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Regulatory Energy Transition Accelerator

Building the Future Transmission Grid

Strategies to navigate supply chain challenges

International Energy Agency

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Abstract

The urgency to expand and modernise the electricity transmission network infrastructure around the world is putting pressure on supply chains.

This report explores the evolving landscape of investment in electricity transmission networks and key trends related to the supply chain of key components. Based on a survey of industry stakeholders in 2024 by the International Energy Agency (IEA), it provides insights into how increasing infrastructure needs are affecting prices of components, lead times and related market dynamics.

Building on the analysis Electricity Grids and Secure Energy Transitions, this report identifies actionable strategies to address challenges related to the supply chain for grid infrastructure, with a focus on transmission lines with voltages that exceed 66 kilovolts. It highlights growing constraints in the supply chain, the need for long-term procurement mechanisms, and the importance of coordinated planning to ensure timely infrastructure development. The findings serve as a guide for policymakers, regulators and industry leaders to navigate the complex landscape of transmission expansion and modernisation in the clean energy transition.

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Executive summary

Invest in grids today or face gridlock tomorrow

Expanding and modernising transmission grids is essential for a secure, affordable and sustainable energy system. Analysis from the International Energy Agency has repeatedly highlighted the crucial role of electricity grids, notably in the comprehensive 2023 report Electricity Grids and Secure Energy Transitions. The importance of this issue is underscored further by the accelerating pace of demand growth for power as the world enters an Age of Electricity. The latest IEA near-term forecast is for global electricity consumption to grow at close to 4% annually through 2027. Demand is rising both in emerging market and developing economies and in many advanced economies, driven by industry and by the growing use of air conditioning, appliances, electric vehicles, heat pumps, artificial intelligence and other technologies. Transmission grids are essential to link new sources of generation with expanding demand centres. Strengthening and upgrading transmission infrastructure is also essential to enable the cost-effective deployment of wind and solar power and to enhance cross-border interconnections.

Around 1.5 million kilometres of new transmission lines have been built worldwide over the last decade, but inadequate transmission remains a major constraint on power system development, electrification and energy security. Among other issues, grid infrastructure has struggled to keep pace with the rate at which new renewable sources are entering the system. This mismatch has led to delays in project deployment and increased financial uncertainty: in 2024, the IEA tracked 1 650 GW of solar and wind projects in advanced stages of development that are awaiting grid connections, a major missed opportunity to bring clean, cost-effective sources of generation into the mix. At the household level, connections to the grid have picked up in recent years, but 750 million people remain without access to electricity around the world – 80% of which are in sub-Saharan Africa.

A rise in transmission spending is putting the spotlight on bottlenecks in supply chains

Recognising the urgency, investment in transmission has started to pick up as many countries make grid infrastructure a key priority in their national energy plans. Europe, the United States, China, India, and parts of Latin America are leading the way, and global investment in power transmission grew by 10% in 2023 to reach USD 140 billion. There is a strong regional imbalance in investment patterns, with advanced economies and China accounting for about 80% of the global total. Under today's policy settings, this spending would need to exceed USD 200 billion per year by the mid-2030s to meet rising needs for electricity, and to reach USD 250-300 billion in scenarios that achieve national and global emissions goals in full. The required increases in investment are particularly steep in many emerging market and developing economies outside China.

Permitting remains the primary cause of delays in transmission projects, particularly in advanced economies, but supply of cables, transformers, materials and other components is also becoming a limiting factor. Growth in global demand for transmission capacity, driven by simultaneous expansion plans in many regions, is putting increasing pressure on supply chains. Demand is intensified by a wave of investment in high-voltage and ultra-high-voltage transmission projects to facilitate long-distance power transfer, and by the rise in offshore wind power that boosts the need for high-voltage subsea cables.

Prices and waiting times for new transformers and cables have almost doubled

An IEA survey of leading industry players conducted for this report finds that it now takes two to three years to procure cables and up to four years to secure large power transformers. Average lead times for cables and large power transformers have almost doubled since 2021. Some specialised components are even more difficult to source: waiting times for direct current cables – often preferred for long-distance transmission lines – extend beyond five years. High demand has also substantially driven up prices. Prices for individual orders are highly dependent on their complexity and capacity, which vary from project to project, but the results of our survey suggest that prices for cables have nearly doubled since 2019, and the price of power transformers rose by around 75%. Underlying materials like copper, aluminium and grain oriented electrical steel have also experienced price increases. The combination of rising component costs, extended procurement lead times, and a significant backlog of orders is contributing to higher project expenses as well as delays.

Manufacturers are responding with plans and investments to increase production capacity, but this will take time, and uncertainties remain over the extent of future demand and the availability of a skilled workforce. The visibility and credibility of national and regional transmission plans, and their translation into component demand, is vital to underpin investment decisions to expand manufacturing capacities. A shortfall in specialised labour is a concern both for manufacturing and for broader expansion of the grid. Around 8 million people are employed worldwide in constructing, maintaining and operating grids, and the IEA estimates that this workforce will need to rise by 1.5 million by 2030 under today's policy settings, and even more rapidly in scenarios that meet emissions goals in full.

Coordinated efforts to strengthen the transmission supply chain are essential

Today's tight markets for transmission components highlight the importance of integrated strategies for the entire supply chain as countries seek to ensure timely grid modernisation and expansion. This report makes eight actionable recommendations that can help governments, regulators, buyers, manufacturers and other stakeholders navigate supply chain challenges:

1. **Enhance visibility on future demand**: Integrated, credible visions for electricity sector development at country and regional level, including transparent project pipelines and long-term transmission investment plans, provide essential guidance for manufacturers on the required quantity and types of transmission components. Clear timelines and structured master plans, incorporating technical and regulatory requirements, enhance confidence across the supply chain.

2. **Strengthen the industry dialogue**: System planning is becoming more complex as renewable and distributed generation grows. This underscores the importance of improved coordination among governments, transmission system operators, regulators, developers and manufacturers to underpin well-grounded assessments of demand for transmission projects and components, and their timely delivery.

3. **Encourage proactive grid investment**: In a world where electricity demand is rising fast and some new sources of generation can be built within a few years, the pace of grid investment needs to step up to prevent bottlenecks, including a regulatory framework that supports anticipatory expansion and modernisation. With rising costs and longer lead times, proactive strategies are needed to align transmission development with power system needs.

4. **Design effective procurement frameworks:** Long-term agreements provide certainty on prices and supply volumes, encouraging manufacturers to expand capacity and enabling buyers to secure essential components. Standardising procurement procedures across markets enhances transparency and simplifies bidding processes. Aligning procurement policies to national infrastructure and energy plans ensures consistency, scalability and investment confidence.

5. **Streamline permitting:** Transmission expansion projects are complex and prone to delays, with permitting remaining a key uncertainty. Maintenance of essential safeguards needs to be combined with removal of unnecessary administrative barriers and prioritisation of key infrastructure projects. Greater predictability for permitting timelines and processes provides benefits all along the supply chain by helping to ensure projects stay on schedule.

6. **Maximise existing grid infrastructure**: Optimising the use of existing grid infrastructure through digital technologies enhances efficiency and maximises the use of existing assets, providing a safety valve for networks and supply chains. Solutions such as real-time monitoring and operational performance improvements allow transmission lines to function more effectively, alleviating the pressure on some new infrastructure investments. Additionally, performance-based regulation drives the development and adoption of digital technologies, fostering innovation and operational efficiency.

7. **Promote diverse, resilient and sustainable supply chains**: The supply of certain grid components is concentrated among few top-tier suppliers, hindering diversification, particularly in emerging and developing economies. Governments can support this by pooling procurement needs and collaborating with local or second-tier suppliers.

8. **Ensure a skilled workforce**: The demand for skilled workers is increasing across the supply chain. Building a strong talent pipeline and integrating digital skills into training are essential. Skilled labour is key to develop infrastructure projects and expanding manufacturing. Governments and industry stakeholders need to work together to align skills development with all stages of transmission projects, from design to construction and maintenance.

Chapter 1: Grids in the Age of Electricity

Grid infrastructure is the backbone of a reliable, clean and interconnected energy system. As electricity becomes ever more central to modern economies, strengthening grids is essential to meet growing demand and adapt to evolving needs, while ensuring long-term security in an affordable manner. Integrating clean energy into the grid and meeting new demand require a robust and expanded transmission network to connect generation sources and balance supply and demand across regions. Additionally, expansion in grid infrastructure is essential to achieve universal access to electricity.

Efforts to expand and modernise grids require an integrated and strategic approach to the entire supply chain, from the manufacturing of key components to the deployment of infrastructure. Investments and policies need to align across different parts of the supply chain to avoid bottlenecks that can impede progress towards a safer and more sustainable electricity system.

Transmission grids as the key to clean, electrified and secure energy systems

Global electricity demand has been growing at twice the rate of overall energy demand over the last decade and this is set to accelerate further in the years ahead, adding the equivalent of Japan’s demand to global electricity use each year in the IEA’s Stated Policies Scenario (STEPS). This growth rises even more quickly in scenarios that meet national and global net zero goals. It is driven by a rise in conventional uses, notably for cooling in emerging market and developing economies (EMDE), and by new sources of demand linked to electrification in transport and heating and rapid expansion of data centres. The latest IEA near-term forecast is for global electricity consumption grow at close to 4% annually through 2027. Electricity now accounts for around 20% of the world’s total final energy consumption and this continues to rise in all IEA scenarios[1].

Governments worldwide are adopting policies to accelerate electrification, particularly in advanced economies and the People’s Republic of China (hereafter “China”). Heat pumps are outselling fossil fuel-based heating systems in many

[1] Electricity is highly efficient at the point of use, so its share in providing useful energy to consumers is higher than its share in total final energy consumption.

parts of the world. Electric cars now account for one in five of total car sales. Sales of electric two- and three-wheelers are growing fast in many EMDE, as are electric buses[2].

Renewable energy now accounts for around a third of global electricity supply, and this share is expected to keep growing. Investment in renewable energy has more than doubled over the past decade, led by solar PV which now accounts for more investment that all the other sources of generation combined. Record-low solar PV and battery prices, driven by expanding global manufacturing capacity, especially in China, have further accelerated deployment. Grid infrastructure is key to integrating renewables, but it has struggled to keep up with this growth. This mismatch has led to delays in project deployment, increased financial uncertainty, and potential setbacks in the clean energy transition. In 2024, the IEA tracked 1 650 GW of solar and wind projects in advanced stages of development that are still awaiting grid connections, a major missed opportunity to accelerate the transformation of the electricity sector.

As the deployment of renewable energy accelerates, modernising grids and expanding transmission networks will continue to be essential. Many solar PV projects and offshore wind farms are often located far from key demand centres like cities and industrial hubs. Without significant grid expansion, these resources cannot be fully and cost-effectively harnessed. Strategic investments in transmission interconnectors also help balance supply and demand across regions, improving electricity market stability and reducing price volatility. Beyond expanding physical infrastructure, better coordination between generation, storage, and demand response is essential to manage variability in electricity supply and maintaining price stability. Without these measures, increasing grid congestion and curtailment of renewables could require additional backup capacity, driving up overall system costs.

The pressing need to modernise aging infrastructure while driving expansion

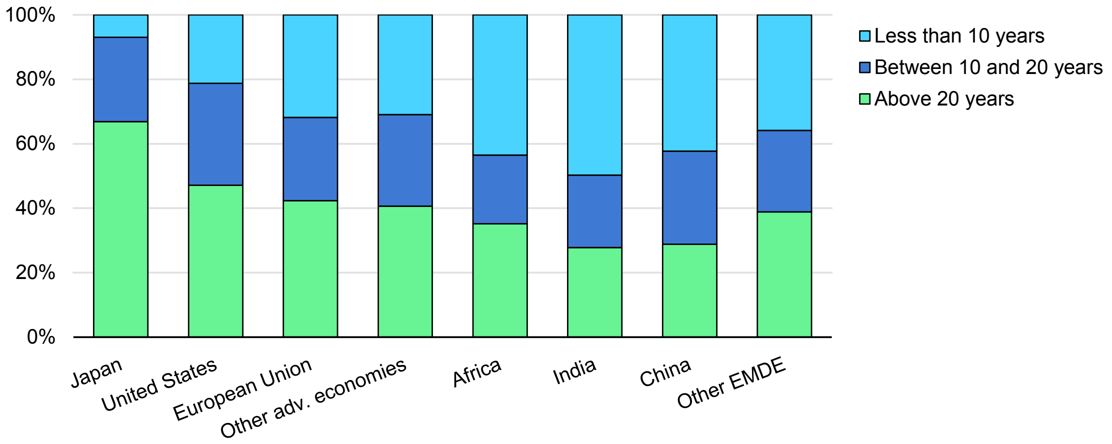
Over the past decade, approximately 1.5 million km of transmission lines have been constructed worldwide, of which EMDE account for nearly 90%. This rapid expansion is driven by rising electricity demand, accompanied by efforts to improve energy access. The variable nature of wind and solar, combined with the need to enhance energy security, also spurred the development of extensive transmission infrastructure and, in many cases, cross-border interconnections.

[2] India, for example, recently approved a scheme supporting the rollout of 38 000 electric buses between 2025 and 2029.

More than one-third of the global transmission grid expansion over the last decade took place in China. China constructed more than 500 000 km of lines, including ultra-high-voltage (UHV) connections that link renewable energy-rich northern and western provinces to eastern demand centres. Over the same period, India added nearly 180 000 km of transmission lines, a 70% increase, and Brazil expanded its grid by more than 100 000 km, a 50% expansion.

Advanced economies have seen a more gradual expansion of their transmission networks, with a 9% increase in the past decade, about 130 000 km of new lines. This reflects the relative maturity of electricity markets and infrastructure in these economies, along with higher population densities in countries such as Japan and Korea that reduce the need for extensive grid expansion. This also means that the average age of grid infrastructure in advanced economies is higher than in EMDE.

Share of transmission length by age by country/region, 2023



Note: Other EMDE = emerging market and developing economies other than China.
Source: IEA analysis based on Global Transmission.

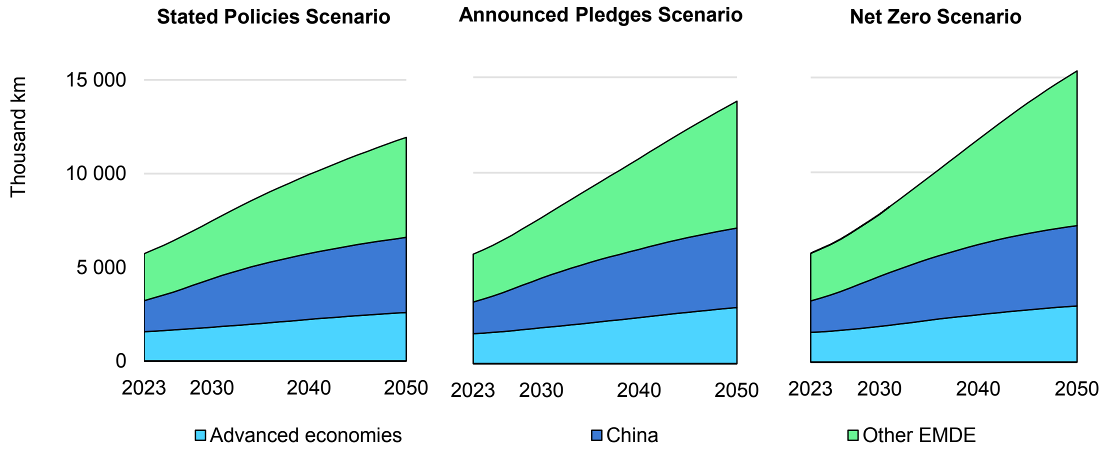
As a result of these differences, there is a greater emphasis in advanced economies on the replacement and modernisation of ageing transmission lines to ensure reliability, to accommodate digital solutions, and to integrate renewable energy sources effectively. Meanwhile, investment strategies in EMDE are more focused on expanding transmission networks to meet growing electricity demand and to ensure access.

Access to electricity remains a crucial indicator of economic and social progress, and grid infrastructure is a cornerstone of this effort. In 2023, the number of people without electricity access saw a decline, reversing a period of stagnation where population growth had outpaced new connections. Preliminary data for 2024 suggests continued improvements in this trend. While regions such as developing Asia and Latin America are close to universal access to electricity, substantial gaps persist in many countries in sub-Saharan Africa. This region accounts for around 80% of people without electricity access, but there has been a positive recent acceleration in grid connections, with over 6.5 million new connections established in 2023, a 60% increase from 2021. Strengthening grid infrastructure, in conjunction with scalable solutions such as mini-grids and stand-alone systems, is critical to support broader social and economic development goals.

The role of transmission in clean energy transitions

Expanding and modernising grids is a key component of electricity security in each of the IEA scenarios. Adequate electricity transmission networks have strategic significance in outlooks that meet national and global climate goals. In both the Announced Pledges Scenario (APS) and the Net Zero Emissions by 2050 (NZE) Scenario, advanced economies nearly double their transmission capacity to 2050, while EMDE triples theirs. Beyond capacity expansion, replacement and modernisation of ageing infrastructure requires substantial investment.

Length of transmission lines by scenario, 2023-2025

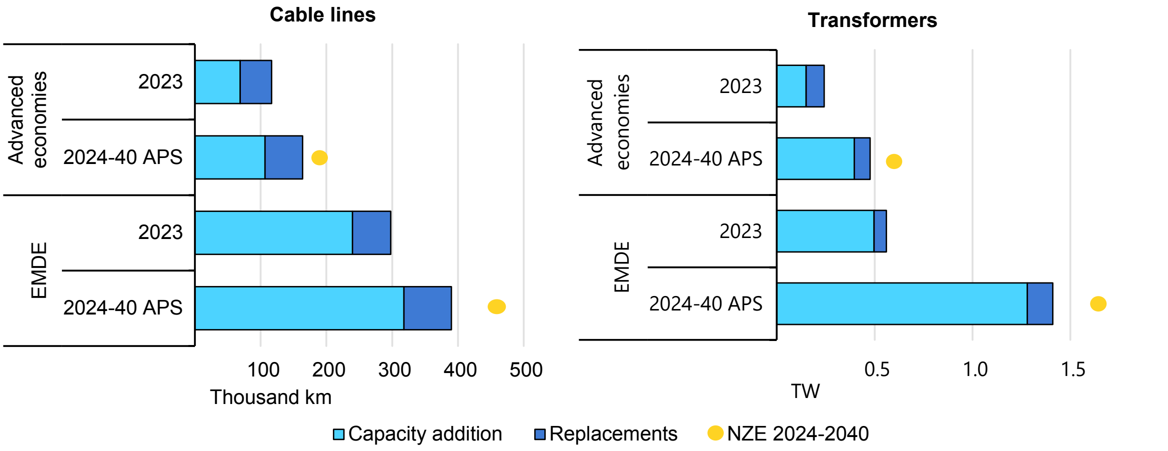


Note: Other EMDE = emerging market and developing economies other than China.

In the APS, advanced economies and China need to develop and/or replace transmission lines totalling 120% of their current length by 2035. Meanwhile, other EMDE need to develop and/or replace transmission lines equivalent to 100% of their current length over the same period.

Meeting these goals will require proactive planning and timely increases in investment, with strong consequences for demand for cables and transformers. In advanced economies, approximately 60 000 km of transmission lines are replaced annually in the APS, equating to about 4% of the current grid each year through to 2040. By that year, the advanced economies construct 1.8 million kilometres of new lines while replacing an additional 970 000 km. In contrast, EMDE face a more expansion-driven challenge, with a need to add 2.3 million kilometres of new lines and replace 425 000 km by 2040. This replacement activity averages around 2% of the current grid annually but rises steadily in the years to 2040 in the APS.

Average annual capacity additions and replacement per region in the Announced Pledges and Net Zero Emissions by 2050 scenarios, 2023-2040



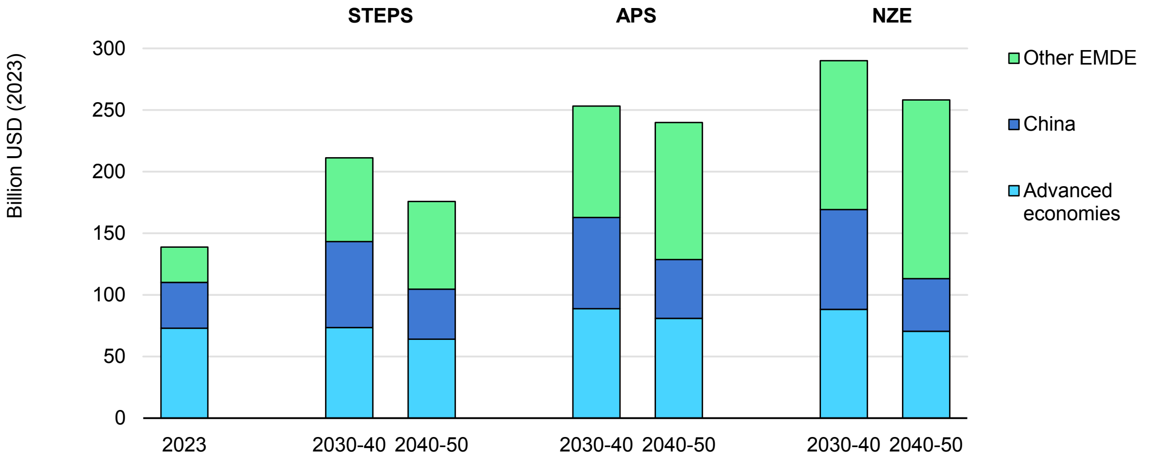
Note: NZE = Net Zero by 2050 Scenario.

In the APS, global transformer capacity is projected to reach 28 terawatts (TW) by 2040, with new capacity required across all types of economy, and the pace of expansion is even faster in the NZE Scenario. Advanced economies face greater near-term challenges to replace older transformers because of the age of their current infrastructure. In the APS, advanced economies need to replace an average of 8% of their installed capacity annually over the next 15 years, while the replacement rate for the EMDE is considerably lower at 3% per year.

Regional plans and investment efforts are stepping up

Investments in transmission picked up globally in 2023, but in most cases they remain a long way from the levels that are needed. Europe, the United States, China, India, and parts of Latin America are leading the way in spending on transmission, but there is a strong regional imbalance in investment patterns, with advanced economies and China accounting for about 80% of the global total. Global investment in power transmission grew by 10% in 2023 reaching USD 140 billion. Looking forward, global efforts need to increase sharply in all scenarios, and to more than double by the 2030s in scenarios that meet national and global climate goals.

Average annual investment in transmission by region and scenario, 2023-2050



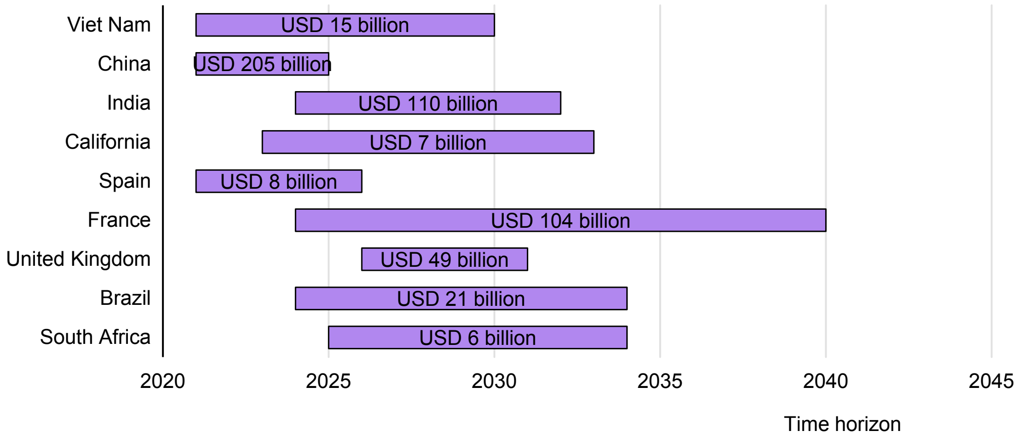
Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NZE = Net Zero by 2050 Scenario. Other EMDE = emerging market and developing economies other than China.

Among the advanced economies, many governments have introduced policies to accelerate transmission investment, with some extending their planning horizons and setting clear renewable energy targets. Examples include the European Union's Grid Action Plan, aims to double cross-border transmission capacity. In the United States, the Department of Energy has developed a USD 2.5 billion Transmission Facilitation Program to help projects in their final stages of approval, as part of the Infrastructure Investment and Jobs Act.

In 2023, China invested around USD 40 billion in high-voltage transmission and remains committed to expanding its ultra-high-voltage (UHV) network under the 14th Five-Year Plan, with 38 UHV lines already operational in 2024.

For Other EMDE, the investment challenge is much bigger. The APS requires a tripling in current investment levels on average in the next decade and the NZE Scenario requires a quadrupling. Some countries such as India and Brazil have shown substantial progress in investing in transmission infrastructure and there are plans elsewhere to expand infrastructure, such as the ASEAN Power Grid initiative. However, in aggregate, transmission investments in EMDE are far below the levels that will be needed to support national energy and climate objectives.

Planned transmission investments and time horizons in selected countries and regions



Source: Viet Nam, Power Development Plan 8; China, 14th Five-Year Plan; India, National Electricity Plan; California, 2023-2024 transmission plan; Spain, Transmission Grid Development Plan 2021-2023; France, Ten-year network development plan; United Kingdom, RIIO-T3 Business Plan; Brazil, Plano Decenal de Expansão de Energia 2034; South Africa, Transmission Development Plan.

In 2024, India released its National Electricity Plan, outlining the transmission required to achieve 500 GW of installed renewable energy capacity by 2030 and 600 GW by 2032. The plan also addresses cross-border interconnections, energy storage requirements and substation capacity expansions. Brazil more than doubled its transmission infrastructure investments in 2023 and auctioned a record 10 500 km, where China State Grid won the biggest lot.

National investment plans are increasingly recognising the role of transmission infrastructure in achieving clean energy goals. Governments are extending their focus and planning horizons to ensure transmission networks are developed in alignment with long-term energy transition objectives.

A growing trend towards developing higher-voltage transmission lines

The global shift to renewable resources of power generation is driving unprecedented investment in high-voltage and ultra-high-voltage (UHV) transmission infrastructure, with systems adopting solutions to facilitate long-distance power transfer. Direct current (DC) transmission is also gaining momentum as it is well-suited for long-distance transmission. The surge of offshore wind power generation has boosted the need for high-voltage subsea cables, especially in Europe.

The global length of high-voltage direct current (HVDC) lines nearly tripled between 2010 and 2021, exceeding 100 000 km. This reflects an expansion of long-distance overhead lines in China and Brazil, as well as underground and subsea cables in Europe.

China leads the way in ultra-high-voltage direct current (UHVDC) technology. It has announced over USD 200 billion to be invested in transmission lines by 2025. The 800kV Gansu-Zhejiang DC line started construction in 2024 and is designed to transmit around 4 GW of renewable energy yearly, costing nearly USD 5 billion. China accounted for nearly 50% of the global HVDC line length in 2021.

Brazil has outlined plans for a major UHVDC power transmission project to transport clean energy from the northeast to the central part of the country, which is expected to be operational by 2029. The State Grid in China, which was the successful bidder on the largest-ever infrastructure transmission auction in Brazil in 2023, will handle the construction.

India also plans to expand its HVDC infrastructure, as outlined in the latest National Electricity Plan for Transmission, which includes linking 33 GW through HVDC systems between 2023 and 2032. In 2024 India commissioned a 765 kV line to transmit around 3 GW from Khavada to Bhuj. Another major project scheduled to be commissioned by the end 2026, is the 800 kV HVDC line to conect Gujarat and Maharashtra, evacuating power from a planned renewable energy zone of up to 8 GW.

In Europe, the North Sea is home to several key DC subsea cables for electricity transmission, including the 525 kV Viking Link and the 515 kV North Sea Link, each spanning over 700 km. Recently, TenneT, a European electricity transmission system operator, opened a 2 GW programme for 525 kV DC offshore cable.

Chapter 2: Transmission supply chains under strain

The surge in global demand for transmission capacity is shaping the supply chain landscape

Growth in global demand for transmission capacity, driven by simultaneous expansion plans in many regions, is putting pressure on supply chains and the availability of cables, materials and critical electrical components. Manufacturers are experiencing skyrocketing demand, leading to higher prices, longer procurement lead times, and record-breaking order backlogs.

The market is reacting to this surge in demand and many manufacturers have announced plans to scale up production. Yet, substantial challenges remain. The industry's technical complexity, especially for some components, continues to be a challenge. High-voltage systems, long-distance subsea cables, and DC converters require highly customised solutions to meet the increasingly sophisticated needs of modern transmission projects. While the market has responded positively, scaling up manufacturing capacity takes time and component manufacturers also have experience of fluctuating demand patterns and periods of lower returns or fewer orders in the past. This highlights the importance of long-time visibility on demand in order to bolster confidence in future equipment and component needs and to help mitigate the risks associated with expanding manufacturing facilities.

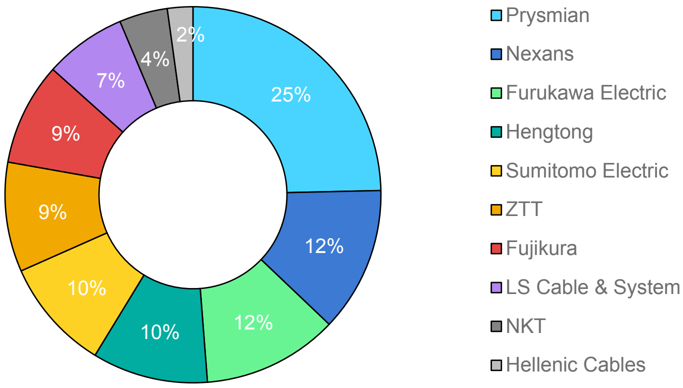
Cable manufacturers are scaling up production

There are several manufacturers of alternating current (AC) and DC transmission cables, with production facilities spread across different countries. While the medium-voltage cable market is relatively standardised, higher-voltage cables, particularly those for long-distance transmission and subsea projects, require greater customisation. This includes tailoring insulation, environmental resilience, and protective features to meet the specific demands of each application.

The location of these factories is a critical factor in cable manufacturing, as transportation requires logistical efforts especially for submarine or high-voltage and impacts the price. The cable market generally expands through the establishment of new subsidiaries in strategically selected locations within advanced economies, whereas EMDE predominantly drive growth by increasing trade.

Prominent players in the cable industry include Prysmian (Italy), Nexans (France) and Furukawa Electric (Japan) which collectively account for half of the top ten global players by revenue. While these manufacturers maintain extensive global operations, distinct regional patterns emerge in their market presence. Sumitomo Electric (Japan) and LS Cable & System (Korea) are prominent in the Asia-Pacific region, benefiting from their proximity to this high-demand market. Prysmian has cultivated a significant presence across the United States and Europe, and Nexans and Prysmian are key suppliers in Africa.

Market share by revenue for the top ten cable manufacturers, 2023



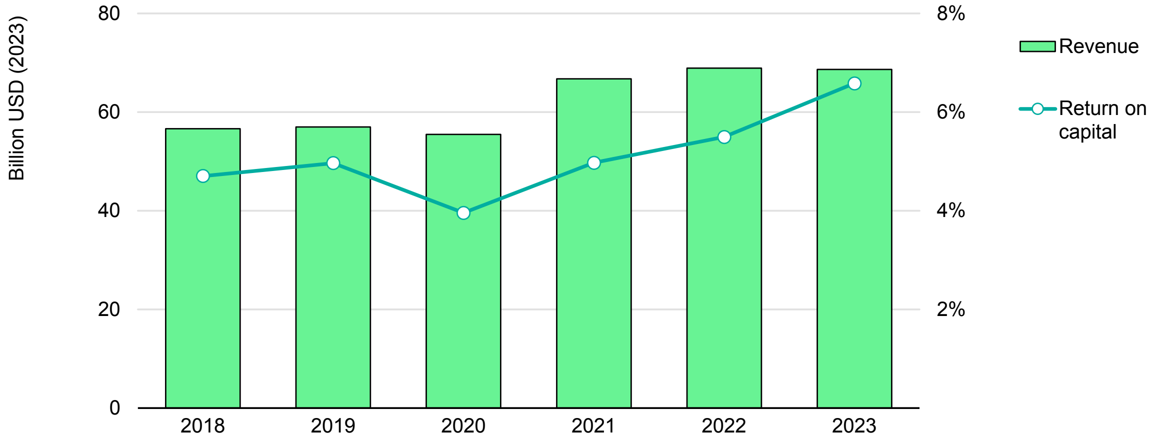
Note: Top ten cable manufacturers account for around 50% of the global market.
Source: IEA analysis based on S&P Capital IQ.

Many of these manufacturers are investing in capacity expansions in response to the recent uptick in demand. Building a factory takes around three to four years, and it requires not only capital but skilled labour to do so, which can be a bottleneck. The visibility and credibility of national and regional transmission planning, and its translation to component demand, is vital to underpin investment decisions in new or existing manufacturing capacities.

Prysmian has announced a USD 2 billion investment in capacity expansion through 2027, including doubling production of 525 kV submarine cables and 400 kV AC cables by 2026. Nexans has announced a USD 109 million investment for a new medium-voltage cable plant in partnership with the Moroccan government, set to be operational by 2026. Additionally, the company is investing USD 98 million to meet the growing demand for offshore cables in Europe, as well as building a new cable laying vessel worth over USD 205 million. NKT (Denmark) also announced plans to build more high-voltage capability by investing over USD 1 billion between 2023 and 2026.

Investment incentives can play a key role in supporting and accelerating these expansion efforts. In the United States, for example, cable manufacturers are planning to leverage the incentives in the Inflation Reduction Act to expand their production capacity. Hellenic Cables secured tax credits to support the development of a new cable manufacturing facility in Maryland in the United States. Similarly, LS Cable & System will benefit from investment tax credits for its planned submarine cable manufacturing plant in the United States, expected to begin operations in 2027.

Revenue and return on capital for top ten cable manufacturers, 2018-2023



Note: Top ten cable manufacturers based on fiscal year 2023 revenues.
Source: IEA analysis based on S&P Capital IQ, Annual reports.

Profitability in the cable manufacturing sector has shown notable improvements over the past three years, with the average return on capital reaching an average of 6.8% for the top ten global players in 2023. The surge in demand has created an opportunity for manufacturers to sustain and enhance these returns. As the market expands rapidly, companies are under increasing scrutiny to deliver strong performance and capitalise on growth while managing rising operational and supply chain challenges, as well as financing production expansions.

Electrical equipment manufacturers are also seeking growth with strategic investments

Transformer manufacturing is a highly customised process, with designs specifically tailored to meet the unique requirements of each project. Key factors such as grid configuration, operational load, and space constraints significantly influence the design, to ensure that transformers are optimised for their intended applications.

These components are critical to maintaining the reliability and stability of electrical networks. The production of power transformers requires advanced and specialised facilities, including drying ovens and high-power testing laboratories, which reflects the technical complexity of the manufacturing process. Given the customised nature of transformers, close collaboration between manufacturers and buyers is essential to ensure precise alignment with project requirements. The bespoke nature and critical importance of electrical components drive the market's reliance on long-standing buyer-supplier relationships.

The global market for transmission system electrical equipment is experiencing significant growth, driven by surging demand for transformers and high-voltage products. India provides an illustration as represented by two leading manufacturers, Indo Tech Transformers and Transformers & Rectifiers India Ltd, who have experienced strong revenue growth and record-high stock prices.

Today, order books in the transformer industry are full and industry leaders are looking at expanding manufacturing capacity in response. Some manufacturers have expressed uncertainty about the extent of future demand, underscoring that expansion requires strong, long-term visibility on orders to build confidence that new capacity will be utilised.

Hitachi announced a major investment of USD 1.5 billion in 2024 to ramp up its global transformer manufacturing capacity. This expansion will include facilities in Germany, China, Viet Nam, Australia, Brazil, and various locations across the United States. HD Hyundai Electric plans to invest around USD 270 million to expand production capacity by 30%, in the United States and South Korea by early 2026. Schneider Electric, recognising the need for increased production capacity, has committed to investing USD 140 million in the United States, which will also involve hiring around 750 new skilled workers to support its expanded operations. In India, Toshiba is expanding its manufacturing capacity by 50% by 2027 with a USD 60 million investment. Turkish company Astor plans to establish factories in Spain and the United States, with the United States serving as the primary export market for Turkish power transformers. Siemens Energy announced in 2024 its first power transformer manufacturing facility in the United States, worth USD 150 million.

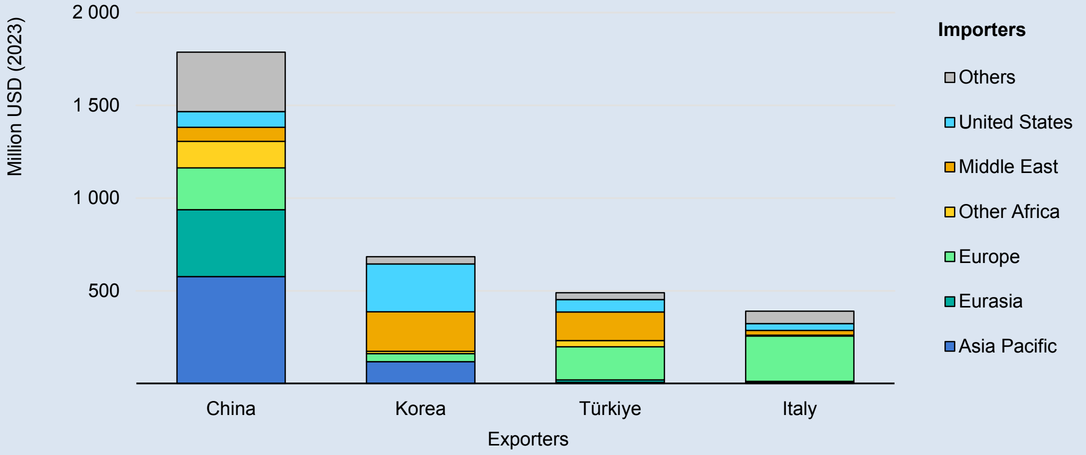
The expansion of HVDC infrastructure has also increased the demand for highly specialised components such as converters and circuit breakers, both of which are critical to the operation and reliability of HVDC systems. Converters facilitate the transition between DC and AC systems, playing a central role in addressing current and future HVDC needs. Circuit breakers, essential for protecting HVDC systems from overloads and faults, are equally critical and face similar market tightness due to their complex manufacturing processes.

Supply chain constraints for semiconductors are another challenge. High-power semiconductors, vital for HVDC converter valves and circuit breakers, have experienced shortages driven by market volatility. Materials like silicon, steel, aluminium, copper, and nickel are also critical to manufacturing various components. The anticipated surge in HVDC infrastructure demand over the next decade risks exacerbating these supply chain pressures, emphasizing the need for strategic planning to address material and workforce shortages.

Rising demand boosts global power transformer trade

Trade plays an increasingly important role in the global power transformer market. Global trade in power transformers was worth USD 13.5 billion in 2023 and between 2018 and 2023, the trade value for exports from the top four exporting countries rose by 80%. China, Korea, Türkiye and Italy accounted for 50% of total global trade in 2023, and China alone for one-quarter.

Top 5 power transformer exporters by value, 2023



Note: Power transformers exceeding 10 MVA. Countries and regions within each bar represent importers.
Source: IEA analysis based on UN Comtrade (2024).

On the import side, both the United States and Europe have more than doubled their trade value for power transformers since 2018. The United States primarily sources transformers from Mexico, Europe, and Korea. Latin America relies on China for nearly two-thirds of its imports.

Africa has also seen a notable increase in imports, rising by 20% since 2018, with key suppliers including China, Germany, India and Türkiye. These trends underscore the evolving dynamics of global power transformer trade, shaped by regional demand patterns and shifting supply chains.

Increasing prices for key components

The increase in transmission component costs reflects several key drivers. Strong global electricity demand growth is the key underlying element, accompanied on the supply side by the rise of wind and solar PV as sources of generation. In addition, some specific supply chain constraints have added to the pressure, including disruptions in global logistics, tight markets for materials, and skills shortages for manufacturing and installation. Inflation and rising energy costs in some markets have also contributed to rising prices, with production and logistical expenses exacerbated after Russia's full-scale invasion of Ukraine.

Among raw materials, the volatility in the costs of copper and aluminium, which peaked in early 2022, and the price of grain oriented electrical steel (GOES), which doubled between 2021 and 2023, have contributed to the cost surge in transmission components. All these factors have contributed to the cost surge in transmission components.

Material prices for transmission components are feeding through into higher costs

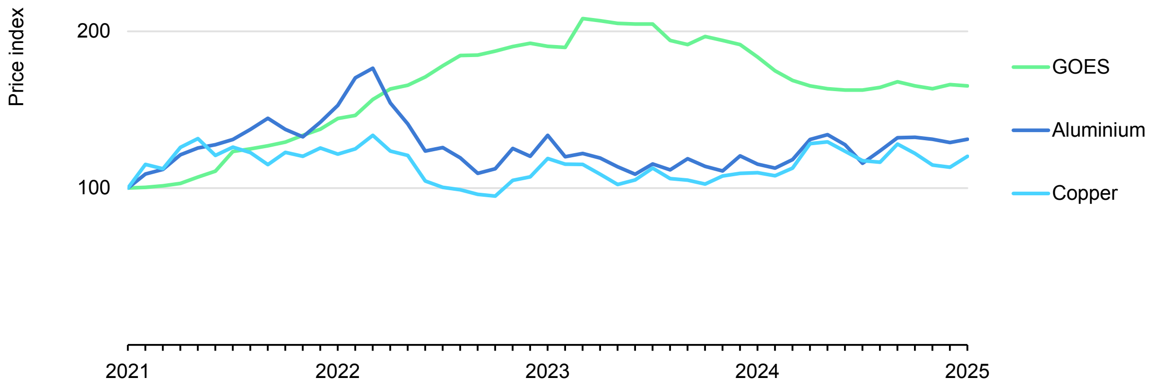
Rising demand for transmission infrastructure has brought with it a surge in material requirements. Copper, steel, GOES and aluminium are among the key materials directly affected by this growing need. These raw materials are not only essential for manufacturing but also represent a significant portion of costs. As a result, fluctuations in material prices have a substantial influence on the overall cost of transmission line projects, making resource availability and pricing pivotal to future grid development.

In the case of large power transformers, raw material suppliers for GOES, copper wire and insulating materials have a significant influence on the transformers final price. The GOES used in the transformer core represents more than 20% of the transformer's total cost; adding in other materials needed for the manufacture of transformers, including copper, aluminium and insulating materials, can bring the share of materials in total cost to more than 50%.

Copper and aluminium are the primary materials used in the production of cables and power lines. Due to its superior conductivity-to-weight ratio compared with copper, aluminium is typically used for overhead power lines and is increasingly utilised for underground and subsea transmission cables. Copper, on the other hand, is predominantly employed in underground and subsea applications.

In a high-voltage overhead line, aluminium accounts for approximately 18% of the total composition, with the remaining portion comprising the steel poles. For cables, copper makes up about 60% of the total weight, while the rest consists of insulation materials. In the case of aluminium cables, aluminium can account for up to 80% of the total weight.

Price index for key materials: GOES, copper and aluminium, 2021-2025



Source: IEA analysis based on data from Bloomberg, T&D Europe, Federal Reserve Economic Data.

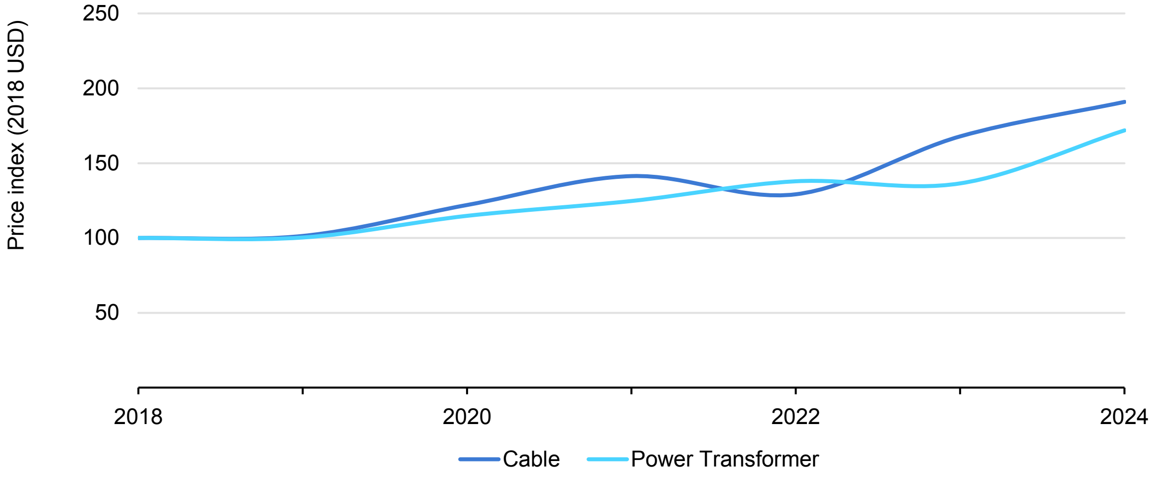
GOES prices have doubled between 2021 and mid-2023. This price increase is primarily due to the surging demand for transformers, coupled with growing demand in other applications, such as EV charging stations. The production of non-oriented electrical steel (NOES) used for electric motors in EVs, has contributed to the issue, as some manufacturers have shifted focus away from GOES production to meet NOES demand. China continues to be the main manufacturer, accounting for around a third of global production.

Copper prices experienced an increase in 2021 and early 2022. However, from 2021 to 2023, supply grew at a faster pace than demand, leading to a decline and stabilisation of prices. Aluminium experienced similar price trends, peaking in 2021 due to pandemic-related disruptions and rising electricity costs. As of 2025, aluminium prices are around one-third higher than in 2021.

Rising global price index for cables and power transformers

Based on a survey conducted by the IEA, high demand for cables and power lines has substantially driven up prices. Prices for cables nearly doubled in the past five years, despite a plateau in 2022 as the market stabilised following earlier supply chain disruptions and high inventory levels built up in response to those disruptions. Post-2022, as the market recovered, raw material prices rebounded, and demand surged for high-voltage cables driven by major infrastructure projects and power grid upgrades.

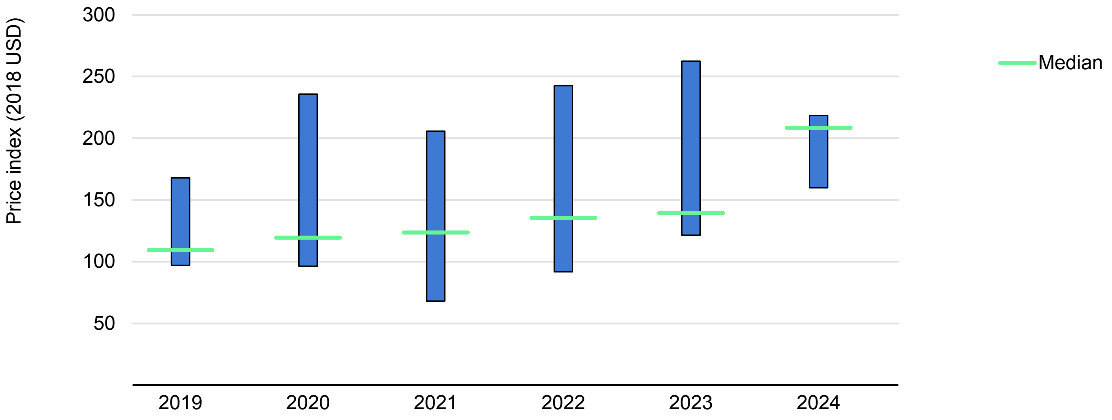
Power transformer and cables price index in real terms (2018 USD), 2018-2024



Note: Analysis based on cable auctions >320 kV (excluding submarine) and IEA survey for underground cables.
Source: IEA Survey 2024.

Our survey also reveals a sharp increase in the price of power transformers since 2022, although prices for individual units are highly dependent on their complexity and capacity, with values varying widely according to the customised design. This variability makes it difficult to establish a standard price, as each project has its own unique requirements. In some cases, transformer prices have surged to as much as 2.6 times their pre-pandemic levels, in real terms. Similarly, a transformer project in a region with challenging infrastructure or environmental conditions may see costs escalate due to the added complexity of installation and maintenance. These price increases are creating additional pressure on already stretched supply chains and investment plans for transmission infrastructure.

Spread of power transformer price index, 2019-2024



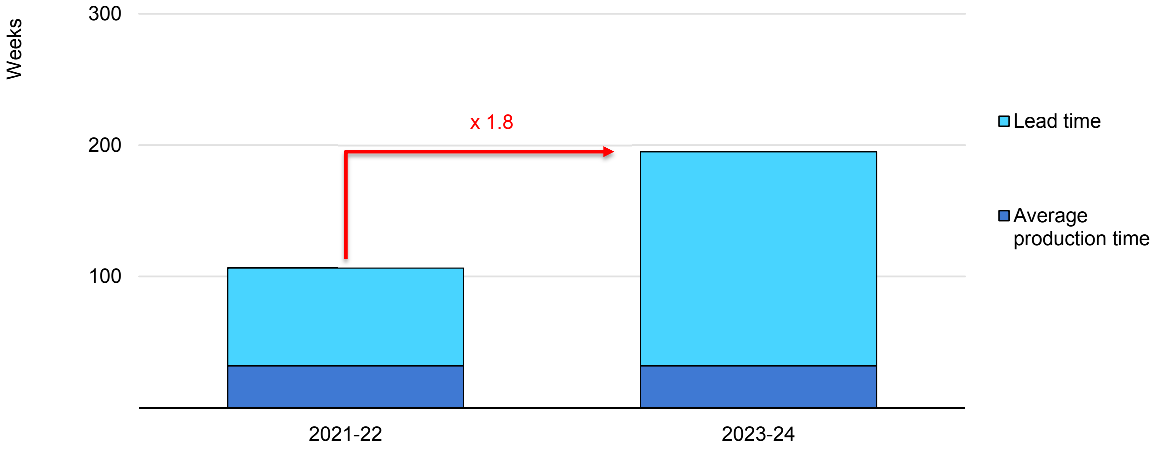
Note: 2018 = 100
Source: Analysis based on IEA Survey 2024.

Looking ahead, market sentiment suggests that prices are expected to continue to rise in 2025. High demand, combined with persistent inflationary pressures and a shortage of skilled construction labour, is likely to drive up labour and overall costs.

Rising lead times and record-high order backlogs

Lead times for cables have increased significantly, now extending up to two or three years depending on the complexity of the project, compared to just one or two years a few years ago. This increase is largely driven by high demand and more complex projects, such as long-distance HVDC cables or submarine installations, which have put additional strain on procurement timelines. Leading manufacturers in advanced economies have already committed their production capacity through 2029. For example since March 2023, NKT has confirmed high-voltage contract awards and booking commitments of more than USD 5 billion. This situation is not expected to change in the immediate future. New manufacturing facilities for cables are not expected to be operational until 2026 and building a new manufacturing facility typically takes around three to four years.

Average lead time for large power transformers, 2021-2024

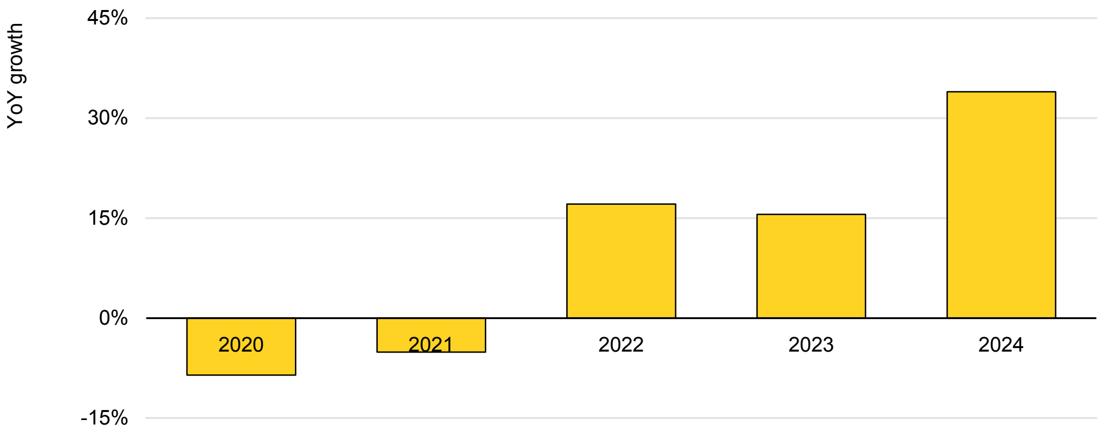


Source: Analysis based on IEA Survey 2024.

The situation in the transformer market is similar, with lead times having almost doubled on average over the past two to three years according to the IEA Survey (2024). Manufacturers have reported a record backlog of orders in 2024, with orders measured in USD increasing by one-third in just one year. HD Hyundai Electric and Hyosung Heavy Industries, two of Korea's largest transformer manufacturers, have reported a combined order backlog exceeding USD 10 billion by the end of the third quarter, reflecting a one-third increase year-on-year.

Similarly, Končar Group, a prominent manufacturer in Croatia, has reached an order backlog of USD 2 billion, with three-quarters of its new contracts dedicated to export markets, indicating both strong international demand and an increasingly competitive global market for transformers. Hitachi Energy, one of the largest players in the sector, has seen its order backlog more than triple in the past four years, now surpassing USD 30 billion. This rapid growth in backlogs highlights the surge in market demand, leaving manufacturers struggling to keep up with the pace of new orders.

Increase in power transformer order backlog in selected manufacturing companies, 2020-2024



Note: YoY = year-on-year. Based on order backlogs of Hitachi Energy, Schneider Electric, Siemens Energy, GE Vernova

However, while lead time increases have affected project timelines and costs, the primary cause of delays in transmission projects remains permitting, particularly in advanced economies. In regions like Europe and the United States, it typically takes an average of 8 years to develop an extra-high-voltage line, compared to just 3 years in India and 1.5 years in China.

Facing the procurement challenges

A tight market for transmission components has several important implications, and one of the most notable is the shift in the balance of negotiation power. Buyers, who once had the option to choose between multiple suppliers based on price and quality, are now competing for limited production slots. In many cases, there is only one supplier available, and companies often need to negotiate years in advance to secure their needs. In Europe and the United States, buyers are booking a manufacturing slot rather than the traditional model of buying material for delivery.

In response to these market conditions, buyers are increasingly turning to long-term framework agreements, which provide greater stability for procurement and offer manufacturers better visibility, allowing them to expand production capacity with more certainty. This is a trend especially seen in the European context, as contracts in the United States are generally still project based.

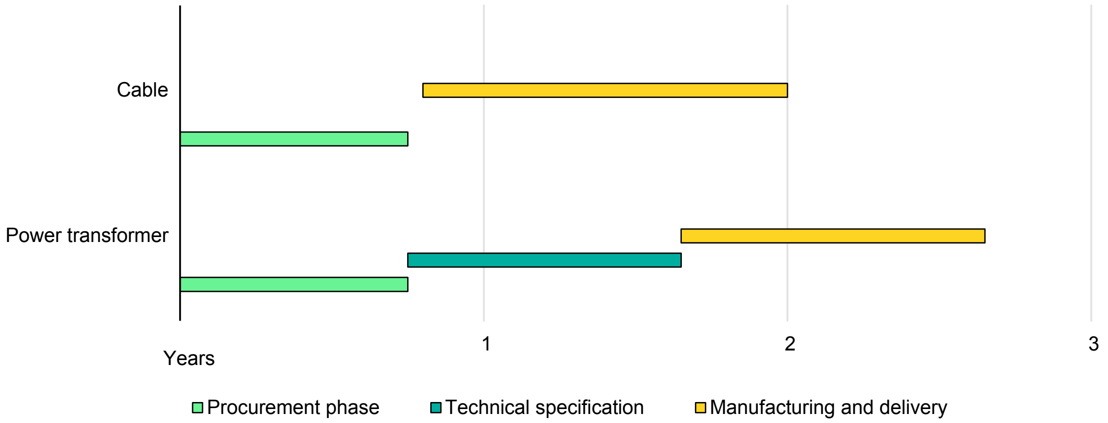
Framework agreements have typically been used for smaller equipment with two to three-year terms, but they are now being extended to larger equipment and longer timeframes, typically up to five years. These agreements help secure commitments and generally include both fixed and variable price components, the latter commonly indexed to inflation or raw material prices.

There are many examples of framework agreements. Terna for example, awarded a USD 1.75 billion contract in 2021 to design, supply and commission 1 500 km of submarine cable. TenneT awarded USD 5.7 billion of framework agreements with several cable suppliers for 7 000 km of HVDC projects. Similarly, RTE entered into contracts with five European suppliers to secure underground cable supplies for its projects through 2028, with a total value of approximately USD 1 billion.

There are also long-term agreements happening for power transformers, as Hitachi Energy signed an 8 year framework agreement with the Swedish TSO, with deliveries planned from 2027 to 2032.

National grid has announced the development of an Advanced Procurement Mechanism as part of their latest Transmission Business Plan in December 2024, aiming to enable larger and longer commitments. They have also procured over 14 000 kilometres of cable as part as a long term strategy to serve HVDC large projects.

Cable and power transformer procurement timeline, 2024



Source: Analysis based on IEA Survey 2024.

Procurement timelines can differ significantly depending on the regulatory framework and the duration of the contract. In some regions, navigating regulatory changes and compliance requirements can introduce additional challenges, potentially affecting project schedules. Long-term contracts often require more time to finalise due to their complexity and scope. Furthermore, TSOs must work within their local regulatory environments, which may add layers of intricacy to the procurement process.

Emergence of non-traditional buyers in the market

The procurement processes for electrical components for TSOs and industrial buyers differ significantly, driven by differences in project scope, regulatory requirements, and timelines. While industrial buyers typically procure lower-voltage components for smaller applications, they often rely on the same suppliers as TSOs, increasing competition in the market.

Procurement process: TSOs vs Industrial buyers

	TSO	Industrial buyer
Scale and customisation	Large-scale Highly customised	Smaller-scale More standardised
Procurement strategy	Long-term frameworks Competitive tenders	Shorter contracts More flexibility
Regulation	Strict regulation	More flexible

The surge of energy demand from data centres, driven by the increasing reliance on cloud computing and digital infrastructure, also increases competition for critical electrical components. Data centres require substantial electrical infrastructure, including high-capacity power transformers and specialised cables. Recently, Virginia Transformer (United States) secured multiple contracts to supply transformers for data centres, with deliveries scheduled between 2026 and 2027. As energy demand from data centres continues to rise, such contracts are expected to become increasingly common in the market.

The hurdle of offshore and submarine transmission lines

Demand for submarine cables and HVDC systems is rising rapidly, driven by the rapid expansion of offshore renewable energy projects, particularly wind farms. Europe, the United States and China are at the forefront of these developments.

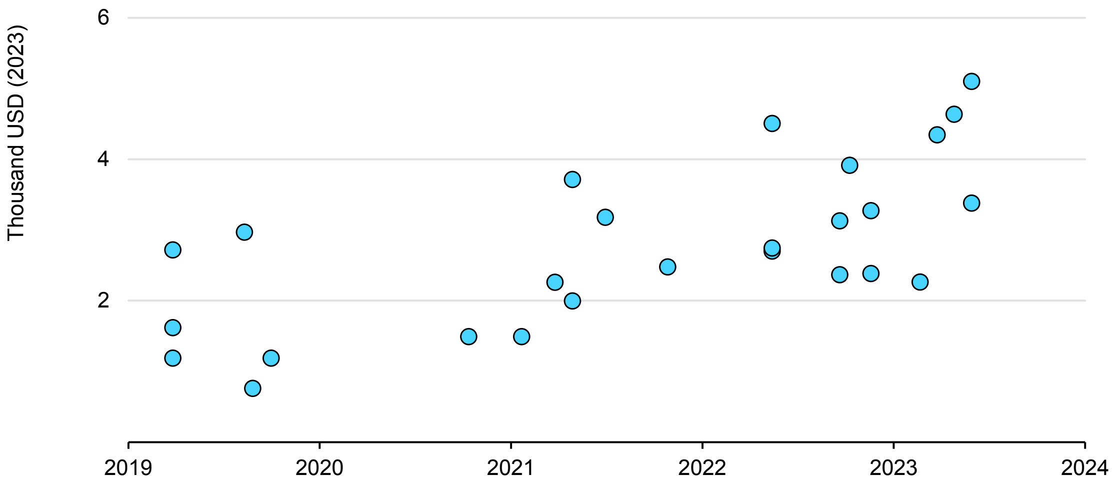
In Europe, the European Network of Transmission System Operators for Electricity (ENTSO-E) estimates that around USD 420 billion will need to be invested in offshore transmission assets. This includes the development of 54 000 km of transmission lines across European markets by 2050.

The United States offshore wind generation market is currently facing uncertainty, as leasing has been paused. While the future of offshore generation remains unclear, several significant projects are still in the construction phase.

HVDC technology has become critical in connecting offshore wind farms to power grids and facilitating long-distance interconnections. Offshore plants are becoming larger and are being built further from the coast, requiring more advanced and specialised infrastructure. The average auction price for offshore wind projects has doubled from 2019 to 2024, underscoring the growing complexity and costs associated with these ventures. Furthermore, contracts signed in auctions are increasingly more expensive also underscoring higher prices as well as higher project complexity.

China has emerged as a global leader in HVDC development, and its strategic investment in HVDC technology has allowed it to sidestep many of the supply constraints facing other regions. Cable manufacturers in China primarily cater to domestic demand, ensuring adequate supply for its ambitious renewable energy projects. This contrasts sharply with the situation in Europe and the United States, where limited production capacity and surging demand have led to bottlenecks. European manufacturers, including NKT (Denmark), Prysmian (Italy), and Nexans (France), represent around two-thirds of the global HVDC market, now have capacity slots booked until 2030.

HVDC contract prices per km per kV, 2019-2024



Notes: kV = kilovolts. The data are for >400 kV HVDC projects
Source: IEA analysis based on market tenders.

Procuring DC cables involves significantly longer waiting times compared to AC cables, with some waiting lists now extending more than five years. This bottleneck is further compounded by the limited number of vessels and skilled operators capable of laying and maintaining submarine cables. Offshore cable installation is a highly technical process requiring specialised vessels and expertise. Only around 60 vessels worldwide can handle these tasks, and many of these have already been in service for decades, which adds to the constraints.

Projects are becoming increasingly expensive and are experiencing delays, partly because of the cost overruns in submarine lines. For example, the Princess Elisabeth Island project in the North Sea, designed to meet nearly a third of electricity demand in Belgium, has seen costs balloon from an estimated USD 2.3 billion in 2021 to USD 7.3 billion. The Harmony Link project connecting Poland and Lithuania, originally slated for completion in 2025, has been pushed to 2028 due to budget overruns.

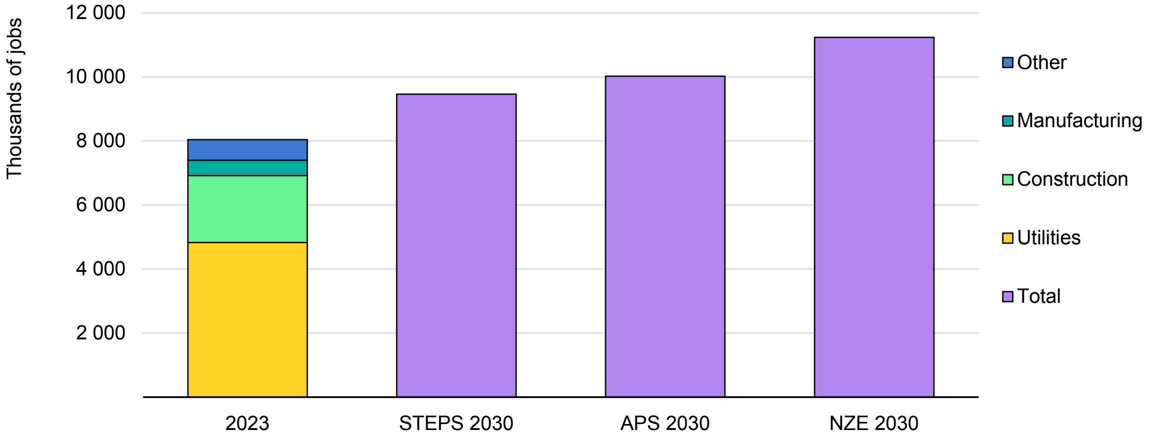
The 1.5 million job gap in the power grid sector

Global employment in the power grid sector increased steadily, to reach over 8 million jobs in 2023. This growth is unevenly distributed, with China and the advanced economies accounting for more than half of the total employment in the sector. Despite rising energy infrastructure investments in EMDE other than China, job growth in regions such as Africa and Southeast Asia has been slower. In Africa, the initiatives to provide universal electricity access is driving job creation, particularly in mini-grid and off-grid solutions, rather than in large-scale high-voltage projects.

In the transmission and distribution sectors, around 60% of jobs are in grid operation and maintenance, where workers handle outages, customer connections, and tasks like meter reading. In countries with rapid power grid expansion, a larger proportion of the workforce works in manufacturing and construction. For example, construction workers make up 42% of the power sector workforce in China.

By 2030, the number of jobs in transmission and distribution reaches 9.5 million in the STEPS, an 18% increase from 2023. About 80% of this increase is projected to be in the EMDE. This indicates a gap of 1.5 million job in the power sector, which is starting to become evident. With ambitious goals for transmission modernisation and infrastructure development, countries are facing increasing shortages of skilled workers. These jobs require highly trained expertise and specialised knowledge which adds to the challenges of fulfilling the skilled labour gap.

Global employment in the power grids sector by scenario, 2023-2030



Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario. Employment in grids include jobs in electricity transmission, distribution and storage.

The problem is not limited to the demand for skilled labour to design and execute transmission projects; there is also a critical need to support the simultaneous expansion efforts of manufacturers. This further strains the capacity to meet both labour and manufacturing requirements at scale, making it progressively more complex to fulfil the expanding needs for grids in order to provide secure and affordable electricity in the transition to a net zero emissions power sector.

The Australian Energy Market Operator forecasts that electricity sector jobs will peak between 2025 and 2029, with demand in Australia expected to at least double in this period. Most of this demand will be driven by wind and rooftop solar installations, with transmission construction as the next key contributor. This highlights the growing need for skilled workers in these areas as countries strive to meet their clean energy transition goals. The Transmission Business Plan in the United Kingdom outlines a strategy to address the skills shortage in the power sector and establishes an initiative, the Great Grid Partnership, to tackle the skilled labour issues.

According to the latest job survey by the World Economic Forum, the demand for electrotechnology engineers is projected to rise 20% between 2025 and 2030, while the need for electrical equipment installers and technicians is expected to increase by around 12%. In addition, environmental and renewable energy engineers are among the fastest growing professions, highlighting the increasing need for a skilled workforce in the short term to spur the clean energy transition.

Chapter 3: Actionable recommendations

Provide greater visibility on future demand for transmission components

Clear signals on future demand, including firm and transparent project pipelines, are essential to secure adequate investments in supply chains. Effective planning and collaboration, based on a credible, integrated vision for the electricity sector development (and the universal access to electricity, where this remains to be achieved), is instrumental to set parameters for the quantity and types of cables and electrical equipment that will be needed. Such an outlook can then shape the planning of manufacturers and underpin their investment decisions so that their operations are efficient and provide the needed components in a timely manner. It also enables industry and governments to right-size programmes to train and sustain a skilled workforce.

Actionable timelines and commitments, for example in a well-structured master plan for system development that incorporates technical specifications and regulatory requirements, reinforce confidence across the supply chain, allowing suppliers and manufacturers to align their capacity and resource planning with projected needs. Governments should request long-term grid investment plans to be prepared domestically and regionally. Endorsing these plans and tracking their implementation can improve the security and pace of grid investment and incentivise the development of supply chains.

Enhance dialogue between governments, TSOs, regulators, developers and manufacturers

Strong coordination and dialogue between governments, TSOs, regulatory bodies, developers and manufacturers is key to ensure timely delivery of transmission projects, strengthen supply chain resilience, and accelerate the transition to clean energy systems. System planning for power grids has become significantly more challenging as variable renewables and distributed generation have taken a larger share of the generation mix. This adds complexity to system operations and calls for alignment among a broader range of stakeholders. Coordination between transmission and distribution levels in power systems has also become more complex, as distribution systems increasingly host generation and flexibility resources. New tools, methods and processes are needed to assess infrastructure demands effectively. Integrated approaches are needed that address connections within the power sector and across other sectors.

Policy makers, regulators and utilities must support institutions, regulations, technical standards and collaboration platforms to build consensus on effective planning approaches that take full account of the changes in the profiles of power systems and their operations. Encouraging TSOs to share procurement and capacity planning data with regulators will further support informed policymaking.

Encourage proactive grid investment strategies

Transmission development inherently operates on slower timelines compared with distributed energy resources and renewable generation projects. To prevent grid infrastructure from becoming a bottleneck, grid planning and development needs to get ahead of the curve to ensure that investments are made in a timely way, including by ensuring that regulatory risk assessments allow for anticipatory investments. With today’s tight market, rising component costs, and increasing lead times, proactive investment strategies are required to synchronise infrastructure build-out with other aspects of power system development, and to provide the predictability and certainty that manufacturers need to secure future orders and encourage expansion in production capabilities.

Design effective procurement frameworks

Support long-term agreements: Long-term contracts provide parties with greater certainty and visibility on prices and volumes and help to ensure a reliable supply of essential components. They offer manufacturers the confidence to invest in capacity expansions while enabling buyers to secure the resources needed for large-scale grid infrastructure projects. Procurement frameworks should be designed in a way that support the conclusion of long-term agreements by aligning with project timeline.

Standardise procurement procedures and criteria: Currently, the lack of certainty about the specifications for future projects and significant diversity across markets act as barriers to manufacturers setting up the needed delivery capacity. Harmonising procurement procedures and criteria, where possible, helps create a more transparent and accessible process for suppliers, making it easier for them to participate in tenders. This not only simplifies the procurement cycle but also enhances efficiency, ultimately accelerating the procurement timelines.

Introduce standards to ensure interoperability between grid components from different manufacturers, particularly for DC technology. DC grids have much greater potential for interoperability challenges than AC technology, which risks causing delays to new grid projects if components from different manufacturers do not work well together.

Align with national plans and policies: Procurement frameworks should be aligned with national infrastructure and energy transition plans to ensure consistency, scalability. By integrating procurement policies with national development goals, governments and organisations can promote investment certainty, drive industrial growth, and avoid bottlenecks that could slow down critical projects.

Streamline permitting processes

Transmission expansion projects, especially high-voltage interconnections, are inherently complex and therefore are highly susceptible to delays. In addition to the challenges posed by equipment availability limits, permitting delays can significantly hinder progress. Accelerating the permitting process, while maintaining its safeguards, is an essential step to avoid severe delays, which could ultimately have a more significant impact than supply chain constraints. It is crucial to prioritise the permitting of key infrastructure by removing unnecessary administrative barriers. Streamlining the processes, through granting priority status and simplifying requirements, helps to ensure that transmission system projects proceed on schedule and contribute to meeting energy, economic and environmental goals.

Make better use of existing grid infrastructure

Measures to optimise the use of today's infrastructure, often via the deployment of digital technologies, play an important role in relieving pressure on supply chains. Real-time monitoring and enhancements in operational performance improve the efficiency of transmission lines, minimising the need for immediate new infrastructure investments and optimising maintenance requirements. Dynamic line rating, for example, involves real-time monitoring of weather conditions and line temperatures to adjust the current carrying capacity of transmission lines. This technology allows lines to operate closer to their thermal limits safely instead of using fixed values, optimising and increasing transmission capacity. Performance-based regulation is an important tool to foster operational efficiency and encourage investment in innovative and digital assets.

Promote diverse, resilient and sustainable supply chains

The manufacture of some grid components currently has a high concentration among only a handful of top-tier suppliers, which makes diversification of the supply chain challenging. Accessing suppliers can be difficult, especially for EMDE. Governments can support the diversified supply of grid components that have a very limited number of top-tier suppliers by pooling their procurement needs and working with local or second-tier suppliers to increase their competitiveness. They can also consider measures to incentivise sustainable practices in supply chains, for example by rewarding the circular economy and CO_2 impact reduction when evaluating proposed investments by TSOs.

Ensure a skilled workforce

The demand for skilled workers is intensifying across the entire supply chain at managerial, technical and manual labour levels, as well as in system operation and regulatory authorities. Developing a strong talent pipeline is critical, alongside ensuring that digital skills are incorporated into power industry training programmes.

Skilled labour is essential not only to meet the demands of infrastructure projects and installations but also to support the expansion of manufacturing capabilities. By fostering a skilled workforce, governments can better equip the sector to scale manufacturing and operational capacities effectively. Stakeholders in the transmission industry also need to collaborate closely to ensure skills development is integrated into the planning of transmission line projects. This collaboration can help identify the specific skills needed at every stage – from design to construction to maintenance – and ensure the workforce is prepared to meet those needs.

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