a target of 80% renewable energy penetration by 2035, while Victoria called for 95% penetration by then, up from 16% and 27% penetration, respectively, in 2023. Many state governments are now rolling out renewable energy zones (REZ) that aim to coordinate generation, transmission, firming and storage projects to alleviate grid connection issues—an ongoing pain point for developers. New South Wales has launched a 10-year tender process to award REZ access rights and provide revenue certainty for generation and storage assets.

Network Development

Australia boasts one of the longest interconnected electricity systems in the world, according to Energy Networks Australia. The country's power grid is set to almost double in length to more than 1.6 million kilometers by 2050, based on the BloombergNEF (BNEF) Net Zero Scenario.

Under this scenario, Australia is due to spend $300 billion on the grid between 2022 and 2050, mainly to reinforce the system so it can cope with the substantial number of renewable projects connecting to the network. This includes $83 billion to sustain or replace existing assets, and $217 billion to expand the grid for increased electricity distribution, consumption and to accommodate new connections.

Australia's 2022 grid expenditure of A$3.73 billion ($2.4 billion) is much lower than BNEF's estimate that annual spending of A$ 8.84 billion ($5.8 billion) is needed to reach net zero, given the evolution of generation, increasing demand and aging assets.

If supportive policies are implemented, Australia could see offshore wind assets start to come online after 2030; it would need to install some 1,000 kilometers of submarine cable, on top of the 1,000 km of HVDC cables needed to transmit power to and from remote parts of the country. Abundant wind power and solar resources in remote areas attract project developers to the fringes of the grid, but projects in these regions can face congestion problems at older connection points, which can increase transmission losses for projects and drive up curtailment.

Early in 2022, under its Rewiring the Nation program, Australia's federal government allocated A$20 billion ($13 billion) to expand the grid and fast-track renewable energy zones within each state. The program also aims to ensure that grid investment is more coordinated with renewable capacity. The Marinus Link, one of the proposed transmission projects under this plan, is a two-way undersea transmission interconnector between Tasmania and Victoria that would give mainland Australian states access to Tasmanian hydropower.

Australia has also implemented several power flow control projects in its Transgrid and AusNet Service territories that have unlocked just under 200 MW of capacity.

In terms of demand, Australia currently lags behind other markets in EV penetration—3.8% of car sales are electric compared to 17% in the EU in 2023—and it lacks a national fuel efficiency standard and EV target, although all of the states and territories have their own EV goals.

Power demand from data centers is predicted to grow to 3.2 GW by 2029. Industry accounts for half of total energy use, so industrial decarbonization will be key to Australia meeting its emissions targets. Heat pump installations grew 70% in the first half of 2023 from the same period in 2022, and the government expects demand to continue to grow until at least the mid-2030s.

Digitalization

When it comes to smart meters, progress is uneven. The Australian Energy Market Commission (AEMC) has made recommendations to drive 100% smart meter uptake in the country by 2030. Victoria has already achieved near-universal uptake of smart meters, while Tasmania has a program to accelerate their deployment. The recommendations are expected to have the most impact in New South Wales, the Australian Capital Territory, Queensland and South Australia.

Energy Storage

Battery storage investments have benefited in recent years from high energy prices and volatility. These investments have been encouraged by the Capacity Investment Scheme (CIS), proposed by the federal government in December 2022 and recently extended to 2027, which supports ambitious targets for new storage projects. The scheme aims to underwrite zero-emission storage or dispatchable technologies to catalyze A$10 billion ($6.55 billion) in private investment, complementing existing state-based mechanisms.

A number of large-scale battery storage projects supported by state governments are being developed in New South Wales, Victoria and South Australia, and by 2030, BNEF predicts that 10 GW of utility-scale battery projects will be in operation across Australia. New South Wales has a 2030 target of 2 GW of installed long-duration storage, and Victoria aims to install 2.6 GW by 2030 and 6.3 GW by 2035, while Queensland has committed to 16 GW of storage by 2035.

Brazil has a long history of transporting clean power, but its grid needs exponential investment.

Renewable Connections	Network Development	Digitalization	Energy Storage	Index Score
68%	**42%**	**6%**	**N/A***	**44.9**

Brazil has a long history of transporting clean power from the remote north to population centers in the south and east.

But the electricity system faces an increase in energy demand across the country, and Brazil also needs to address customer calls for an improvement in the quality of services. As shown in the index, the ratio of networks to renewables investment, as well as large-scale storage penetration, is low.

Renewable Connections

More than 90% of the country's power is generated from clean energy sources, with hydro providing 63% of Brazil's electricity. Itaipu, the most iconic of its hydro dams, is one of the world's largest hydroelectric plants, with an installed generation capacity of 14 GW. Situated on the border between Brazil and Paraguay, the dam opened in 1984, and the National Electric System Operator (ONS) of Brazil has decades of experience transporting clean power thousands of kilometers across its network.

The amount of wind and solar energy on the Brazilian grid is increasing rapidly. Wind power is the second-largest source of energy, with 23 GW of installed capacity and an additional 3.8 GW contracted or under construction and expected to come online in 2023, according to BNEF. Several offshore wind projects are in the pipeline, with some linked to the potential generation of green hydrogen for export to Europe.

According to Brazil's energy research office, Empresa de Pesquisa Energética (EPE), renewables are expected to provide 83% of Brazil's power by 2031. In the long term, solar power capacity may rival wind power, according to the US International Trade Administration (ITA). More than $20 billion of investment has been allocated for utility-scale solar energy projects and $1 billion has been invested in distributed solar generation since 2012, according to BloombergNEF (BNEF) and investment is expected to increase exponentially in the coming years. According to EPE, the installed solar capacity reached 37.8 GW in 2023, a 54.8% increase on the previous year.

Network Development

Brazil has more than 171,000 km of high-voltage transmission lines (above 230 kV) and has one of the world's most extensive transmission grids. This network is set to expand by 40,233 km by 2030, with total investments in the power transmission sector to 2030 projected to reach $18 billion, of which $13 billion will be in transmission lines and $5 billion in substations, according to the ITA.

The country's distribution networks are run by 105 power distribution companies. Around $6.6 billion will be invested in Brazil's grid every year through 2028, according to Brazil Regulator´s Distribution Development Plan: 66% to expand the grid, 20% for upgrades and 13% to refurbish distribution networks. In the near future, investment will be needed to facilitate demand connections, to adapt the grid for new customer uses and for digitalization.

The country invested $5 billion in its grid infrastructure in 2022, compared to $12.1 billion invested in renewable energy, according to BNEF. In many markets that might suggest under-investment in the grid, but Brazil already has a relatively robust network that has integrated large amounts of hydro and other renewable power, and its connection speeds are among the best in the world.

In terms of energy demand, Brazil's energy consumption is predicted to peak in the 2030s and remain more or less steady until 2050, according to the EPE PNE 2050 Stagnation scenario, with electricity's share of the energy mix rising from 19% in 2020 to 26% by mid-century.

According to Associação Brasileira de Veículos Elétricos, Brazil has had approximately 141,000 battery and plug-in electric vehicles in circulation since 2012. This number is projected to increase to 1.4 million by 2030.

The country is looking to leverage its low-carbon energy mix to build domestic capacity in hard-to-abate sectors such as sustainable aviation fuel, aluminum and steel. Demand for air conditioners is predicted to grow approximately 7% a year between 2024 and 2028, and will likely increase thereafter as temperatures continue to rise. New rules will phase out less efficient A/C units by 2026, which should save 40 million tons of CO2 and deliver $2 billion in savings by 2040.

Digitalization

In 2022, smart meter penetration in Latin America was just 6.2%, but the market is forecast to grow at a compound annual growth rate of 21.7% to 38.4 million units by 2028, up from around 11.7 million units in 2022, according to Berg Insight analysis. In Brazil, smart meter penetration is set to rise from 5.7% in 2022 to 21.5% in 2028.

Brazil's Ministry of Mines and Energy (MME) recently stated that digitalization of the country's electricity networks is essential to improve efficiency and enable consumers to be more proactive participants in the energy system. This will require new policies covering all of the country's distribution companies, and huge investments in a nation with 90.5 million domestic and business electricity consumers.

Energy Storage

To date, energy storage in Latin America has been slow to take off due to obstacles including regulatory barriers and a lack of established business models, but recent reforms and new projects in Brazil could pave the way for larger energy storage projects.

The country commissioned its first large-scale energy storage project in 2022, in Sao Paulo State. BNEF expects this first project to pave the way for more storage capacity on the transmission network in coming years, particularly in areas with weak grid infrastructure and recurring seasonal electricity shortages.

Historically, Brazil has used its many hydropower plants with large reservoirs to reliably balance its grid, but as this index exclusively measures countries' battery storage and pumped hydro storage capacity, Brazil receives a "not applicable" rating. However, new energy storage projects are expected to flourish in tandem with the country's rapidly growing wind and solar sectors. BNEF forecasts that 1.5 GW of storage capacity will be added every year by the end of the decade, from just 40 MW in 2022. Brazil also has up to 9 GW of commercial diesel generators providing backup services that could be replaced by batteries, and the commercial segment will reach a total storage capacity of more than 4.3 GW by 2030. Energy-shifting projects should also increase in tandem with the country's rapidly growing wind and solar sectors, growing to a total of 2.1 GW by the end of the decade.

*N/A: BNEF's energy storage calculation incorporates battery storage and pumped hydro capacity. Brazil is not rated in this category, as a "zero" score would not reflect the country's use of hydropower to balance its grid.

Limited grid investment and a slow connection process have left the **UK** with a lot of ground to make up.

Renewable Connections	Network Development	Digitalization	Energy Storage	Index Score
34%	**51%**	**55%**	**31%**	**42.7**

The UK needs to catch up to other nations in its grid development. As the index shows, this lag is due to a low ratio of grid investment to clean energy investment, and a slow process of connecting wind and solar capacity to the transmission system. Steps have been taken to facilitate network growth, including accelerating the permission process for significant strategic projects to deliver the government's 2030 net-zero ambitions, but there is still room for improvement.

Renewable Connections

The UK's offshore wind capacity is second only to China's and the country boasts the world's largest offshore grid, with about 5,000 km of cable as of 2022. However, substantial further investment is needed in the BloombergNEF (BNEF) Net Zero Scenario, which includes about 23,680 km of additional submarine cables by 2050 to integrate a planned 75 GW of offshore wind capacity. The onshore wind sector will need a further 9,870 km of high-voltage direct current (HVDC) land lines by 2050. For this to become a reality, the approval process for new grid projects will need to be significantly accelerated.

The UK's investment in its grid has been low compared to its investment in clean power generation, with data suggesting that for every pound spent on renewables, only a quarter was spent on the grid. According to the Net Zero Scenario, the UK needs to invest more in the grid than in generation capacity in the late 2020s and early 2030s, before settling back to a ratio of around 1:1.

According to the UK electricity system operator (ESO), over 250 GW of projects are contracted to connect to the transmission system, due to an unprecedented growth in applications in the last two fiscal years. The ESO has launched a connections reform project to address these challenges and update the connections process, which was written 20 years ago and designed for fewer, larger-scale power plants. The total connections queue, across transmission and distribution, is likely to exceed 800 GW by the end of 2024. This is over four times the installed capacity the ESO's anticipates needing by 2050.

Network Development

Under BNEF's Net Zero Scenario, the UK needs to invest $107 billion on its electricity grid between 2022 and 2030. Much of the initial spending needs to be on transmission grids, as the UK has substantial wind generation in the north, while most of the demand is in the south. The country also needs to invest in distribution to support the wider electrification of the economy, society and a broader rollout of distributed energy resources.

In 2022, the nation invested $5 billion—only half of the figure required in the Net Zero Scenario —which suggests that it is currently under-investing. However, it is planning several HVDC transmission lines to ease bottlenecks in transporting wind energy from the north to load centers in the south.

Ofgem, the UK's independent energy regulator, has set up the Accelerated Strategic Transmission Investment (ASTI) framework to speed up investment decisions for significant projects, manage key products and streamline the procurement practices of onshore network construction by 2030.

The National Energy System Operator (NESO), which operates the high-voltage network in England and Wales, is using new power flow control technology—the world's first large-scale deployment—to enable grid operators to throttle power transfer along a given transmission line and unlock 1.5 GW of network capacity. The technology routes power through circuits with available capacity, maximizing use of the existing network.

In terms of clean energy demand, the government is on target to meet its goal of having 21.8 million EVs on the road by 2035 five years early, but it is behind in its aim to install 500,000 public charge points by the same date.

The UK's Net Zero Strategy aims to replace around 50 TWh of fossil fuels per year in industry by 2035 with low carbon alternatives including green electricity, hydrogen, and biomass. However, the nation's target of installing 600,000 heat pumps a year by 2028, is not on track according to BNEF. Meanwhile, there are 345 data centers, around one-third of them in London.

Digitalization

While the UK's smart meter rollout has been beset by delays and controversy, at the end of 2022, 31.3 million smart and advanced meters had been installed in homes and small businesses, representing 55% of all meters. According to the UK's National Audit Office, average savings from smart meters equated to $70 annually per household.

On the other hand, the British model, where the grid distributor is not managing the smart meters, creates some barriers to optimizing grid operation in favor of customer service and affordability.

Energy Storage

The UK has one of Europe's largest utility-scale energy storage markets, which is projected to become the seventh-largest market globally by 2030, driven by the contracted capacity market. Contracted storage projects are expected to reach 10 GW by 2027, according to BNEF.

During 2022, the UK added a record 800 MWh of new utility-scale energy storage capacity, bringing connected battery storage capacity to 2.4 GW. The UK's total energy storage pipeline increased by 34.5 GW in 2022, according to Solar Media Market Research.

Japan must scale up investment or risk falling further behind its OECD peers in the race to net zero.

Renewable Connections	Network Development	Digitalization	Energy Storage	Index Score
12%	**37%**	**91%**	**100%**	38.7

Trailing behind most of its OECD peers in the energy transition, Japan must accelerate renewable power project development and scale up grid investment to support a higher uptake of clean energy to meet its net-zero goals.

Renewable Connections

Japan has a relatively low penetration of renewable energy capacity compared to the size of its grid, despite having few fossil fuel resources and a nuclear power sector that has not recovered from the impacts of the Fukushima disaster.

The country is making efforts to speed up the permitting of wind projects following delays to projects planned for 2022. Annual onshore wind capacity additions were set to grow to 690 MW in 2023, up from 166 MW in 2022, according to BloombergNEF (BNEF) forecasts. However, BNEF has reduced its forecast for wind installations in 2024–25 by 12%, as some projects have moved slower than expected through the lengthy community outreach and permitting process required to implement wind projects.

By contrast, the country installed 6.2 GW of solar capacity in 2022, adding around 5 GW in 2023, and will add similar amounts for each of the next three years, based on BNEF forecasts.

Network Development

Japan's energy demand peaked in 2005 and is predicted to fall in the coming decades by 3% from 2021 to 2050, due to a combination of a falling population and increased electrification of the economy, according to BNEF.

However, under BNEF's Net Zero Scenario (NZS), electrification of industrial processes increases the share of electricity in final energy use from 29% in 2022 to 49% in 2050. The share of electricity use may accelerate following the recent agreement by the G7 to phase out the use of coal in power generation, a move that affects Japan more than other members of the group.

Japan's declining population also contributes to a smaller passenger vehicle fleet by 2050. At the same time, the country has been a laggard in adopting electric vehicles. Although EV sales rose 50% in 2023, they accounted for just 2.2% of all new passenger car sales, in part because of a slow rollout of charge points.

In terms of heat pumps, 90% of households already use them for heating and cooling according to the Heat Pump and Thermal Storage Technology Center of Japan.

Japan is one of the most energy efficient countries in the world. Electricity already accounts for 52% of final energy use in buildings, rising to 79% in 2050 in the NZS.

To reach net zero, BNEF estimates that Japan needs to invest $489.3 billion in its grid between 2022 and 2050; some 60% of this investment will go to its distribution grids. Three-quarters of the funding will facilitate the integration of solar and wind power through new connections and system reinforcements, with annual spend on these two areas almost doubling from an average of $5.2 billion a year in the 2020s to $10.3 billion in the 2030s. Spending on asset replacements will also grow steadily.

The transmission network needs to more than triple in length from 2022 to 2050, while the distribution grid needs to double in size to connect more renewables to the grid—including distributed generation—and to move renewable electricity across the nation, given that demand centers such as Tokyo are typically far from the areas with high levels of renewable power capacity.

The Japanese grid will also see significant amounts of submarine cables installed, from a mere 20 km in 2022 to 21,000 km in 2050, based on BNEF's Net Zero Scenario analysis. This will mainly support the country's nascent offshore wind sector, which has the potential to grow significantly in the years to 2050.

Digitalization

Japan is already a leader in grid digitalization. As the result of an advanced metering and intelligent grid infrastructure project, the country has around 80 million smart meters in operation nationwide, with all customers expected to have smart meters by the end of March 2025, according to Japan's Electric Power Information Center.

The country accounted for the largest share (42%) of partnerships in power digitalization in the Asia Pacific region in the second half of 2022, according to BNEF.

However, BNEF's Net Zero Scenario also shows that Japan needs to spend more on digitalization in relation to the size of its grid than any other country in the index—around $2,700 per km of grid between 2022 and 2050.

Energy Storage

Japan achieved the best score in the index for energy storage, thanks to high population density in its cities and the strong growth it will likely see in rooftop solar systems. In BNEF's Net Zero Scenario, Japan's small-scale solar capacity will rise from 18 GW in 2022 to 136 GW in 2050, with annual installations in 2030 expected to reach 7.6 GW. The best way to manage such a dense grid, with a high proportion of distributed energy resources, is through digital solutions such as distributed energy resource management systems (DERMS).

Energy storage capacity should increase further as the country introduces more sources of demand, such as EVs and electrolyzers for the production of green hydrogen. When it comes to the supply side, Japan has 27.5 GW of pumped hydro storage, and interest in grid-connected energy storage projects is growing due to the reduced cost of batteries.

With the world's third-largest power grid, **India** needs over $2 trillion by 2050 to meet rising energy demand.

Renewable Connections	Network Development	Digitalization	Energy Storage	Index Score
22%	**60%**	**3%**	**18%**	35.1

At 9.57 million kilometers, India's grid trails only those of China and the US in scale, and the country also ranks third in grid investment. It is one of the world's fastest-growing grid markets, where annual spending will increase five-fold to 2030, then six-fold to 2050, for a cumulative total of more than $2 trillion, in the BloombergNEF (BNEF) Net Zero Scenario.

Renewable Connections

According to BNEF, India must increase investment from $14 billion in 2022 to $70 billion in 2030 to both maintain its grid and meet its net-zero target. The country is seeking to install around 800 GW of non-fossil fuel capacity, including solar PV and storage.

BNEF calculates that India will need to connect an average of 148 GW of new generation capacity every year between 2022 and 2050, of which around 80% is solar and wind. India added roughly 3.2 GW of onshore wind in 2023, 78% more than in 2022, while solar additions reached an estimated 15.9 GW.

India's power plants are currently concentrated in a handful of provinces. Eight of India's 28 states each have more than 20 GW of generation capacity, comprising more than two-thirds of the country's installed capacity. Under most operating conditions, the northern and southern regions of India import power from the western and eastern regions.

Meanwhile, India is set to create a sizable hydrogen economy, with electrolyzers requiring 545 GW of power by 2050 in the Net Zero Scenario—more than twice the nation's total peak demand today, which could comprise 36% of forecast peak demand by mid-century.

Network Development

India's increase in installed capacity, with more of it renewable and smaller-scale, means that a dramatic rise in the number of new grid connections is needed, along with network reinforcements to ensure that power can meet demand in all possible scenarios.

India's grid was only unified into a national network in 2013; previously, it was split into several unconnected and asynchronous grids. India's network is not yet robust, with limited ability to provide reliable power 24 hours a day in many areas, and some Indian homes and businesses use diesel generators to provide backup power.

To improve the resilience, robustness and reliability of this national grid and enable electricity to flow easily between centers of demand and regions that are adding generation capacity, India will need to invest in expanding regional interconnectors. Unlike more mature markets, where demand is driven largely by the electrification of the economy, India is experiencing significant demand growth as it adds capacity.

The country's network needs to more than double in length to supply growing demand and complete the nation's electricity infrastructure. A significant proportion of that growth will be in high-voltage lines: India recently commissioned a 1,765-km HVDC transmission line from Chhattisgarh to Tamil Nadu to boost the national power system, and its HVDC transmission network will grow to 30,520 km by 2050, with ultra-high-voltage lines increasing to 62,710 km over the same period, in BNEF's Net Zero Scenario.

Distribution grids will increasingly take a higher share of investment through 2050, as the power generation fleet becomes more decentralized. In 2022, transmission represented 38% of total grid investment, and this is expected to rise to 47% by 2050.

With a target of net zero by 2070, India is expected to witness a fourfold growth in electricity demand and new investments of between $1.2 trillion and $1.6 trillion by mid-century. About 70% of its emissions are driven by six sectors: power, steel, automotive, aviation, cement, and agriculture.

Industry is the largest and fastest-growing energy end-use sector and is expected to be the single largest source of CO_2 emissions by 2040. India is the second largest producer of both steel and cement, which combined account for 15-20% of India's emissions. Without action, emissions from these sectors are expected to increase threefold by 2050.

Electric vehicles could account for more than 40% of India's automotive market by 2030, up from 5% in 2023. India significantly lags other geographies on charging infrastructure, with roughly 200 EVs per commercial charging point in India, compared to around 20 in the US and fewer than 10 in China. But there are ambitious plans to change that. For example, EV charger provider ChargeZone plans to install 1 million charge points by 2030. Currently, there are just 11,000 nationwide.

India's data center capacity is also expanding rapidly, with energy demand set to more than double from 2 GW in 2024 to 4.77 GW in 2029, an annual growth rate of more than 18%.

Digitalization

The decentralization of the grid will drive $566 billion of investment in digitalization, representing about one-fifth of cumulative grid investment to 2050 in BNEF's Net Zero Scenario. Use of digital tools such as automation and sensors are slowly growing on the Indian distribution grid.

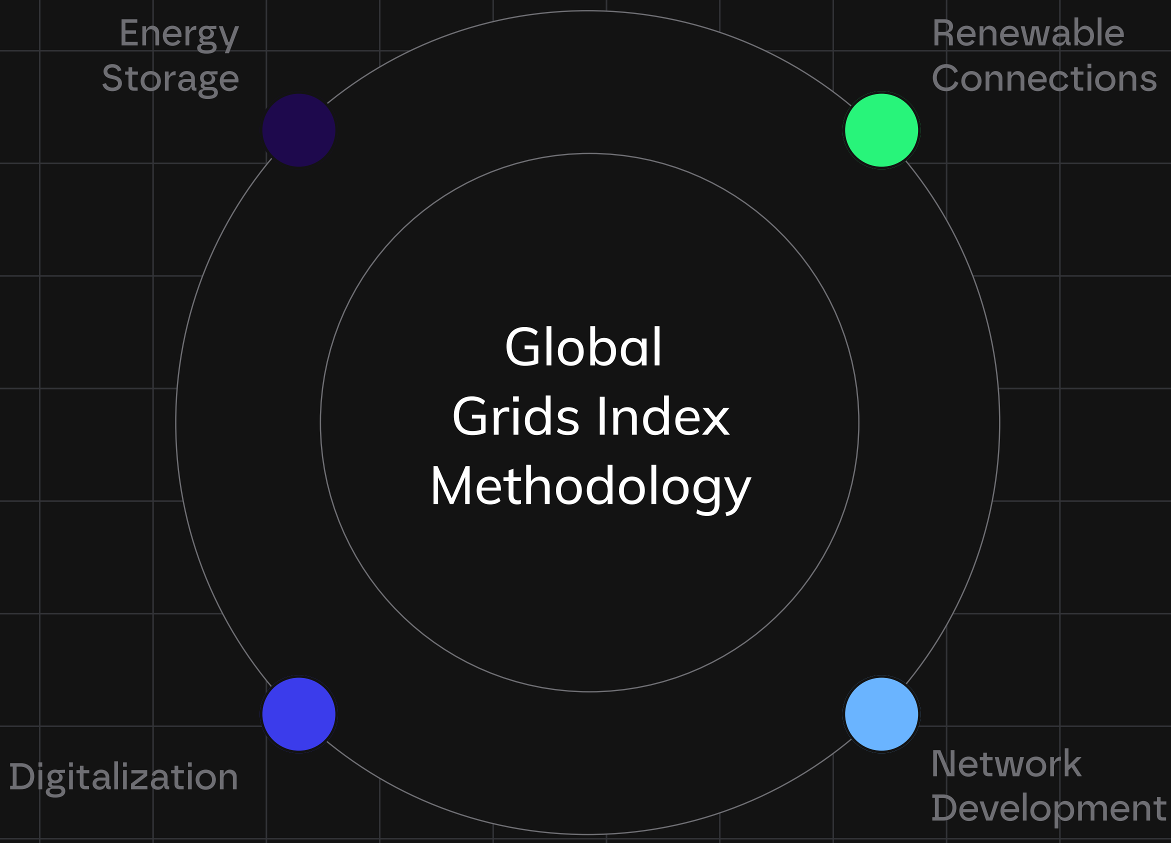
The use of smart meters is also expanding, although from an extremely low base: In 2022, only about 3% of properties had a smart meter. However, India plans to install 250 million smart meters by 2026.

Energy Storage

The country ranked 20th for energy storage in 2023, but it is set to be the fifth-largest global storage market by 2030, thanks in part to the provision of funding for 4 GWh of grid-scale batteries in the government's 2023–2024 annual expenditure budget.

While around 1% of the energy consumed in the country in 2023 came from renewables paired with energy storage, this should rise to 4% of total energy consumed by the start of 2030. The government's modeling indicates that India's 2030 optimal generation mix requires 42 GW of battery storage; however, energy storage capacity is expected to reach 20 GW by 2030.

Once deployment of technologies such as battery storage, demand response and distributed energy resource management systems (DERMS) reaches sufficient scale, it will enable a more flexible power system that can balance India's increasing share of renewables.



The Bloomberg Global Grids Index explores how prepared the electricity networks of 10 key countries are to integrate the large amounts of renewable energy capacity being installed in the effort to decarbonize the global economy and reach net-zero emissions.

Each country has been assessed on its generation mix; connection speed; network development; the scale of network investment compared to the investment in renewables; smart meter penetration; and energy storage deployments. The performance of each country in these metrics shows how prepared its electricity transmission and distribution infrastructure is to integrate new renewable power into its energy mix.

Renewable connections

Generation Mix

The generation mix looks at how much progress the country has made in decarbonizing its energy system by installing renewable energy capacity, in particular wind and solar, which are key technologies playing a critical role in the energy transition. Several markets have seen an astonishing increase in renewable energy capacity, while others are still dominated by fossil-fuel generation.

Generation mix is calculated as the cumulative wind and solar capacity installed as of 2022 divided by the total system peak demand in 2022. This metric is given a weight of 20% in the overall index.

Source: BloombergNEF.

Connection Speed

This metric shows how long it takes renewable energy projects to connect to the grid. In many markets, delays can run into several years. The reasons for this are complex, and include aging transmission infrastructure built to service a highly centralized power system—not one with multiple sources of generation inputting power to the grid.

Often, there is a lack of capacity on the network, which needs to be upgraded to cope with additional power generation. Planning processes can be enormously cumbersome and lengthy, and developers may have to pay fees, which can be so costly that they prevent projects from proceeding. In some markets, there is significant resistance to new overhead lines, which can slow down development or lead to a shift to underground cables, which are more expensive and compete for cable production capacity with the growing demand for submarine cables to service offshore wind farms and undersea interconnectors.

One key issue for developers is a lack of transparency about how long connections will take, making it hard for them to plan. Some regulators are starting to tackle this issue; the US Federal Energy Regulatory Commission, for example, is moving from a first-come, first-served system to a first-ready, first-served process. Some utilities face fines if they take too long to execute network connection plans.

Connection speed is calculated as the average capacity of annual wind and solar installations between 2020 and 2022 divided by the country's 2023 gross domestic product. This metric is given a weight of 20% in the overall index.

Sources: BloombergNEF, IMF.

Network Development

Network scale

The scale of electricity networks in this index varies considerably, from China's grid of more than 12 million km to Germany's grid of 687,170 km. In part, this reflects geography—not just the size of a country, but the distance between cities, and between generation sources and load centers. For example, it would be difficult to justify the economic value of linking Perth in Western Australia or Darwin in the Northern Territory to the network linking the cities in the south and east of Australia.

It is no surprise that the biggest grids are in China, the US, India and Brazil—but even considering the size of the country and its economy, the Chinese grid is vast. This reflects the fact that many of its generation resources, particularly renewable resources, are in remote locations far from the coastal cities where demand is concentrated.

Network scale is calculated using a composite scale variable (CSV), harmonized by GDP, as a benchmarking tool employed by UK energy regulator Ofgem to assess capital expenditures for electric utilities. There are various versions of these composites, but the one used in this metric is as follows:

CSV = Number of customers in millions 0.5 x Annual energy consumption in TWh0.25 x Network length in thousand km0.25

This method estimates the number of customers by calculating the number of households in the market, annual energy consumption and network length, which includes transmission and distribution grids above 1 kilovolt. This metric is given a weight of 10% in the overall index.

Sources: BloombergNEF, Ofgem.

Combined grid investment - divided into:

Grid investment to network scale

This metric assesses the amount of money being invested in the network compared to its current size, which gives a sense of whether sufficient resources are being allocated to the grid.

There are many paradigms for upgrading power systems. Some network operators have an "invest and connect" approach: They invest in the grid and then connect power generation projects when there is sufficient network capacity. Others operate a "connect and manage" system, allowing generation projects to connect to the network by managing the grid through curtailment, while the wider work of network reinforcement happens in parallel. The UK has one such system, but because the pace of grid connections has been so rapid, it has fallen behind in upgrading the grid and has hit the limits of what "connect and manage" can achieve.

This metric is calculated by dividing the investment in transmission and distribution grids in 2022 by the network scale metric calculated above. This metric is given a weight of 20% in the overall index.

Source: BloombergNEF.

Grid investment to renewable energy investment

Renewable capacity is often clustered in areas where wind or solar resources are high and development costs are low, but these resources are often long distances from the centers of demand. That means that integrating more renewable energy often requires more investment in electricity networks. For every dollar spent on renewable energy, how much is being spent on the grid? Long-term modeling suggests that this figure should trend toward 1:1 to align with a net-zero pathway.

This metric is calculated as the annual investment in transmission and distribution grids in 2022 divided by the average annual investment in renewable energy generation between 2020 and 2022. This metric is given a weight of 10% in the overall index.

Source: BloombergNEF.

Digitalization

Smart meter penetration

Digital technologies are crucial to the energy transition because the amount of new linear infrastructure needed for the energy transition cannot be built immediately, and therefore, every power line must be used as effectively and efficiently as possible.

According to the International Energy Agency, "Digital technologies can greatly improve the functioning of power grids to help successfully integrate clean energy sources, but a lack of investment in these networks could slow down the energy transition and increase costs, particularly in emerging and developing economies." The IEA says that digital technologies could save $1.8 trillion of grid investment globally through 2050 by extending the lifetime of grids, while also helping to integrate renewables and minimize supply interruptions.

A crucial first step in digitalization is smart meter penetration. Smart meters are an integral part of digital power architecture, giving consumers and producers greater awareness of how much power is being consumed and when. This transparency opens up the possibility of new products and services, including variable tariffs that encourage consumers to lean into the growing availability of renewable energy. Smart meters also enable homes that produce their own energy—primarily through solar PV—to sell their power back to the grid or to their neighbors.

Smart meter penetration is the share of customers with a Smart meter. This metric is given a weight of 10% in the overall index.

Sources: ACER, Australian Energy Market Commission, Astute Analytica, Berg Insight, BloombergNEF, GII Research, Smart Energy International, UK government.

Energy Storage

Storage deployments

Energy storage can make an energy system balance out the intermittency of renewables and reduce the need to use fossil fuel generation. It plays a crucial role in integrating renewable energy into the grid, allowing variable generation sources such as wind and solar to supply power more reliably and at times when it is most needed. Energy storage combined with the increased visibility offered by smart meters gives consumers and utilities more flexibility and lowers costs.

This metric is calculated as the sum of battery storage and pumped hydro capacity as of 2022 divided by the cumulative wind and solar capacity as of 2022. This metric is given a weight of 10% in the overall index.

Source: BloombergNEF.

Index data compiled August 2023–October 2024