



UNEZA
UTILITIES FOR NET ZERO ALLIANCE

Progress on the COP29 Global Energy Storage and Grids Pledge

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About UNEZA

The Utilities for Net Zero Alliance (the “Alliance”) is the international platform for co-operation among entities operating within the power utilities ecosystem, to address and overcome common barriers to the realisation of net-zero ambitions and more near-term emissions reduction targets. Through it, members are shaping dynamic new partnerships, and forging effective channels for dialogue with key public and private stakeholders.

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Cover photo: São Paulo–Minas Gerais transmission line, Source: (Iberdrola, 2025)





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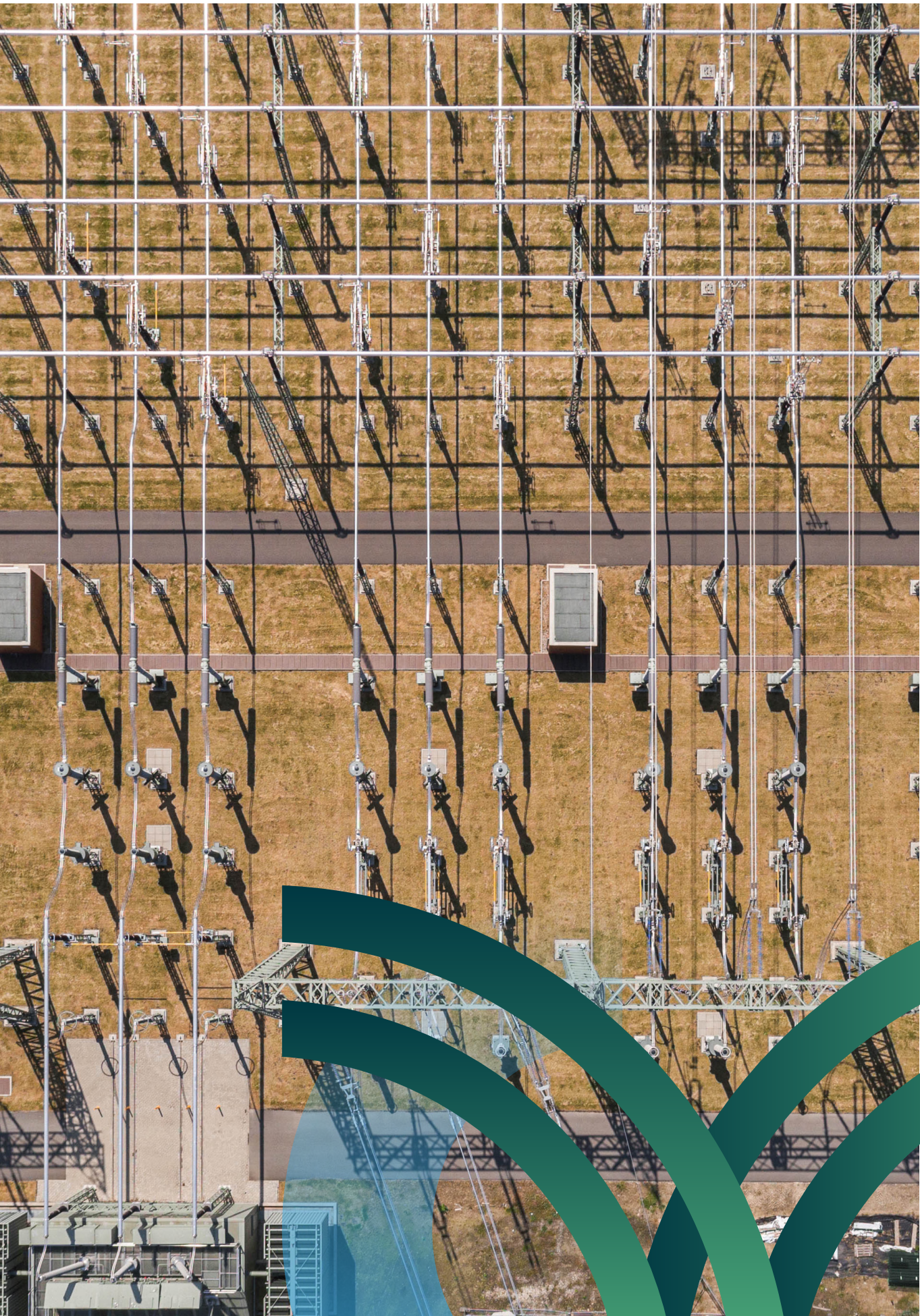
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Abbreviations

AI	artificial intelligence
APAC	Asia-Pacific
ASTI	Accelerated Strategic Transmission Investment
BESS	battery energy storage system
CATL	Contemporary Amperex Technology Co. Limited
COP29	29th Conference of the Parties
CO₂	carbon dioxide
DSO	distribution system operator
EMEA	Europe, the Middle East and Africa
ENTSO-E	European Network of Transmission System Operators for Electricity
EU	European Union
EV	electric vehicle
GGC	Global Grids Catalyst
GW	gigawatt
GWh	gigawatt hour
HVDC	high-voltage direct current
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
km	kilometre
kV	kilovolt
kWh	kilowatt hour
LDES	long-duration energy storage
LFP	lithium iron phosphate
M300	Mission 300
MDB	multilateral development bank
MWh	megawatt hour
Mt	million tonnes
NESO	National Energy System Operator
Ofgem	Office of Gas and Electricity Markets
SSB	solid-state battery
T&D	transmission and distribution
TWh	terawatt hour
TSO	transmission system operator
UNEZA	Utilities for Net Zero Alliance
USD	United States dollar





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Executive summary

At the 29th United Nations Climate Change Conference (COP29), 65 states and 46 non-state actors, including the Utilities for Net Zero Alliance (UNEZA), endorsed the [COP29 Global Energy Storage and Grids Pledge](#). This pledge commits to a collective goal of enhancing grid capacity through a global initiative to add or refurbish 25 million kilometres (km) of grid infrastructure by 2030. It acknowledges global analysis indicating that an additional 65 million km must be added or refurbished by 2040 to align with net-zero emissions by 2050 (COP29, 2024). Achieving this target will require average annual investments in transmission and distribution of USD 700 billion through 2030. The pledge also includes a commitment to deploy 1 500 gigawatts (GW) of energy storage capacity by 2030.

Box S1 UNEZA targets and progress towards 2030

Members of the Utilities for Net Zero Alliance (UNEZA) are united in their commitment to support the global goal of tripling renewable energy capacity by 2030. Through co-ordinated investments and joint actions, they aim to mobilise approximately USD 148 billion of investment annually, which includes about USD 79 billion for grids, USD 3 billion for energy storage and USD 66 billion for renewable energy generation.

These efforts are expected to result in up to USD 1 trillion in cumulative investments by 2030, driving a 3-fold increase in the members' collective total installed renewable capacity – from 351 GW in 2023 to over 1 074 GW by 2030. These achievements underscore the Alliance's expanding influence and the unwavering commitment of its members to accelerate the energy transition through collaborative action and investment.

This report, prepared by UNEZA, assesses global progress on energy storage and grid infrastructure in relation to the COP29 Global Energy Storage and Grids Pledge. It highlights investment needs and technological pathways, while offering policy recommendations to accelerate deployment towards 2030 and beyond. It also features case studies from UNEZA members, showcasing practical actions and lessons that can inform and inspire broader implementation.



Energy storage: Status and next steps

Global energy storage is expanding rapidly, but at the current pace, the world risks falling short of the COP29 pledge of 1 500 GW of storage by 2030.

1. **Gap to meet COP29 targets.** Estimates indicate that total global installed battery storage could grow from 164 GW in 2024 to between 360 GW and 900 GW by 2030, while pumped hydro is expected to expand to about 320 GW (BloombergNEF, 2025a; IRENA *et al.*, 2025). Together, these developments would amount to roughly 1.2 terawatts (TW), leaving a shortfall of around 300 GW to meet the COP29 commitment of 1.5 TW of storage by 2030, underscoring the urgent need to expand annual additions.
2. **Current pace of progress.** In 2024, an additional 8.3 GW of pumped hydro storage capacity were installed, bringing total global capacity to about 150 GW (IRENA *et al.*, 2025). This momentum was projected to continue in 2025, with total installed battery storage capacity reaching 258 GW, representing an annual growth rate of 58% (BloombergNEF, 2025a).
3. **Role of battery energy storage systems (BESSs).** To triple global renewable energy capacity by 2030, energy storage must expand six-fold. BESSs are expected to deliver most of this growth, accounting for close to 90% of all additions, with additional support from pumped storage, compressed air and flywheels. Sustaining an annual increase of around 25% in battery deployment will be important to maintain this trajectory (IEA, 2024a).
4. **Supply chain risks and opportunities.** The supply chain for BESSs is primarily concentrated in China, for numerous reasons that include access to rare earth metals and minerals, dominance in raw material processing, and the capacity in resources, skills and land. This concentration facilitates economies of scale, which are a key factor in reducing global costs. Replicating this scale and access to resources in other parts of the world would be challenging, thereby increasing supply chain security risks. Nevertheless, there is a significant opportunity for battery recycling, which can mitigate these risks to some extent. Diversifying with alternatives such as compressed air energy storage, using widely available materials and offering long-duration flexibility, can further enhance resilience. Targeted policies can support and accelerate these initiatives.
5. **Future of pumped hydropower.** Some part of the expansion of energy storage will come from pumped hydropower, with opportunities to expand and modernise existing installations. To leverage this opportunity, targeted policy instruments and financing could encourage the expansion, modernisation and life extension of the exploited pumped hydro potential. Changing weather patterns are likely to increase uncertainty around precipitation patterns. Meanwhile, greater digitalisation will further optimise pumped hydro production.
6. **Thermal storage** plays a significant role in long-duration energy storage especially when it comes to aggregating heating and cooling demand in industrial clusters or district heating and cooling networks.



Grid infrastructure: Status and next steps

1. **Targeted and current grid length.** Delivering the COP29 pledge of adding or refurbishing 25 million km of grids by 2030, followed by an additional 65 million km by 2040 to align with net-zero targets, would require an unprecedented expansion. Assessing the extent of transmission lines globally is inherently challenging, as many countries do not publicly disclose detailed data on their transmission networks for security or commercial reasons. Based on available datasets, such as OpenStreetMap and the IRENA Global Atlas, the global transmission network is estimated to comprise around 830 000 km of lines below 35 kilovolts (kV) and 4.8 million km above 35 kV; taken together, this suggests that today's grid totals around 5-6 million km.
2. **Investment and policy support.** Global grid investment rose to around USD 361 billion in 2024 and is projected to exceed USD 400 billion in 2025. By 2030, transmission and distribution investment needs are estimated to reach about USD 700 billion (IEA, 2024b, 2025; IRENA *et al.*, 2025). Regulators can support grid expansion by providing certainty to developers, allowing flexibility in price controls and using public funds strategically to crowd in private capital. Since public funding alone will not suffice – given the long payback periods and regulatory uncertainties that deter private investors – blended finance models will be essential to reduce the cost of capital, although these models still require further development. Meanwhile, policy plays a strong role in sending positive signals to supply chains, which will be under strain to meet manufacturing needs. Given current trajectories, the COP29 pledge is at risk: investment remains well below required levels, and bridging the gap will necessitate higher capital flows alongside regulatory certainty, streamlined permitting and innovative financing to mobilise private investment.
3. **Planning.** Grid infrastructure is a critical enabler of the growth of clean energy infrastructure systems. Long-term, integrated and holistic grid planning, based on a target for the 2050 grid and aligned with climate targets, is essential. Long-term planning and co-operative ordering can further support progress, while holistic management of the energy system across all vectors is crucial for effective signalling and planning.
4. **Permitting.** Rapid infrastructure development that intersects with communities and natural ecosystems can raise concerns among local communities and stakeholders. To address this, permitting and regulatory approval processes need to be streamlined, transparent and co-ordinated across authorities. Considering the wider system value during planning, alongside early and active interaction with stakeholders, can encourage broader support for grid expansion, while also ensuring that benefits are distributed equitably, and felt by everyone, while knock-on impacts are mitigated.
5. **Capacity and optimisation.** While expanding capacity is critical, it is equally important to optimise the utilisation of existing infrastructure. The roll-out of innovative technologies that boost grid efficiency can help relieve pressure as new capacity becomes operational.
6. **Cross-border co-ordination** through inter-connectors can enhance market integration, providing flexibility and stability to grids with significant shares of renewables. Forward-looking and co-ordinated planning, supported by financial incentives and regulatory improvements, will be essential for accelerating the development and effective use of inter-connectors, facilitating more efficient power flows across borders.



7. **Flexibility.** As the share of renewables grows, grid flexibility will become increasingly important. Four primary levers can provide this flexibility: generators (including inverter-based resources), inter-connectors, demand-side optimisation and energy storage.

UNEZA continues to take impactful actions under the *Plan to Accelerate Solutions Expansion and Grid Resilience* adopted at COP30, supporting global efforts to strengthen storage deployment and modernise grids in line with the 2030 goals (COP30, 2025; IRENA, 2025a).

In alignment with these efforts, UNEZA is advancing a set of delivery mechanisms under its Global Infrastructure Programme to mobilise capital and accelerate investment in grid infrastructure.

- Delivery mechanism to unlock ‘stranded GWs’ of renewable generation in ‘queues’ for grid connection.
- Delivery mechanism to advance harmonisation, demand aggregation and pooled procurement in small island developing states (SIDS) in close cooperation with the IRENA SIDS Lighthouses Initiative and the Supply Chains Mission of the Gulf Petrochemicals and Chemicals Association (GCPA).
- Delivery mechanism for investment mobilisation based on the agreed grid financing principles.

To help meet this challenge, the Green Grids Initiative – supported by UNEZA and a working group of development banks, financial institutions and investors – has developed the Climate Finance Principles to Unlock Grid Financing. The Principles harmonise taxonomies, define quantitative eligibility criteria and provide common guidance for how financial institutions can assess and support grid investments. By creating a more transparent and coordinated approach to financing, they seek to unlock the capital needed to build the grids that will support the expansion of renewable energy.

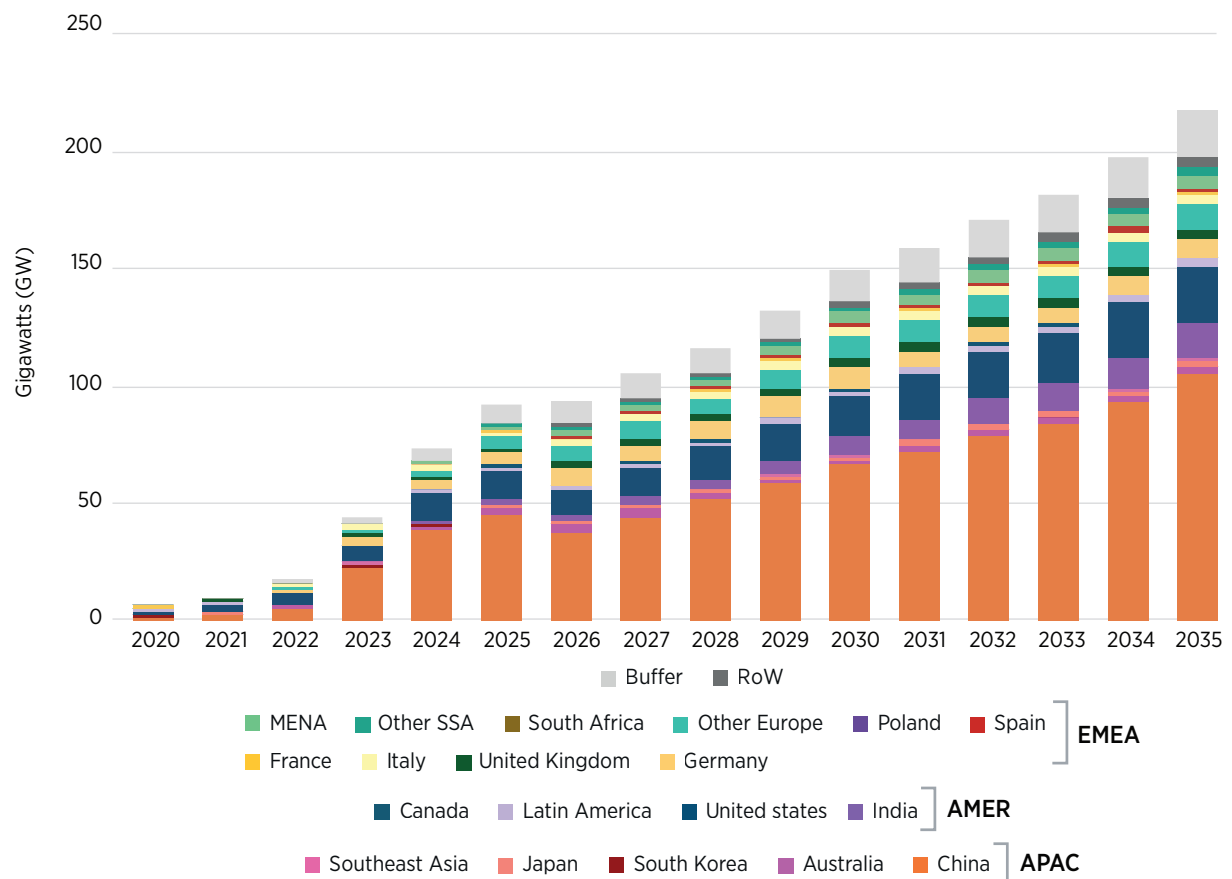


1. Introduction

Achieving global net-zero goals by 2050 requires rapid and significant changes across all industries. Capacity additions in both 2023 and 2024 fell short of the required 16.1% annual growth rate. As a result, tripling renewable power capacity to 11.2 TW now calls for average annual additions of 1 122 GW through 2030, representing a 16.6% compound annual growth rate (IRENA, *et al.*, 2025). Cumulative investments of about USD 29-30 trillion will be required in renewables, grids, flexibility measures, energy efficiency and conservation between 2025 and 2030 to meet the renewable energy and energy efficiency goals outlined in the United Arab Emirates (UAE) Consensus. In other words, an average of USD 5 trillion a year is needed (IRENA *et al.*, 2025).

The objective of tripling renewable power capacity by 2030 calls for strategic planning and investment in grid development and energy storage. Progress in grid expansion and energy storage is most pronounced where policy makers set quantifiable targets and back these ambitions with lasting incentives and clear, reliable regulatory frameworks (Figure 2). However, outdated regulatory structures in the power sector and marginal pricing mechanisms provide limited signals for investing in flexibility solutions such as storage. Meanwhile, policy uncertainty continues to undermine investor confidence (IRENA, 2024a). Industry and financial stakeholders can take the lead by complementing policy efforts with decisive actions to pursue and capitalise on business opportunities presented by the global transition to clean energy (IRENA, 2025b).

Figure 1 Global gross energy storage additions, by market

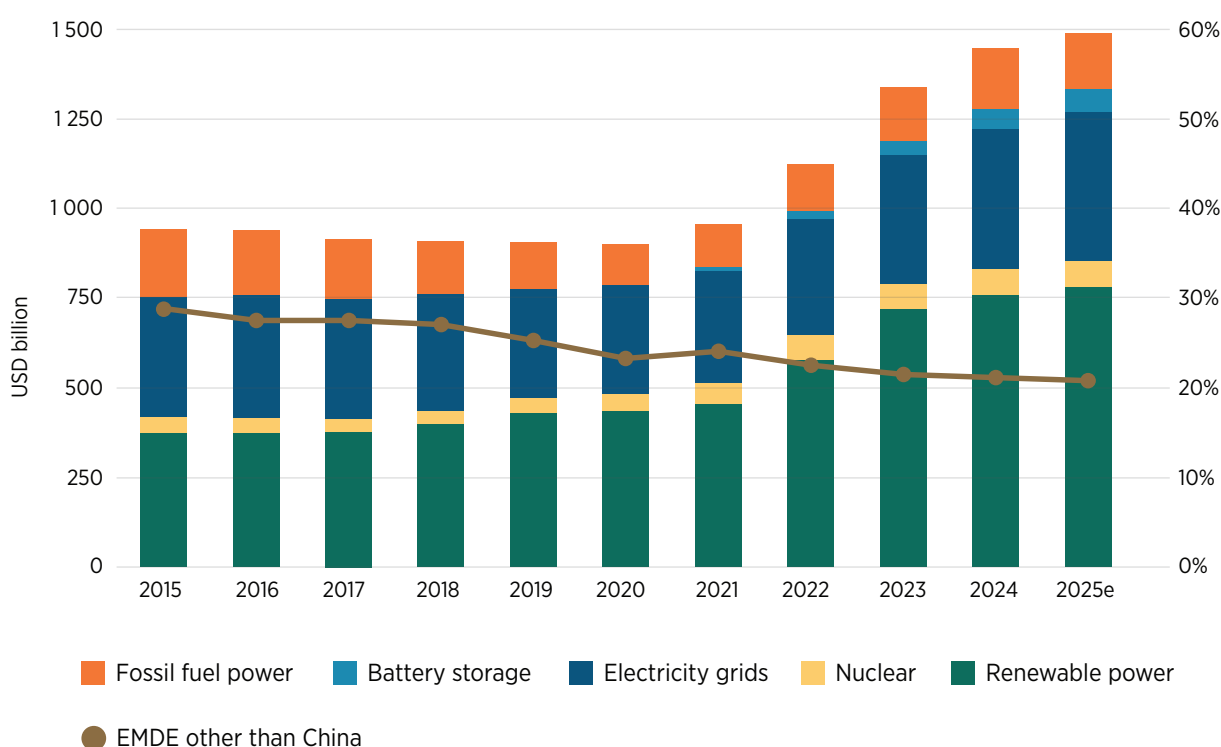


Based on: (BloombergNEF, 2025b).

Note: Buffer is an estimate that is not explicitly allocated to any specific application. AMER = the Americas; APAC = Asia-Pacific; EMEA = Europe, the Middle East and Africa; RoW = Rest of the World.



Figure 2 Global annual investment in the power sector, by category, and EMDE share, 2015-2025



Source: (IEA, 2025).

Notes: Investment across the period is measured as ongoing capital spending on new and existing power capacity. Fossil fuel power includes that with unabated and abated emissions. Low-emissions generation encompasses renewables, nuclear and fossil fuels or non-renewables waste equipped with carbon capture and storage (such as municipal or industrial waste). Pumped hydro storage is included under renewables, not battery storage. EMDE = emerging market and developing economies; MER = market exchange rate; 2025e = estimated values for 2025.

Transmission and distribution networks, acting as the critical link between supply and demand, will require not only physical expansion but also modernisation to enhance resilience, safety and security. Energy storage will play a critical role in providing flexibility as distributed generation increases, thermal generation is phased out and variable renewables become the dominant energy source. In the 29th United Nations Climate Change Conference's [COP29 Global Energy Storage and Grids Pledge](#) (COP29, 2024) countries and stakeholders commit to expand and modernise grids and storage capacity, recognising the central role this infrastructure plays in enabling reliable, flexible and integrated energy systems.

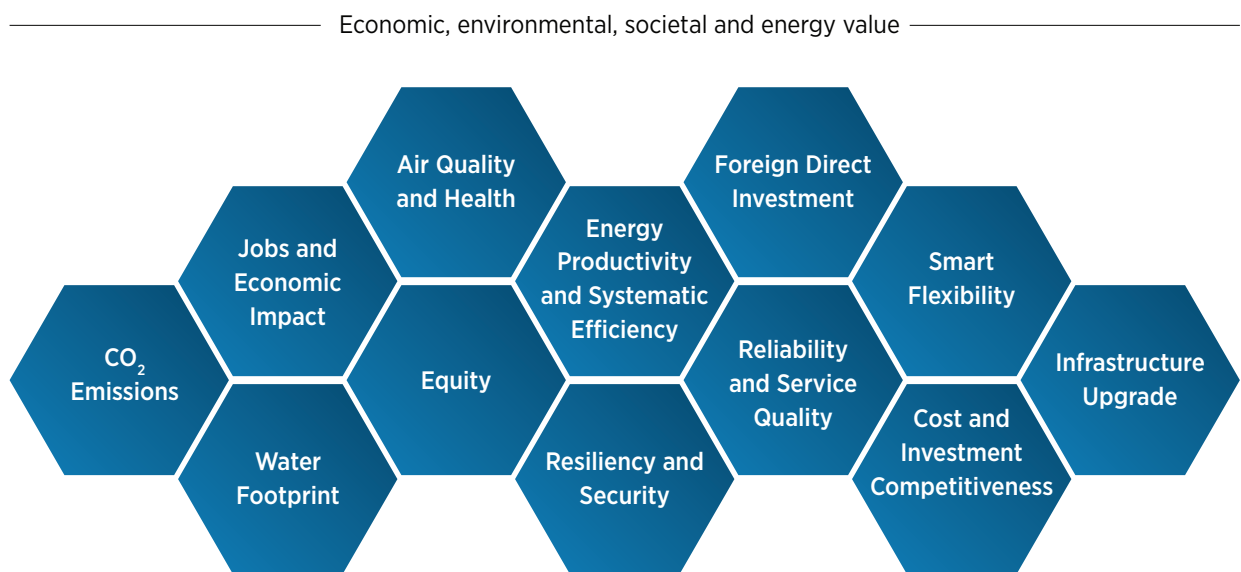
The pledge acknowledges the findings of the International Renewable Energy Agency (IRENA) and the International Energy Agency (IEA), which indicate that batteries and other energy storage technologies can cost-effectively support energy grid reliability in various ways, including: (1) smoothing out the variability of renewables, (2) alleviating grid congestion and (3) providing services such as voltage and frequency control. These technologies greatly enhance the potential of renewables to contribute to reliable, flexible and highly integrated energy systems that support the achievement of global net-zero emissions. Moreover, distributed energy resources, such as solar paired with storage, can support decarbonisation, resilience and the electrification of isolated areas.

1.1 Focus on system value

To keep the rise in global temperatures below 1.5°C, the energy system must undergo a fundamental transformation, and the way its value is assessed plays a central role in that shift. Traditionally, cost has been the main factor guiding decisions on investments in low-carbon technologies, as well as on related business models and initiatives. However, to accelerate progress towards a net-zero future, a broader perspective is needed – one that recognises a wider set of benefits and values.

Considering *system value* means evaluating the economic, environmental, social and technical outcomes of potential energy solutions. A system value framework (Figure 3) seeks to move political and commercial attention beyond cost to encompass overall value, enabling policies, investments and projects that are assessed for their broader impact (World Economic Forum, n.d.).

Figure 3 System value framework



Source: (World Economic Forum, n.d.).

To enable a smooth energy transition, all regions should focus on enhancing system flexibility through demand-side management, grid optimisation and the accelerated deployment of storage solutions.



2. Expand energy storage

A wide range of energy storage solutions is now available, including electrochemical systems such as lithium-ion batteries, flow batteries and other chemistries; thermal storage technologies that use materials like rocks, bricks or molten salts to retain heat; mechanical storage methods that employ compressed air, liquid air or gravitational potential; and chemical storage, which captures energy in chemical bonds, such as hydrogen and its derivatives.

Pumped hydropower, with around 150 GW of installed capacity, plays a crucial role in enhancing grid stability, maintaining energy security and enabling the smooth integration of renewable energy into the global power system, as well as providing long-term system flexibility (IRENA *et al.*, 2025) (see Box 1). However, stationary battery storage is set to expand rapidly, with capacity expected to rise from 86 GW in 2023 to as much as 900 GW by 2030, depending on the deployment of complementary flexibility options such as demand-side management, inter-connections and sector coupling (IRENA *et al.*, 2024). If realised, this expansion would surpass the generation capacity of pumped hydropower, which is projected to reach 320 GW by 2030. Nonetheless, as pumped hydropower generally offers longer storage than batteries, it will continue to play a key role alongside short-term storage options in balancing the growing share of variable renewables in the energy mix.

Box 1 Global Alliance for Pumped Storage (GAPS)

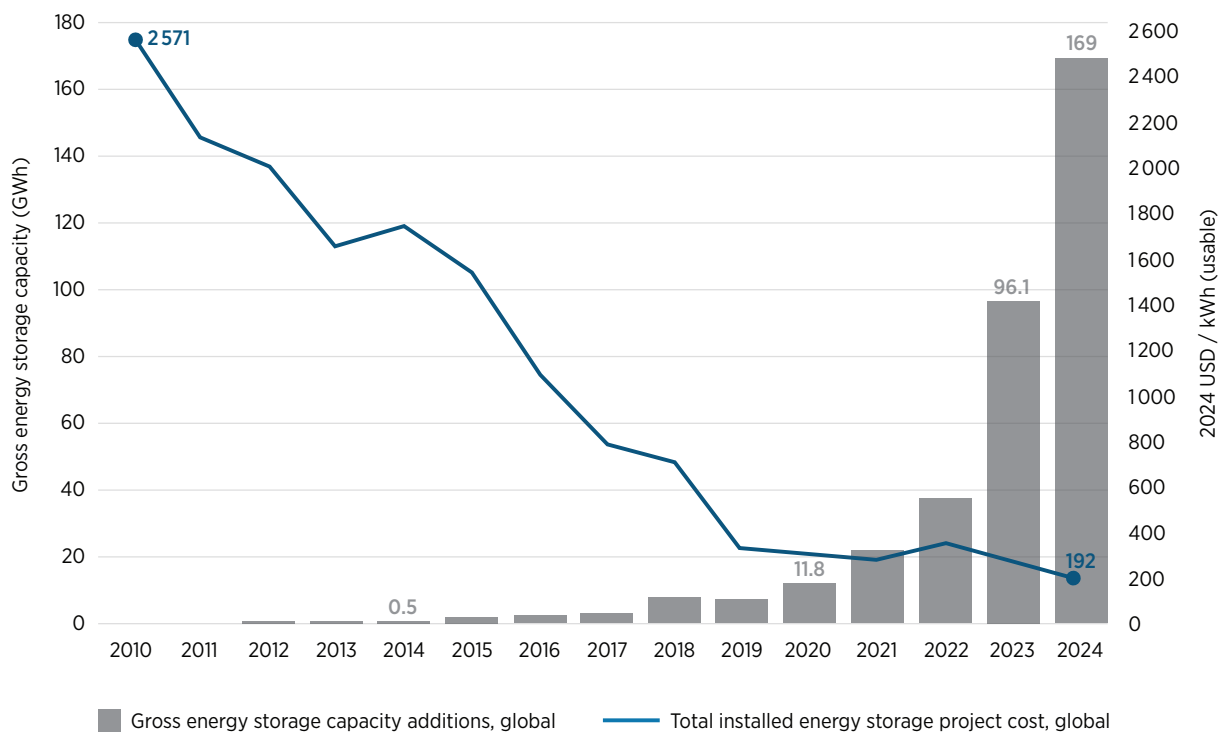
The **Global Alliance for Pumped Storage** established a global framework for the sustainable expansion and modernisation of pumped storage hydropower through the GAP Principles and Workplan. The principles have been recognised by governments and international agencies as a key instrument to accelerate the clean energy transition using pumped storage hydropower. They underline the critical role of pumped storage in ensuring energy security, flexibility, resilience, affordability, climate adaptation and economic growth. The principles also promote investment, environmental integrity and digital innovation to strengthen the contribution of pumped storage to reliable and resilient power systems.

Source: (IHA, 2025).

The rapid rise in battery storage is underpinned by sharp cost declines. Between 2010 and 2024, the total installed cost of utility-scale battery energy storage systems (BESSs) fell by 93%, from USD 2 571 /kilowatt hour (kWh) to USD 192 /kWh (Figure 4), driven by manufacturing scale-up, improved materials efficiency and optimised processes. Over the same period, annual gross BESS deployment expanded from just 0.1 gigawatt-hour (GWh) to around 169 GWh. Lithium-ion technologies, especially lithium iron phosphate (LFP), have dominated the market due to their scalability, safety and cost advantages. Energy shifting continues to be the primary application, representing 67% of new capacity in 2024, as storage increasingly facilitates peak demand, grid balancing and renewable integration (IRENA, 2024b).



Figure 4 Global battery storage capacity additions, by year, and total installed electricity storage project costs per kWh, 2010–2024

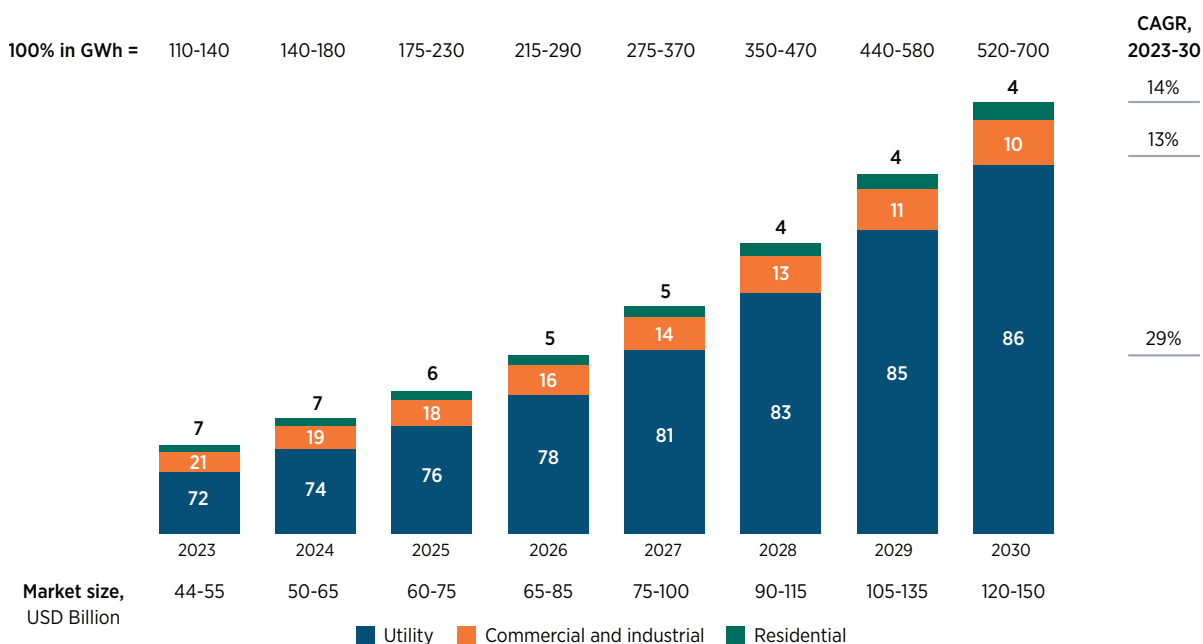


Source: (BloombergNEF, 2024a).

Notes: Cost data from 2010 to 2015 were calculated based on capacity, price and experience curve regression data used for an electrical energy storage technologies model developed by Oliver Schmidt and Iain Staffell. GWh = gigawatt hour; kWh = kilowatt hour.

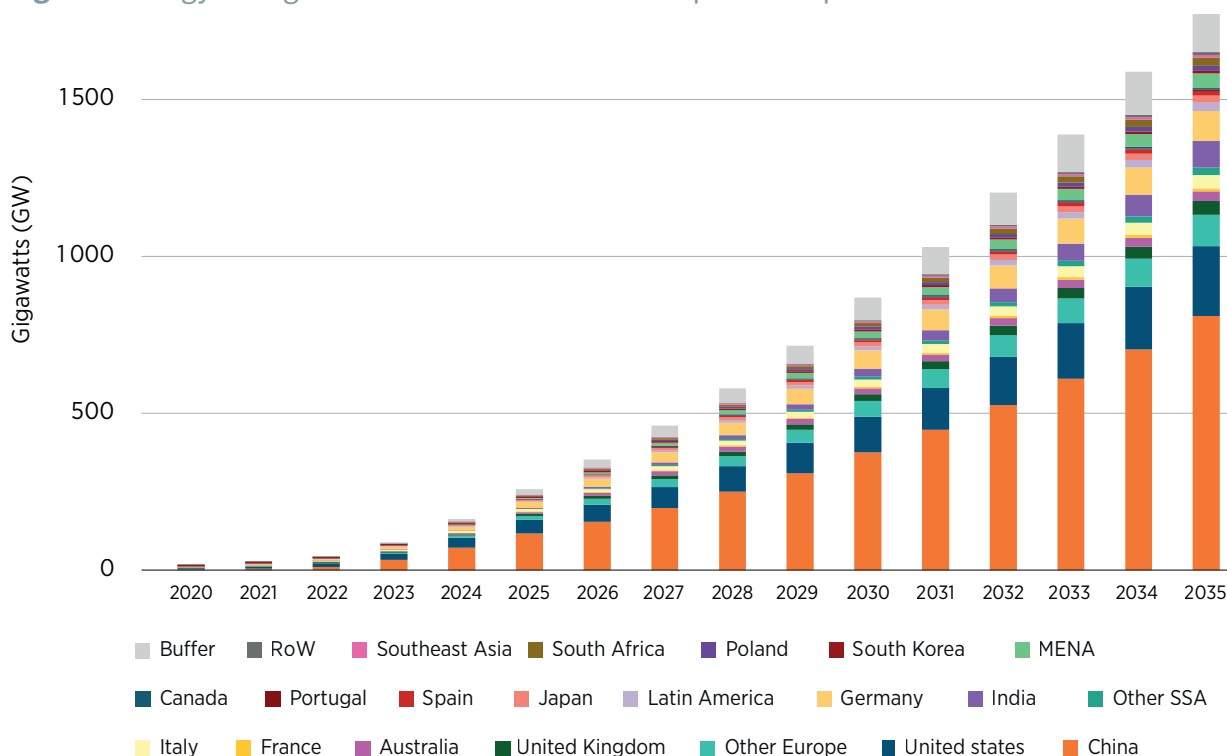
Among the three major market segments – utility-scale, commercial and industrial, and residential – utility-scale BESS is experiencing the fastest growth, at a projected compound annual growth rate of around 29% through 2030. Now accounting for the bulk of new annual capacity additions, utility-scale installations are forecast to reach 450-620 GWh annually by 2030 (Figure 5). This segment is expected to capture up to 90% of the total BESS market, driven by massive grid-scale deployments world-wide (Greencode, 2025; McKinsey, 2023).

Cumulative installed capacity provides a clearer picture of the total global storage base. As shown in Figure 6, battery storage capacity reached around 164 GW in 2024 and is expected to exceed 250 GW in 2025. This trajectory confirms that acceleration of battery storage is the dominant growth area, in contrast to pumped hydro, which, despite having the largest installed base, is expanding at a slower pace.


Figure 5 Battery energy storage system capacity is likely to quintuple between now and 2030


Source: (McKinsey, 2023).

Notes: CAGR = compound annual growth rate; GWh = gigawatt hour.

Figure 6 Energy storage outlook based on cumulative power output


Source: (BloombergNEF, 2025a).

Notes: "Other Europe" includes Czech Republic, Hungary, Slovenia, Slovakia, Denmark, Estonia, Finland, Lithuania, Latvia, Norway, Sweden, Bulgaria, Cyprus, Greece, Croatia, Malta, Romania, Austria, Belgium, Ireland, Luxembourg, the Netherlands and Switzerland. Buffer is an estimate that is not explicitly allocated to any specific application. MENA = Middle East and North Africa; RoW = Rest of World; SSA = Sub-Saharan Africa.

Looking ahead, the BESS market is expected to scale significantly, with annual additions projected to reach between 400 GWh and 1 100 GWh by 2035 (*i.e.* a 21% compound annual growth rate from 2023 to 2035), as shown in Figure 8. Key growth drivers include the increased penetration of variable renewable energy, the need for grid flexibility, declining BESS costs and supportive regulatory frameworks.

The market value of BESS could reach USD 100 billion by 2030, with emerging markets such as the Middle East, Africa and the Asia-Pacific driving demand. In contrast, mature markets such as the United States, Europe and China face slower growth due to saturation. However, supply-side constraints, including local policy restrictions, could limit capacity expansion and hinder the ability to meet demand.

At the same time, global battery demand is projected to reach 7.1 terawatt hours (TWh) by 2035, primarily driven by the mobility sector, which is expected to account for 88% of demand by 2030. China is projected to lead with 43% of global demand in 2030, while North America will contribute 18%, Europe 21% and the rest of the world 20% by 2035. This 3.4-fold growth from current levels will be fuelled by regulatory measures and the increasing adoption of electric vehicles (EVs) and energy storage solutions.

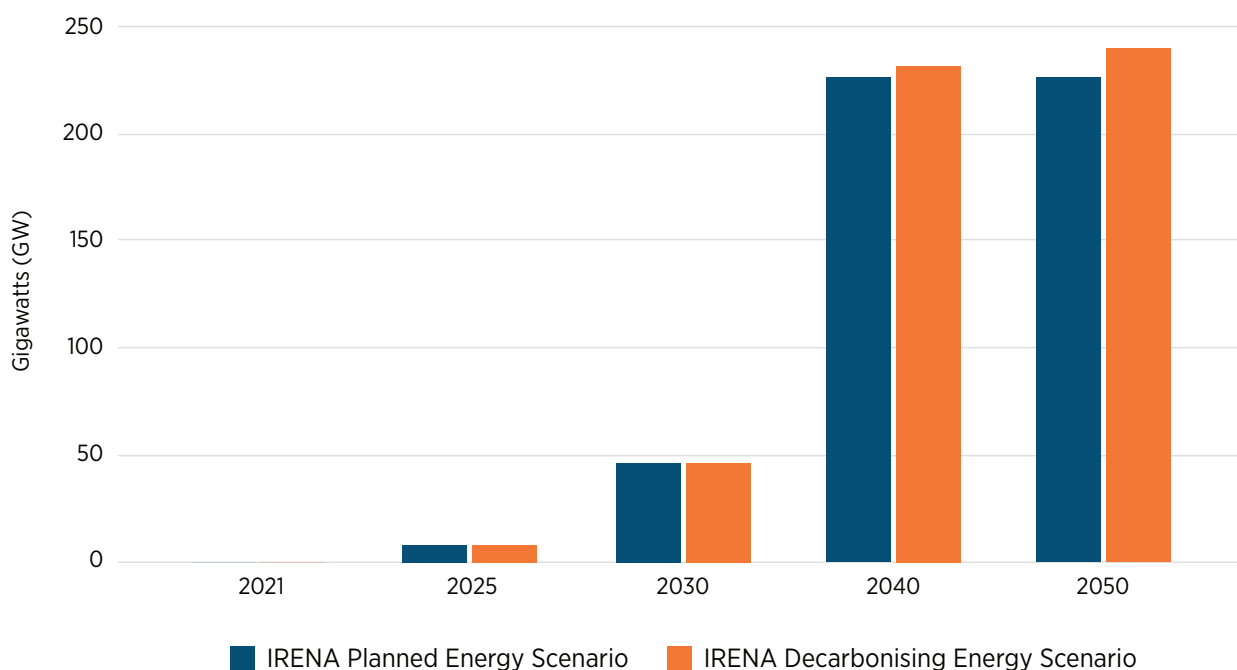
In terms of supply, global lithium-ion cell manufacturing capacity is expanding faster than demand, leading to a projected temporary oversupply through the end of the decade. The IEA estimates that capacity could surpass 6 TWh by 2030, primarily driven by new capacity in China, Europe and North America (IEA, 2023). According to McKinsey's regional analysis, this rapid expansion will keep global supply ahead of demand in the near term, but the balance may tighten after 2030 as EV and energy storage markets mature. Significant regional disparities are also anticipated: China is projected to maintain its dominant position in global lithium-ion battery manufacturing, while Europe and North America may experience localised deficits due to slower project execution and higher production costs (McKinsey, 2025).

For battery-grade raw materials and processing, there is a medium risk of shortages – not for manufacturing lines *per se*, but for the upstream processing of critical inputs such as lithium hydroxide, graphite anodes and nickel sulphates. China dominates these stages of the value chain, while facilities in North America and Europe continue to struggle with scaling up.

In the European Union (EU), battery storage is projected to expand in both the Planned Energy Scenario (PES) and Decarbonising Energy Scenario (DES) (Figure 7). In 2021, installed capacity was minimal, reflecting the technology's nascent role in the power system. By 2030, capacity is expected to rise to about 46 GW under both scenarios, signalling the start of large-scale adoption. By 2040, as renewables provide a greater share of generation, capacity is projected to increase to 227 GW and 232 GW, respectively, before stabilising at 227 GW (PES) and 240 GW (DES) by 2050. This trajectory underscores the role of batteries as a central component of reliable system operation in Europe, ensuring flexibility and resilience (IRENA, 2025c).



Figure 7 Expansion of battery storage in the power sector



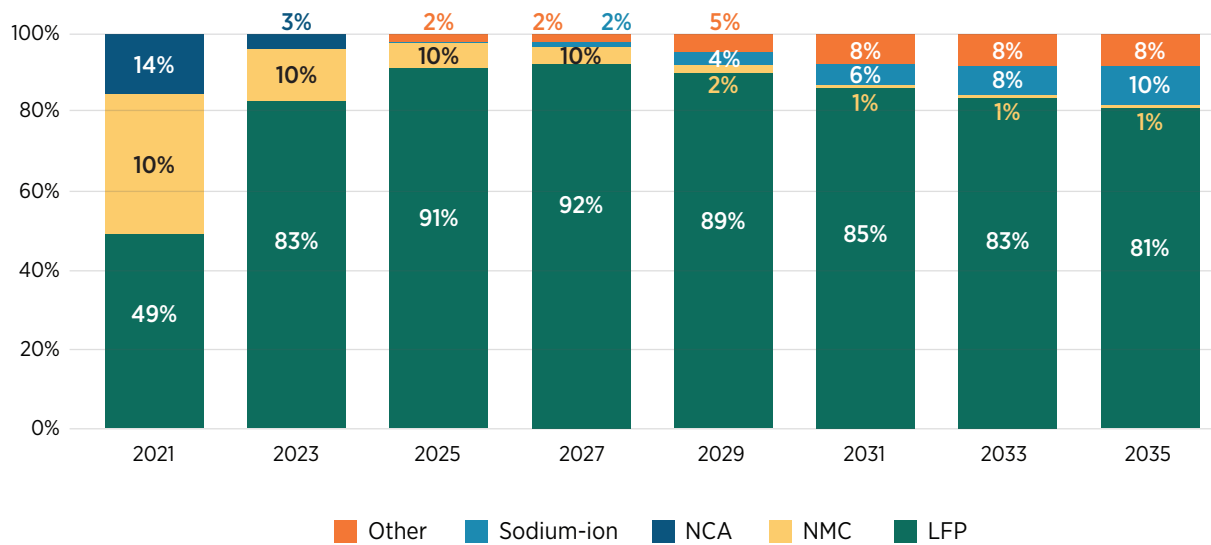
Source: (IRENA, 2025c).

Notes: The Planned Energy Scenario considers current energy plans and policies implemented at both the European and Member State level. The Decarbonising Energy Scenario outlines alternative pathways towards the European Commission's targets and aspirations for combating climate change and enhancing energy security and competitiveness. The gap between these two scenarios illustrates the extent of the additional effort and ambition needed. GW = gigawatt.

In terms of the technology mix, lithium-ion chemistries – particularly LFP along with lithium nickel cobalt aluminium oxide (NCA) and lithium nickel manganese cobalt oxide (NMC) – continue to dominate, while long-duration energy storage (LDES) technologies, still limited today, are expected to grow gradually (Figure 8).



Figure 8 Stationary storage: past and projected technology mix, by share of total gigawatt hours, 2021–2035



Source: (BloombergNEF, 2025b).

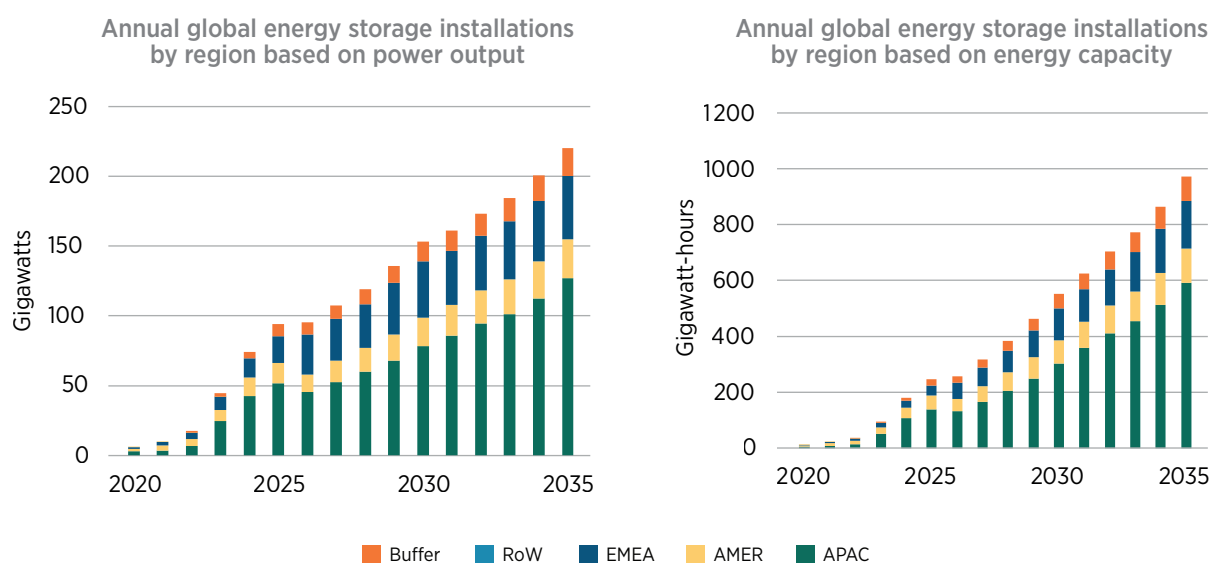
Notes: “Other” refers to the capacity built for “Other” applications in BNEF’s Energy Storage Market Outlook, which includes long-duration energy storage (LDES). Within LDES, various energy storage technologies excluding lithium-ion and sodium-ion batteries will contribute, but BNEF does not specify technologies due to uncertainties regarding commercial scale-up. NCA, NMC and LFP refer to lithium-ion battery chemistries: LFP = lithium iron phosphate; NCA = lithium nickel cobalt aluminium oxide; NMC = lithium nickel manganese cobalt oxide.

Regionally, annual storage is expected to rise sharply, with the Asia-Pacific leading this growth, followed by the Americas and Europe, and the Middle East and Africa (EMEA). By 2035, annual installations could exceed 200 GW of power and nearly 1 000 GWh of energy capacity (Figure 9), underscoring both the scale and global spread of this momentum.





Figure 9 Annual global storage installations, by region



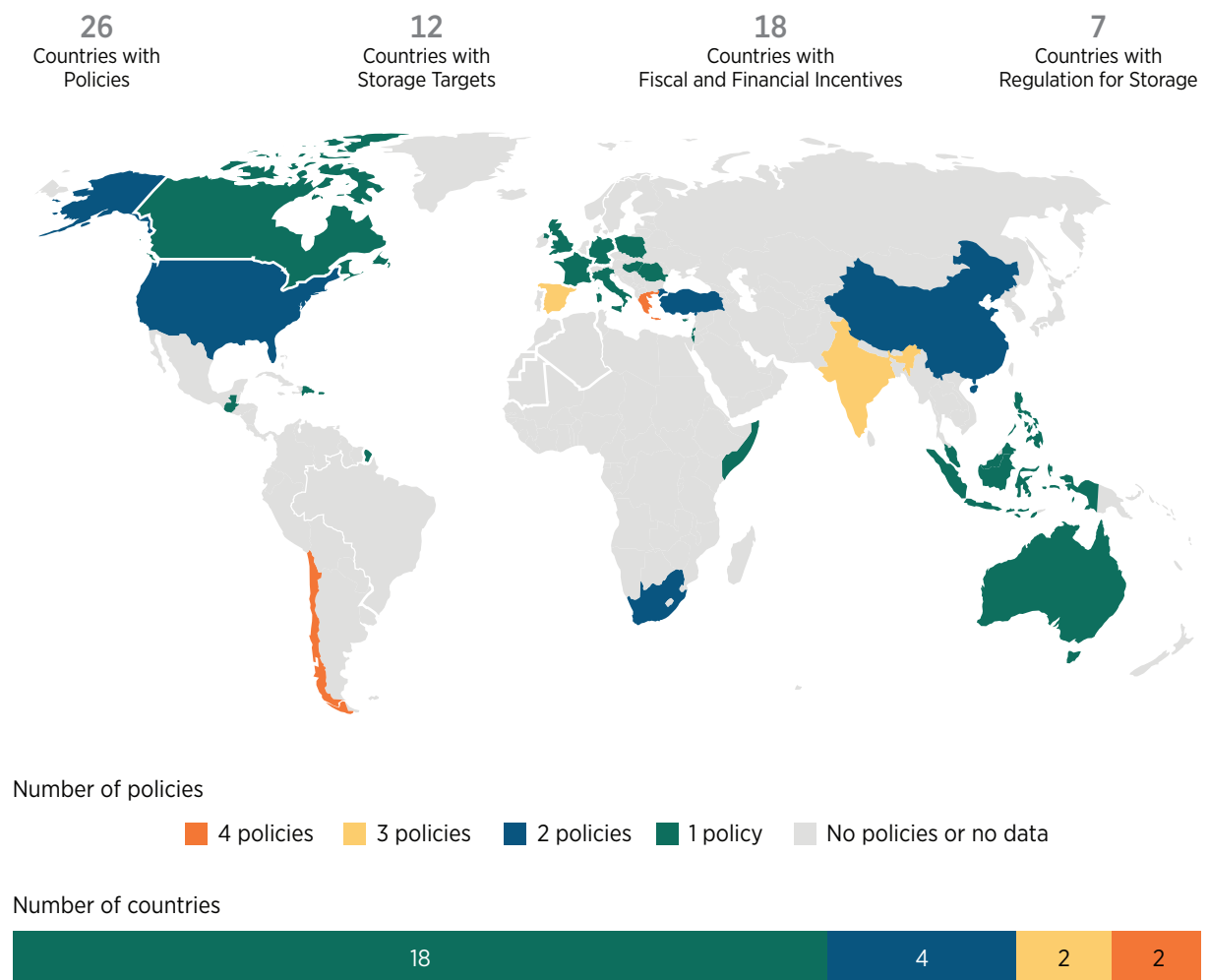
Source: (BloombergNEF, 2025a).

Notes: Buffer is an estimate that is not explicitly allocated to any specific application. AMER = the Americas; APAC = Asia-Pacific; EMEA = Europe, the Middle East and Africa; RoW = rest of world.

2.1 Set policy and regulations to create an enabling environment

Policy and regulatory drivers are critical enablers facilitating the adoption of energy storage solutions, primarily by de-risking investments and providing initial capital, both of which help lower the delivered cost of energy.

Figure 10 Countries with targets, regulations and financial incentives for energy storage, 2024



Source: (REN21, 2025).

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

As of 2024, 26 countries had implemented dedicated energy storage policies, 12 had set storage targets and 18 offered fiscal or financial incentives (see Figure 10). These frameworks play a crucial role in reducing investor uncertainty, enabling early deployment and integrating storage into renewable energy systems.

In the United States, the Residential Clean Energy Credit provides a 30% tax credit for residential storage systems over 3 kWh through 2032 (IRS, 2025a), whereas for commercial properties the Clean Electricity Investment Credit (CEIC) offers a credit of up to 50% of the project cost for battery installations (IRS, 2025b).



In South Africa, the Battery Energy Storage Independent Power Producer Procurement Programme (BESIPPPP) is a competitive tender designed to procure new generation capacity from battery energy storage in line with ministerial determinations issued under the Integrated Resource Plan 2019. The first bidding round sought to procure 0.5 GW in 2023, with an additional 1.2 GW acquired in the second and third rounds in 2024 (World Economic Forum, 2024a). In the recently concluded second round, eight bidders were selected to deliver a total capacity of 615 megawatts (MW) (Energy Storage News, 2024).

In China, Zhejiang Province has pioneered a comprehensive incentive framework for industrial energy storage, featuring discharge, capacity and investment subsidies. Various cities within the province have tailored their support mechanisms – for example, Jiashan offers capacity-based subsidies of RMB 200 /kW, which decrease gradually over three years, while Zhuji provides a one-time subsidy of RMB 200 /kWh. This multi-dimensional policy approach has significantly improved project economics, enabling a 100 MW industrial photovoltaic power plant with a 20% capacity and two-hour energy storage system to achieve a payback period of just 2.95 years. This demonstrates how targeted regional policies can effectively accelerate the deployment of market-based energy storage (World Economic Forum, 2024b).

Recommendations for creating an enabling environment

1. Simplify the regulatory framework for behind-the-meter applications by offering financial incentives to households and small and medium enterprises.
2. Establish policies to facilitate state-of-the-art modernisation and life extension of pumped hydro storage.
3. Implement policies for thermal energy storage that address aggregated heating and cooling needs, such as in industrial clusters or for district heating.
4. Establish policies that encourage circularity and battery recycling.
5. Promote the deployment of diverse long-duration energy storage technologies to strengthen supply chains and unlock investment.
6. Ensure tariff neutrality and consistent rules for storage. Grid-connected storage should not incur double network charges (for both charging and discharging) when it provides system services. Harmonised national rules for connection, metering and tariffs – recognising storage as a distinct asset class – will lower investor risk, shorten lead times and increase participation in local flexibility markets. Clear, technology-neutral frameworks crowd in private capital and accelerate the delivery of COP pledges.
7. Enhance data transparency and interoperability. Greater visibility of grid conditions can stimulate investment in storage and other flexibility solutions. Distribution system operators (DSOs) and transmission system operators (TSOs) should be encouraged to share information such as hosting capacity, congestion forecasts, inter-connection queues and ancillary service volumes in standardised and accessible formats. Providing these data through open, machine-readable platforms, while ensuring privacy and security safeguards, would reduce siting risks for BESS projects, support behind-the-meter adoption, and enable new flexibility services and portfolio optimisation.

2.2 Spur technological development

Energy storage technologies are crucial for enhancing grid stability, integrating renewable energy and ensuring reliable power supply. These technologies vary widely in efficiency and duration, catering to different applications from short-term grid balancing to long-term energy storage. High-efficiency options, such as lithium-ion and zinc bromide batteries, are ideal for short- to mid-duration needs. For longer durations, technologies such as flow batteries, compressed air energy storage, thermal storage and liquefied air energy storage are preferable. Although iron-air batteries are less efficient, they are designed for extended storage periods exceeding 24 hours. Each technology plays a vital role in the varied and evolving landscape of energy storage, addressing specific energy demands and enhancing overall energy security.

Lithium-ion batteries are currently the most suitable option for BESS applications, particularly for storage durations of up to eight hours. This is because of their high technological maturity, modular design, strong performance and cost competitiveness. As costs continue to decline, lithium-ion BESS is becoming increasingly viable for longer-duration storage (over four hours), with eight-hour use cases already being planned, such as in Australia.

While alternative BESS technologies, including redox flow and sodium-sulphur batteries, are being developed for longer-duration storage, they are unlikely to achieve cost parity with lithium-ion systems by 2030. Despite over USD 5 billion in investments as of 2024 aimed at scaling these alternatives (IRENA *et al.*, 2024), lithium-ion batteries continue to hold a clear advantage due to their cost-effectiveness and scalability, solidifying their position as the preferred choice for both short- and medium-duration energy storage.

Looking ahead, innovations in battery technology, particularly in solid-state batteries (SSBs), are expected to gain momentum towards the end of the decade. Significant capacity expansions are anticipated, driven by both new and established players, especially in China, where the announced capacity for this chemistry was projected to grow from 217 GWh in 2022 to 407 GWh by 2024. However, despite these advancements, conventional lithium-ion technology is likely to remain dominant due to its proven scalability and cost advantages. Emerging technologies, such as high-silicon and SSB/lithium-metal batteries, will require critical technological breakthroughs to achieve widespread adoption and cost competitiveness.

SSBs are a key research area for major original equipment manufacturers (OEMs) such as BYD, Contemporary Amperex Technology Co. Limited (CATL) and LG. These companies are seeing rapid maturation of SSB technologies for both prismatic and pouch form factors, making them applicable for a wide range of applications, standards and modularisation approaches. Figure 11 illustrates Iberdrola's Torrejón-Valdecañas complex in Spain, which includes hybrid battery storage as part of its integrated renewable energy system while Figure 12 shows CATL's Desert Peak energy storage project in the United States, exemplifying large-scale deployment of advanced storage solutions supporting renewable integration.

Solid-state lithium batteries have been described as the next generation of battery technology, offering safer operations, significantly higher energy density and faster charging times (Joshi *et al.*, 2025).



Figure 11 Iberdrola's Torrejón-Valdecañas complex (including hybrid battery storage), Spain



Source: Original image provided by Iberdrola.

Figure 12 CATL's Desert Peak energy storage project, United States



Source: Original image provided by CATL.



Circularity

Energy storage technology, especially battery energy storage, has seen significant advancements over the past decades, propelled by the rise of EVs. However, the use of numerous rare earth materials in batteries has intensified the focus on circularity and sustainability.

Battery recycling is rapidly emerging as a multi-billion-dollar industry, attracting new global players. The volume of end-of-life lithium-ion batteries is projected to grow by an average of 25% annually, potentially reaching about 20 500 kilotons by 2040, driven primarily by the rapid adoption of EVs and production scrap. While global business opportunities within the lithium-ion battery value chain are expected to reach USD 302 billion by 2030, recycling and re-use are estimated to account for around 4% of this market, underscoring the growing economic potential of EV battery recycling (UNDP, 2025).

Up to 2030, Europe and North America are projected to spearhead the expansion of recycling capacity, with over 70 and 40 announced projects, respectively. These developments position both regions as vital contributors to the expansion of the global battery recycling ecosystem, although challenges persist due to inadequate development of the value chain (e.g. for cathode material production).

Achieving circularity in battery production and recycling offers a transformative opportunity to align economic and environmental goals. With a projected revenue pool exceeding USD 100 billion by 2040, the financial gains from recycling can be re-invested to accelerate the deployment of 1 500 GW of energy storage globally by 2030 and support net-zero ambitions by 2050. Circularity reduces reliance on virgin raw materials, mitigates supply chain risks and lowers production costs, making energy storage more affordable and scalable. Moreover, the environmental benefits, including substantial reductions in carbon dioxide (CO₂) emissions and resource extraction, establish circularity as a pivotal driver of a sustainable energy future, with several regions already making significant strides in this area.

Scania is sourcing modular battery packs for its main trucking business, with a strong focus on circularity in the design. Scania will continuously assess the individual state of health of each battery module, aiming to refurbish or repurpose those modules that are no longer compliant with e-mobility purposes. Thanks to their modular design, the repurposed batteries can be containerised and used for grid stabilisation. These solutions are developed and sold by Scania Energy Systems. In addition, Scania is using VW battery packs for similar applications, facilitating a circular battery infrastructure that utilises EV batteries in second-life applications for grid stabilisation and ancillary services, among other applications.

As the world's largest producer of renewable energy equipment, China has prioritised circularity as a strategic response to the challenge of renewable waste. Chinese manufacturers are pioneering innovations in material circularity. For instance, CATL has established a global recycling network with over 60 partners across 26 countries and regions, capable of processing 270 000 tonnes of battery waste annually with a recovery rate of 99.6% for nickel, cobalt and manganese metals and 93.8% for lithium. Through its subsidiary, Brunp Recycling, CATL has deployed over 240 recycling sites in China, recovering 128 700 tonnes of waste from batteries and regenerating 17 100 tonnes of lithium salts in 2024 (CATL, 2025). Similarly, Trina Solar has produced the world's first fully recycled photovoltaic module, achieving a conversion efficiency of 20.7% while enabling 100% recycling of materials including silicon wafers, silver powder, glass and aluminium frames



(Trina Solar, 2024). Leading companies like Jinko Solar have incorporated circular practices throughout the entire product life cycle, from research and development to end-of-life management. They have achieved a 99% material recovery rate for selected components through advanced recycling methods and “design for circularity” approaches, which optimise material usage and extend product lifespans (Jinko Solar, 2023).

Digitalisation

A rise in data-driven and predictive maintenance is generating significant value in storage efficiency. The adoption of International Organization for Standardization and International Electrotechnical Commission standards to define a common classification for failure modes has demonstrated benefits in maintenance of a leading European utility company’s hydro assets. This approach allows for the optimisation of maintenance and inspection plans, enabling predictive alerts across fleets, technologies and countries in a future-proofed industry-wide framework.

A leading utilities company in Japan is employing automation to enhance operations at its hydropower sites. This includes using image analytics to automatically detect snow jams and debris at intake gates, preventing damage and long-term operational shutdowns. Additionally, drones equipped with automated video recognition are utilised to inspect penstocks, which reduces inspection times and improves safety.

Beyond these operational improvements, digitalisation is a critical enabler for scaling storage deployment in line with the COP29 pledge. Predictive maintenance extends asset lifespans and reduces downtime, while automation and digital twins improve manufacturing throughput and reduce defect rates. These advancements directly lower system costs and accelerate deployment, making it more feasible to achieve the 1 500 GW storage target by 2030.

The transformative impact of digitalisation and advanced equipment on operational efficiency, quality and sustainability is exemplified by CATL’s Lighthouse factories in Ningde, Yibin and Liyang. These facilities have achieved significant milestones, including a 320% capacity increase at Liyang, a 33% reduction in manufacturing costs, a 75% boost in labour productivity and a 99% drop in quality defects, with defect rates now at parts-per-billion levels. Sustainability improvements include a 50% reduction in greenhouse gas emissions and a 10% decrease in energy consumption.

Key enablers of these advancements include artificial intelligence (AI) and big data for real-time process optimisation, robotics for precision and scalability, digital twins and virtual simulations for predictive insights, and Internet of Things sensors for dynamic energy management.

Collectively, these digital tools unlock unprecedented efficiency, reduce costs, enhance quality and enable sustainable operations – demonstrating the transformative power of intelligent, data-driven manufacturing in shaping the future of industrial performance.

2.3 Address investment needs

Annual investments in BESSs have expanded rapidly, exceeding USD 5 billion in 2022 – a three-fold rise from the previous year (McKinsey, 2023). In 2024, investment in battery storage rose by 33% compared to the year before, reaching a record high of USD 54 billion (IRENA *et al.*, 2025).

These figures underscore the sector's rapid momentum, with the global BESS market projected to nearly triple and reach USD 120-150 billion by 2030 (McKinsey, 2023; Statista, 2025).

Among all the deals, private equity has emerged as the dominant funding source, accounting for 65-75% of total investments since 2021, signalling a moderate risk appetite. Venture capital is a key contributor, focusing on emerging lithium-ion technologies (such as silicon anodes) to drive innovation in the sector.

In India, a 2020 analysis by the Council on Energy, Environment and Water's Centre for Energy Finance estimated that up to USD 136 billion will be required by 2030 to develop energy storage solutions. This demand is driven by the expansion of renewable energy and the increasing adoption of EVs alongside their supporting infrastructure. Proposed interventions to de-risk investments include drawing inspiration from existing mechanisms in India, such as the Partial Risk Guarantee Fund for Energy Efficiency (World Economic Forum, 2022a).

Brazil is the world's second-largest producer of hydropower in terms of installed capacity, and the largest in South America, with a total capacity of 110 GW of which 30 MW is pumped storage. It is estimated that modernising hydropower in Brazil could deliver an additional 4.7 GW of capacity (EPE, 2019) and reduce CO₂ emissions by 57 million tonnes (Mt) by replacing natural-gas-fired thermal power plants. Furthermore, out of the USD 62 billion in cumulative investments across energy sources, about one-third is towards hydro, as per projections by the Inter-American Development Bank. One of the strategic guidelines of Brazil's National Energy Plan is the modernisation of existing hydroelectric plants (World Economic Forum, 2022b).

Similarly, in Europe, Statkraft – Europe's largest renewable energy producer – is investing EUR 1.8-3 billion to upgrade and transform Norwegian hydroelectric plants, and an additional EUR 1.2-2 billion to rehabilitate dams and modernise older power plants (Statkraft, 2024). Norwegian hydropower, which relies on reservoir systems, contributes significant flexibility to both the Nordic and continental power systems, playing a crucial role in providing balancing services for the large volumes of wind energy produced.

2.4 Tighten supply chain security

According to the Utilities for Net Zero Alliance (UNEZA) statement on building a resilient and diverse clean energy technology supply chain (UNEZA, 2024), demand for technologies is increasing significantly. However, building resilient and diverse supply chains presents several challenges such as: (1) ensuring the availability of critical minerals and materials, (2) scaling up manufacturing capacity and (3) developing a skilled workforce. Each of these challenges also presents opportunities for new investment, the creation of new value chains and the development of new skilled jobs (UNEZA, 2024).



Box 2 UNEZA supply chain recommendations for policy makers: Storage

As the world transitions towards power systems, and increasingly entire energy systems, dominated by variable renewable energy sources such as solar photovoltaic and wind, the demand for flexible technologies will become increasingly important. Storage solutions are therefore essential for managing high penetration levels of renewables. Short-duration energy storage helps balance supply and demand in the power system and mitigates the risk of blackouts, while long-duration energy storage (LDES) can discharge energy continuously as electricity or heat for eight hours or more.

As wind, solar and other renewable energy sources become the most cost-effective forms of generation, the demand for LDES systems is rising to address supply and demand imbalances. Analysis by the Long Duration Energy Storage Council indicates that up to 8 TW of LDES may be required by 2040 to achieve net-zero emissions along the most cost-effective pathway, potentially saving up to USD 540 billion annually in system costs.

Equally, in a world with increased renewable generation, energy storage technologies can play an important role in maximising the amount of variable renewable energy that can be harnessed and put to productive use, thereby minimising wasted energy and balancing costs effectively.

Storage technologies come in four main “families”: electrochemical, mechanical, thermal and chemical.

Electrochemical storage encompasses a wide range of batteries. Currently, battery energy storage systems are the most prevalent and rapidly expanding energy storage solution globally, largely due to their ability to be constructed in a matter of months and in most locations. Beyond lithium-ion, technologies such as flow batteries often require very common minerals (e.g. zinc, iron), which have limited supply chain concerns. The components (pumps, tanks, acids) are readily available and easily sourced. While the supply chains for some emerging technologies are still being developed and not yet fully defined, they tend to be similar to flow batteries in that most are based on abundant materials and simpler components. Although recycling facilities for iron, vanadium or zinc-based batteries are yet to be deployed, it is expected that metals could be recovered from these batteries through either pyrometallurgical or hydrometallurgical systems.

Mechanical energy storage operates in systems that use heat, water or air with alongside compressors, turbines and other machinery. Currently, the most widely deployed large-scale mechanical energy storage technology is pumped storage hydropower. Other notable mechanical energy storage technologies include flywheels, gravity-based systems, compressed air energy storage and liquid air energy storage. These technologies do not typically face supply chain constraints, as they rely on readily accessible “fuel” (such as water and air) and commonly available components.

Thermal energy storage converts electric energy from the grid into thermal energy, which is then stored in inexpensive materials for later use as heat, cold or reversion back into electricity. The materials used are typically very common and easily obtainable (including cement, sand and rocks).

Chemical energy storage involves storing energy in the form of chemical bonds. Hydrogen supply chains are being developed globally, with water serving as the basic raw material for “green” hydrogen, produced through electrolysis.





The following are recommendations for policy makers to address storage supply chain challenges:

Regulators and planners should collaborate with industry to maximise alignment between the development of renewable capacity and energy storage, including timing and location. Such collaboration, alongside a mandate to deliver clean energy, can help reduce market inefficiencies and supply chain distortions. Further, to enhance profitability, it is essential to develop the market for time-shifting products and implement forward contracts for dispatch services.

Cross-sectoral investment and harmonised power systems are essential. Investment in storage, to boost power system flexibility and resilience, becomes increasingly urgent as the deployment of renewables accelerates and the importance of flexible energy increases. Policy makers should set ambitious targets for the deployment of storage technologies, introducing mechanisms that provide long-term revenue visibility and remove barriers that artificially constrain deployment. By sending these signals to the market, investment in both existing and developing supply chains will be encouraged. For example, policy makers should ensure that green hydrogen storage is brought forward as part of an integrated hydrogen system strategy to meet the needs of both hydrogen producers and users.

Diversification of storage technologies. Diversifying across the four main storage technology “families” – thermal, electrochemical, mechanical and chemical – offers a way to mitigate supply chain risks. Many of these storage technologies rely on widely available raw materials and components, including minerals such as iron and zinc, mediums such as cement and sand, and components such as pumps and tanks. This availability helps to address geopolitical constraints and broader environmental, social and governance challenges. By enabling the deployment of a breadth of technologies, policy makers can leverage this variety to minimise the risk of constraints affecting any single type.

Skills development. It is important to unlock investment in skills and capacity development by sending clear demand signals. To fully reap the benefits of diverse storage technologies, supply chains must be developed at scale with investments in both people and technology.

Provide long-term revenue visibility. The investment case for storage is often linked to price arbitrage. The presence of storage within the system should help to smooth out prices by responding to fluctuations in supply and demand. However, this can create a barrier to investment in long-term storage assets, as the spread between supply and demand narrows, ultimately impacting the growth of the storage sector. Policy makers must play an essential role in providing revenue visibility and certainty, which will support the creation of sustainable supply chains.

Strengthening recycling. Although storage technologies generally face minimal supply chain constraints due to widespread availability of raw materials and components as well as their long lifespans, policy makers can further strengthen resilience by incentivising the development and scaling of recycling facilities. Valuable insights can be gained from converting existing chemical storage to low-carbon alternatives, thereby building supply chain experience and knowledge. For example, transitioning from natural gas geological storage to hydrogen geological storage can serve as a model for this process.

Source: (UNEZA, 2024).



Battery storage is critical to the global energy transition, with demand surging as countries pursue net-zero goals. Today, China dominates the supply chain, leading in battery production and raw material processing, while regions like North America and Europe strive to localise their operations. However, the sector faces significant risks from geopolitical tensions, export controls, tariff changes and regional conflicts. Addressing these vulnerabilities is crucial for ensuring the resilience and sustainable growth of the energy storage industry, and global efforts are underway to mitigate these challenges.

China leads the world in supplying key components for battery energy storage, making the security of battery supply chains a critical issue in the context of energy security. In contrast, there are notable examples of international collaboration in other energy storage technologies.

The Andalusian Green Hydrogen Valley in southern Spain aims to connect with Northern Europe through a maritime corridor, thereby supporting the continent's clean energy future. Led by Moeve, the valley is set to have an electrolysis capacity of 2 GW, producing 300 000 tonnes of green hydrogen annually by 2030. It will also include green ammonia and methanol plants with significant production capacities, which can reduce CO₂ emissions by 7 Mt per year.

Moeve has partnered with the Port of Rotterdam to develop a maritime corridor from Algeciras, combining Spain's strengths in renewable energy with Rotterdam's strategic position as a major logistics hub. This corridor will facilitate the supply of around 4.6 Mt of green hydrogen to Northwest Europe by 2030. Moeve is also collaborating with Yara Clean Ammonia to transport green hydrogen using ammonia as a carrier. Ammonia can be used as a clean fuel or be converted back into hydrogen for industrial purposes. Inland distribution will be supported by Gasunie's Delta Corridor project, which links Rotterdam with key industrial clusters in Germany, Belgium and the Netherlands. This collaboration shows how international partnerships can connect regions rich in renewable energy with energy-intensive industrial areas, thereby supporting Europe's transition to a cleaner energy system.

Beyond collaboration, countries and regions are making significant investments to incentivise the localisation of battery production through various programmes:

- **United States.** The Inflation Reduction Act incentivises EV buyers with subsidies tied to the domestic sourcing of battery materials and manufacturing, or materials sourced from free-trade agreement partners. This has led to announcements of gigafactories, including 52 GWh from Tesla and 16 GWh from LG Energy Solution for BESS production. However, under the One Big Beautiful Bill Act, these incentives are being phased out, with EV tax credits set to expire on 30 September 2025, creating uncertainty for future investments (IRS, 2025c; Whitecase, 2025).
- **European Union.** The Green Deal Industrial Plan (GDIP) aims to enhance competitiveness by simplifying regulations, improving financing and developing skills. In this context, the Net-Zero Industry Act (NZIA) operationalises these objectives by identifying strategic technologies, including storage, and offering measures such as fast-track permitting to accelerate deployment (European Commission, 2024).
- **India.** The Product Linked Incentive scheme subsidises up to 50 GWh of cell production, emphasising domestic value creation and technical performance. Complementing this, India has announced plans to develop 124 GW of energy storage by 2031-2032 (comprising 74 GW BESS and 50 GW pumped hydro). This initiative is supported by policy incentives such as



viability gap funding, transmission charge waivers until 2028, and declining battery costs to ensure grid reliability and the integration of clean power (Energy Storage news, 2025; Eqmagpro, 2025).

- **China** offers indirect support through subsidised land, preferential loans, streamlined permitting, and research and development incentives.

2.5 Best practices

Energy storage for flexible services

In March 2025, on two separate occasions, four Volvo EVs equipped with bi-directional charging technology supplied a total of 111 kWh of power to Göteborg Energi Elnät's local flexibility market, Effekthandel Väst, through the NODES platform (Nodesmarket, 2025). Box 3 considers a battery storage portfolio, also in Sweden.

Box 3. Case study: Fast-track battery storage portfolio relieving grid bottlenecks in southern Sweden

Context. Southern Sweden (SE3/SE4) has faced increasing congestion and volatility due to the rising penetration of renewables and electrification. Although Sweden is an annual net exporter, transmission constraints and local imbalances have led to widening price spreads and lengthy connection queues.

Intervention. In 2024, Ingrid Capacity deployed a portfolio of 14 grid-scale battery energy storage sites totalling 211 megawatt (MWh), all commissioned in under a year. These assets participate in frequency services and local congestion management and are operated via Ingrid's proprietary optimisation platform, which includes automated forecasting, portfolio dispatch and market participation.

Outcomes:

- System services at speed. Rapidly deployable storage provided flexible capacity where it was most needed, enhancing frequency containment and local grid stability.
- Efficient renewable integration. The portfolio enables time shifting and congestion relief, allowing the system to better accommodate variable wind and solar generation while minimising curtailment risks.
- Scalable delivery model. A standardised, multi-site roll-out lowered unit costs and shortened time to market, creating a replicable template for other regions.

Lessons for other markets:

1. **Speed matters.** Modular battery energy storage systems can be deployed within months, complementing longer timelines required for grid reinforcements.
2. **Market access and data.** Clear access to ancillary markets and transparent grid data can accelerate investment and site selection.
3. **Digital operations.** Portfolio-level forecasting and dispatch are critical for monetising multiple value streams while supporting system needs.

Transferability. This approach is applicable to regions experiencing an increase in renewable energy sources and connection backlogs. It involves fast-tracking battery energy storage systems near substations and load pockets, standardising site design and enabling multi-service market access to maximise system value per euro invested.

Source: (Ingrid Capacity, n.d.).



Promoting system value through equity, education and job creation

TP Renewable Microgrid, a wholly owned subsidiary of Tata Power, adopts a shared value creation approach to community engagement. This model fosters an ecosystem that enables local communities to leverage the benefits of micro-grids for broader socio-economic development, thereby strengthening India's efforts to deliver reliable and clean energy to rural areas still dependent on fossil fuels. Through this programme, company representatives collaborate with social influencers, government entities, local communities, village-level entrepreneurs, farmers and civil society organisations to identify local needs. Solutions are then developed together with technology innovators, skill development partners, philanthropic organisations, financial institutions and other stakeholders. This collaborative approach allows TP Renewable Microgrid to achieve mutual benefits – delivering economic, environmental and social gains to communities while ensuring that projects are efficiently installed, commissioned, operated and maintained. To date, the company has deployed renewable microgrids in 200 villages across northwest India, serving approximately 21 000 consumers, saving over 3 million litres of diesel, reducing more than 8 000 tonnes of CO₂ annually and positively impacting nearly 300 000 lives (World Economic Forum, 2023).

Promoting social awareness

Accenture conducted a survey of over 2 000 consumers and more than 70 suppliers across 12 jurisdictions in Europe to understand the drivers and barriers that affect consumer engagement in the energy transition. The aim was to support energy suppliers in better understanding, serving and activating their customers. Accenture and Eurelectric also conducted roundtables across four regions with players from the wider energy ecosystem (over 60 participants including grid operators, regulators, housing and consumer associations and manufacturers) to brainstorm solutions for enhancing consumer engagement. Key findings from the Eurelectric consumer survey (Eurelectric, 2025) suggest that while there is high awareness (80%) of the need to reduce emissions, there is low adoption of electrification technologies (about 23%). Specifically, battery storage adoption lags (at 9%) despite higher uptake of solar panels (18% adoption). Only 39% of consumers are aware of their suppliers' offerings – pointing to a significant knowledge gap and a clear opportunity to raise awareness about the benefit of energy storage. The top barriers to adopting energy storage solutions include cost (24% believe it is too expensive), compatibility issues with their existing installations (17%) and a lack of interest (10%).

Key recommendations on ways to better inform and empower consumers include:

- **Implement targeted communications to empower consumers.**
- **Engage and include all consumers.** Raise awareness of long-term financial and energy savings, while assisting the most vulnerable or constrained consumers.
- **Explain energy efficiency measures.** Offer clear guidance on the benefits of energy efficiency and the behavioural changes that result in savings.
- **Innovate products and services.** Leverage innovation and digital technologies to create simpler, more automated solutions that promote electrification and give consumers greater control over their electricity use.
- **Promote demand flexibility.** Facilitate behavioural shifts towards more flexible electricity consumption.

3. Progress on grids

The expansion of power grids and a surge in related investments are being driven by the global energy transition, which is underpinned by electrification and the adoption of clean power technologies. Under IRENA's 1.5°C Scenario, the share of electricity in total final energy consumption is projected to increase from 23% in 2023 to 52% by 2050 (IRENA, 2024a). During this period, global electricity demand is expected to triple, establishing electricity as the foundation for new industrial, transport and service sectors. This surge will be driven not only by transport, heating, cooling and industry, but also by rapidly emerging sources of demand such as data centres, AI applications, cryptocurrency mining and electrolyzers. Consequently, significant upgrades and expansions of grid infrastructure will be required to support this transformation (Oxford Institute for Energy Studies, 2025).

A critical component of this transition is the decarbonisation of the power sector, with over 60% of companies committing to net-zero or interim targets (ISS insights, 2025). Renewable energy is anticipated to dominate the global energy landscape, accounting for 90-91% of total electricity generation by 2050 under the 1.5°C Scenario (IRENA, 2024a). Achieving this shift will require annual investments of about USD 1.44 trillion in renewable power between 2025 and 2030 – more than double the 2024 levels – to close the financing gap and meet global tripling goals, particularly in emerging markets and developing economies (IRENA *et al.*, 2025).

As mentioned in the previous chapter, during COP29, countries committed to a collective goal of adding or refurbishing 25 million km of grid infrastructure by 2030. This commitment is based on IEA analysis, which indicates the need to add or refurbish an additional 65 million km by 2040 to align with net-zero emissions by 2050. Achieving this goal will require that investments in transmission and distribution (T&D) reach USD 700 billion by 2030 (IEA, 2024b).

3.1. Investing in grids

Numerous countries and companies world-wide have made substantial progress towards the T&D investment goal, and recognise the critical need for ongoing investment. Long-term planning, stable regulation and stronger public-private collaboration are needed to accelerate delivery and ensure efficient project execution (UNEZA, 2025).

Global investment in grid infrastructure has continued to grow steadily in recent years. According to the IRENA report, *Delivering on the UAE Consensus: Tracking progress toward tripling renewable energy capacity and doubling energy efficiency by 2030*, global grid investment rose from around USD 289 billion in 2020 to USD 329 billion in 2023, reaching USD 361 billion in 2024 (IRENA *et al.*, 2025; IRENA and CPI, forthcoming). Looking ahead, IEA's *World Energy Investment 2025* projects this figure to exceed USD 400 billion in 2025 (IEA, 2025). These figures confirm the rising momentum towards grid modernisation and expansion world-wide, as illustrated in Figures 13 and 14.

While private capital continues to drive a substantial share of global grid investment, financing from multilateral development banks (MDBs) provides a valuable benchmark for understanding recent trends in public and development finance. MDBs have increasingly contributed to



investments in grid and storage. As shown in Figure 13, MDBs committed over USD 7 billion annually on average between 2015 and 2024, representing about 25% of their total energy financing outside Europe. Around 18% of this funding directly supports project designs related to enabling renewable energy. Africa ranks as the second-highest region, accounting for 21-24% of total MDB grid spending, underscoring the role of MDBs in addressing regional equity gaps where private investment is limited. While spending has fluctuated over time, the 2024 increase suggests renewed momentum that could be further accelerated with supportive policy and regulatory frameworks (Energy Finance, 2025).

Figure 13 MDB grid and storage finance (USD billions)



Source: (Energy Finance, 2025).

Notes: The figure does not include projects from Central and Western Europe. The “all other grid projects” category has yet to be analysed in detail to determine whether projects could be further classified. RE = renewable energy.

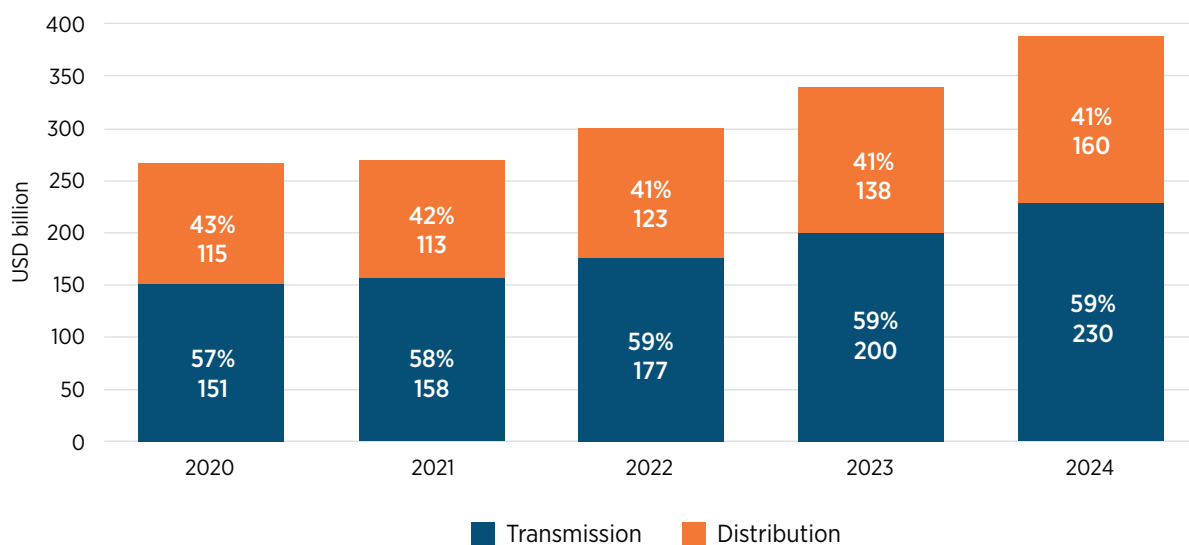
For example, the energy transition in the EU-27 and Norway will require a significant increase in grid investments. Annual distribution investments, which averaged EUR 33 billion from 2019 to 2023, are projected to rise by 80%, reaching EUR 58 billion for the period 2024-2030. Similarly, transmission investments are expected to double, increasing from EUR 15 billion to EUR 29 billion annually during the same time frame (Eurelectric, 2024a).

This surge is driven by the urgent need for timely asset upgrades to support electrification, modernise the grid for improved control and quality and integrate distributed flexibility resources. An evolving generation landscape, increased inter-connections and a growing number of connection requests from renewable energy sources underscore the urgency of expanded and modernised grid infrastructure.

In Europe, there is a strong investor appetite for grid development, yet bottlenecks such as permitting delays and regulatory uncertainty are hindering progress. The European Commission estimates that by 2040, EUR 477 billion will be required for transmission and EUR 730 billion for distribution. In the Netherlands alone more than 15 000 companies are awaiting connections. Targeted reforms and tools such as dynamic line rating, which can increase capacity by up to 30%, are crucial to bridging this gap (Reuters, 2025a).

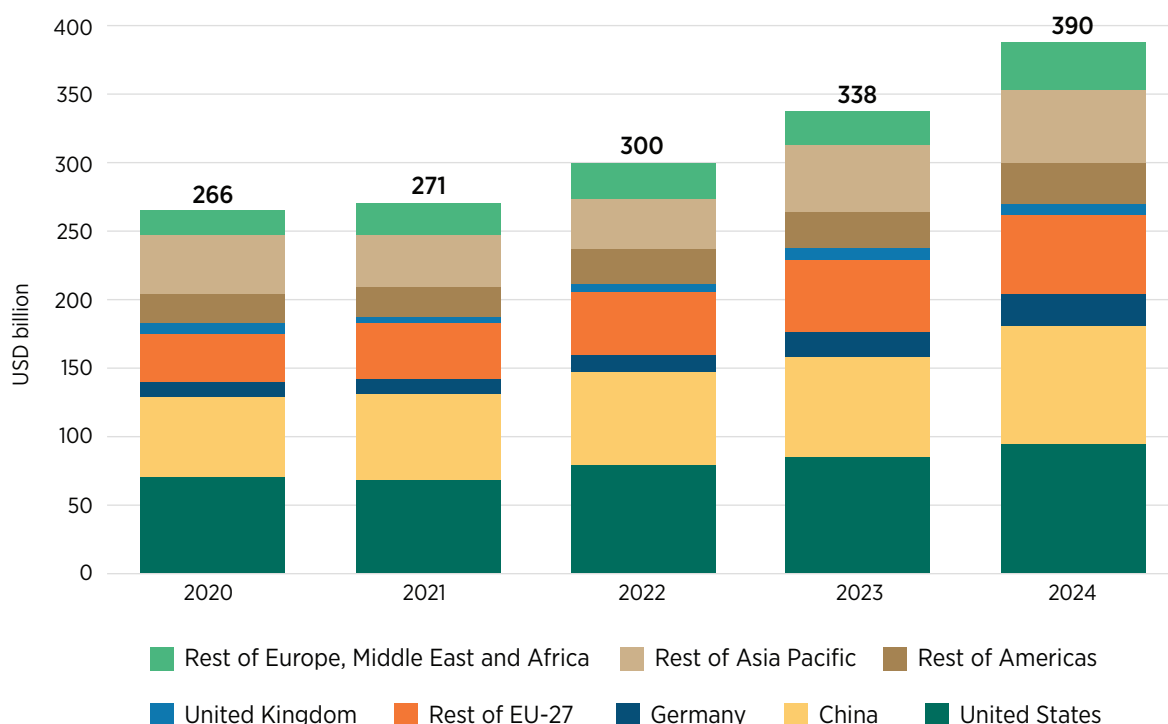
Modernisation as well as expansion of grid infrastructure require substantial investments and careful planning. Certain countries are leading the way with record levels of targeted grid investment. Germany leads Bloomberg New Energy Finance’s Global Grids Index, as it has committed to investing USD 140 billion by 2035 through the 2021 Network Expansion Plan. Italy’s USD 12 billion “hypergrid” scheme aims to double the volume of electricity that can be transported from its generation-heavy southern regions to its demand-heavy northern regions by installing five new electricity backbones. In the United Kingdom, electricity networks are investing around USD 40 billion during the current price control period and undertaking the largest programme of reforms in the history of the grid. Meanwhile, in Asia, China continues to invest unprecedented amounts in its grid infrastructure, with an expected USD 89 billion in 2025.

Figure 14 Global grid investment, by category, 2020–2024



Source: (BloombergNEF, 2024b).

Note: Transmission and distribution definition changes by market.

**Figure 15** Global grid investment, by market/region, 2020–2024

Source: (BloombergNEF, 2024b).

Figures 14 and 15 highlight the steady rise in global grid investments, which reach nearly USD 390 billion in 2024, with distribution systems accounting for the major share. This trend reflects a growing focus on local grid reinforcement and the integration of distributed renewable energy sources. Regionally, China, the United States and Europe are leading in investments, while emerging markets are gaining traction. These developments underscore the global urgency of expanding and modernising grids to facilitate electrification, integration of renewables and cross-border connectivity.

Recently, Spain approved a EUR 13.6 billion grid plan for 2025-2030, raising its investment ceiling to accommodate record levels of solar, wind and storage projects awaiting connection. Concurrently, Microsoft has committed USD 7.7 billion towards new data centres in Wisconsin, which are linked to renewable energy supply and grid upgrades. This underscores the convergence of public and private commitments to accelerate expansion (Reuters, 2025b).

Examples of electricity grid operators include the following:

In the United Kingdom, UK Power Networks has secured nearly GBP 25 million from the Office of Gas and Electricity Markets' (Ofgem's) Strategic Innovation Fund for trial projects such as integrating solar panels with battery storage and developing community heat networks to support grid operations (Greenenergy news, 2024). SSEN Transmission (Scottish and Southern Electricity Networks) is implementing an ambitious programme of critical upgrades in the north of Scotland to help underpin the UK government's goal of achieving clean power by 2030 (Figure 17). This programme is being facilitated by the innovative Accelerated Strategic Transmission Investment (ASTI) framework adopted by Ofgem (SSEN Transmission, 2022).



In the Kingdom of the Netherlands, Tennet proposed EUR 35 billion in additional investments for the period 2024-2031 in a draft investment plan published on 1 January 2024. The planned investments include EUR 23 billion for on-shore (up from EUR 11 billion) and EUR 35 billion for off-shore projects (up from EUR 12 billion). By the end of the ten-year period, Tennet anticipates combined annual spending of EUR 6.5 billion per year, an increase from EUR 1.5 billion today.

Red Eléctrica (Redeia) has proposed an annual investment of over EUR 1 billion (or over EUR 1.8 billion including inter-connections), up from EUR 500 million over the past ten years (Redeia, 2025). To facilitate this increase, the Spanish government has temporarily suspended a law that limited grid investments to a share of gross domestic product (0.065% T&D). Redeia is currently drafting the new plan for 2025-2030.

In Germany, E.ON announced an increased investment plan of EUR 43 billion for the energy transition between 2024 to 2028, with the plan published on 26 February 2025. The planned investments include EUR 35 billion towards network infrastructure (an increase from EUR 34 billion) and EUR 8.6 billion in investments for 2025 (an increase from EUR 7.5 billion) (E.ON, 2025).

Grid infrastructure components

While investment levels are rising across Europe, the supply of critical grid infrastructure components continues to face moderate to high risk of shortages, varying by region. The main components in short supply include high-voltage transformers, cables and conductors, and smart grid components.

These shortages arise primarily because grid upgrades are lagging the rapid pace of renewable energy installations. Supply chains for these components are complex and regionally constrained, creating further bottlenecks in deployment and system integration.

Box 4 Global Grids Catalyst (GGC)

Global Grids Catalyst (GGC) is a new philanthropic collaborative established to modernise grids world-wide, especially in emerging markets and developing countries. GGC aims to drive technical assistance, capacity building, awareness and innovation to address the most pressing challenges facing power grids globally.

Established in 2025, GGC will unite think tanks, grid operators, universities, non-governmental organisations, international organisations, industry leaders, government bodies and philanthropic entities to accelerate the deployment and upgrading of smarter, more resilient and cleaner grids. An initial USD 50 million has been raised, with a goal of securing USD 200 million per year. These funds will be allocated as grants to cover or defray costs associated with planning, research, consulting and negotiating grid investments and policies. As such, they can also complement sources of concessional finance (e.g. loans from international financial institutions).

Source: (Pooled fund for International Energy, 2025).



Recommendations for attracting investment

Regulators can facilitate the required investment levels by attracting funds to grid operators while ensuring electricity remains affordable for consumers through the following actions (World Economic Forum, 2024c):

- **Streamlining permitting procedures.** Currently, permitting timelines in Europe for transmission grids can take up to ten years (World Economic Forum, 2024d). By prioritising the streamlining of these procedures, regulators can ensure timely utilisation of capital and quicker returns, thereby encouraging investment.
- **Assuring revenue.** Establishing adequate regulated rates of return for the long-term investment period for grids will provide certainty for investors. Aligning this approach across countries will further enhance confidence in the investment market.
- **Anticipatory investment.** Encouraging anticipatory investments by acknowledging that assets may sometimes be underutilised or stranded, will support medium- and long-term network needs. A forward-looking regulatory framework can enhance grid investment efficiency by up to 10% (World Economic Forum, 2024c).
- **Flexible price control periods.** Adjusting the duration of price control periods – which, as Ofgem defines, are regulatory mechanisms designed to ensure that energy network companies treat customers fairly, invest in improving their services and support the transition to low-carbon energy – can help accommodate evolving energy and supply chain conditions and influence required investments. For example, the United Kingdom has implemented a RIIO (Revenue = incentives + innovation + outputs) price control framework that provides a long-term multi-year rate plan to create the stability needed for large capital projects, while allowing for mid-period adjustments in response to current conditions (Ofgem, n.d.).
- **Public funding.** Increasing public funding involvement to reduce risks for private debt financing and boost private sector participation is crucial for generating the investment levels required for future energy system developments.

3.2 Modernising and expanding grid infrastructure

The rising volume of renewable and low-carbon electricity projects seeking to connect to the grid calls for grid systems that are modern, flexible and scalable.

Box 5 Case study: Iberdrola's 1 700 km transmission expansion in Brazil

A new power grid in Brazil, scheduled to become operational in November 2025, will feature four high-voltage transmission lines – three operating at 500 kV and one at 440 kV—alongside the new 500 kV “Nova Ponte 3” substation.

Through its Brazilian subsidiary Neoenergia, Iberdrola secured the concession in a 2022 auction to construct 1 707 km of transmission lines connecting northwest Minas Gerais with São Paulo (figure 16). To date this project represents Iberdrola's largest grid development world-wide, reinforcing the company's growth in electricity distribution and transmission while affirming its long-term commitment to Brazil.

Source: (Iberdrola, 2025a).

Figure 16 São Paulo–Minas Gerais transmission line



Source: (Iberdrola, 2025).

Figure 17 SSEN transmission – overhead lines of SSEN’s “Pathway to 2030” project



Source: Original image provided by SSEN Transmission.



Co-ordinated planning

Co-ordinated and timely planning is essential for managing investment and grid capacity constraints. Grid constraints can be addressed through policy reform and the use of digital technologies to support planning.

1. **NESO Connections Reform in the United Kingdom.** The National Energy System Operator (NESO), working alongside distribution network operators, transmission operators and the regulator, has introduced the Connections Reform, which “introduces significant changes to the codes and methodologies that govern how projects enter and progress through the connections process” (NESO, 2025). The reform assigns a status to projects applying for connection, prioritising readiness and alignment with strategic long-term net-zero goals. This initiative aims to address a connections queue of over 770 GW, almost four times the volume required to meet the current 2030 net-zero targets.
2. **Urbio’s AI-powered platform** (Eurelectric, 2024b) manages large-scale building decarbonisation projects across Europe, including district heating. The platform utilises machine learning, a digital twin and AI-powered generative design to simulate various scenarios. Urbio’s AI-powered Software as a Service platform, enhanced by RaYSun’s expertise, effectively identifies profitable projects and their impacts on the grid. It minimises capital expenditure and operational expenditure for DSOs/TSOs by streamlining decarbonisation projects, offering scalable infrastructure improvements and operational efficiency, and ultimately helping in the coordination of decentralised energy system deployment while addressing grid capacity constraints.

Flexible and resilient grids

Energy flexibility services play a critical role in supporting network stability and congestion management. Response times range from fast-acting ancillary services, such as EVs and home batteries, to slower-response ancillary services, such as hydropower and capacity markets, which include grid-scale batteries and renewable generation. Innovative solutions such as localised flexibility exchanges among European DSOs, facilitate the procurement of flexibility for durations ranging from 30 minutes to a few months ahead of dispatch, thereby enhancing market stability. T&D utilities can improve flexibility by investing in measures such as network re-configuration, local flexibility markets, distributed storage, dynamic tariff signalling and forecasted dispatch.

Box 6 Case study: AI-enabled portfolio optimisation for grid flexibility

Ingrid Capacity operates a Swedish battery energy storage system portfolio with a capacity of 211 MWh, by employing automated analytics for forecasting, dispatch and market participation. This approach allows the assets to deliver multiple services while respecting local network constraints. By co-ordinating assets at the portfolio level, system value is maximised and new flexibility is unlocked faster than through grid reinforcements alone. Regulatory recognition of optimisation and inter-operability standards would facilitate the safe scaling of such digital flexibility.

Source: Information provided by Ingrid Capacity, UNEZA member.

Across Europe, certain countries are making significant strides towards flexibility through innovative solutions. For instance, the Kingdom of the Netherlands is investing in the integration of distributed energy resources management, Italy is focusing on congestion and demand-side management, and Ireland is enhancing network visibility. For example, Ireland's "Beat the Peak" scheme is a demand-side response initiative that incentivises both commercial and domestic customers to shift their energy consumption away from peak times, thereby reducing strain on the network. This scheme attracted over 28 000 electricity customers and resulted in the implementation of more than 114 000 actions to support network stability (ESB Networks, 2022). However, there is a need for increased investment in areas such as power flow manipulation and dynamic line and transformer rating across Europe.

Leveraging digital enablers can support the necessary grid flexibility; however, this requires grid operators to be:

- **Data-driven.** Grid operators need to use data effectively to gain continuous insights that inform real-time decisions and facilitate the forecasting complex scenario simulations.
- **Multi-skilled.** It is important to embrace experimentation and adopt a multi-disciplinary approach to benefit from innovative strategies.
- **Integrated.** It is critical for grid operators to establish connections with the broader market in a more cohesive manner and be open to sharing information and insights.

Recommendations to support the digital advancement of grids

Regulators can support the digital advancement of the grid by ensuring the following:

1. Cybersecurity rules and guidelines establish coherent and harmonised requirements for all stakeholders across the value chain, including connected devices such as batteries and inverters. The European Union Agency for Cybersecurity (ENISA) should assess legislative overlaps and evaluate EU bodies.
2. A coherent regulatory framework for data management should be developed, aligning the Data Act – which sets common rules for fair access to and use of data across sectors – with sector-specific regulation, such as implementing acts on data inter-operability (European Union, 2023). For example, the Common European Energy Data Space should be made inter-operable with national energy data platforms, rather than imposing rigid technical requirements on it.
3. The implementation of the EU Artificial Intelligence Act (AI Act), which introduces a risk-based framework to ensure the safe and trustworthy use of AI, can promote innovation by supporting non-high-risk solutions (European Union, 2024). It is crucial to provide clear and sector-specific guidance within the energy sector to define what qualifies as a safety component.
4. Measures to foster grid observability may be expedited by using smart meters, equivalent devices or innovative technologies such as the future EU network digital twin.
5. Regulatory sandboxes should be introduced with provisions to ensure that they are time limited (Eurelectric, 2024b).



3.3 Regional co-ordination on integrated electricity systems

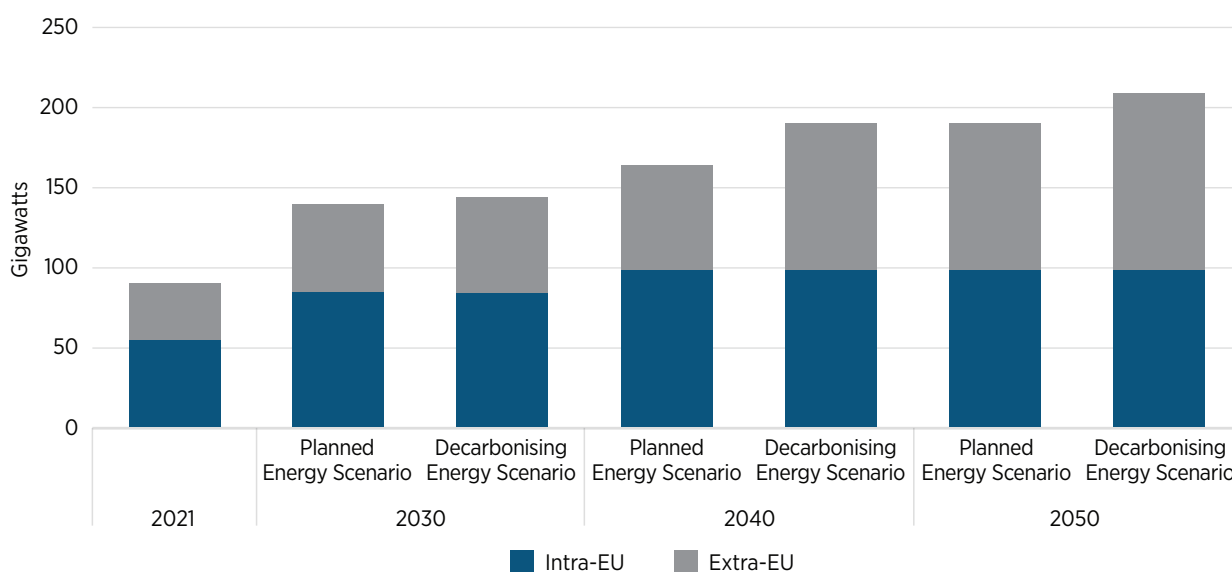
Countries and regions are increasingly collaborating to develop inter-connected power systems that enhance grid stability, facilitate cross-border electricity trading and accelerate the energy transition.

Inter-connectors – specialised transmission lines that link separate grids – are central to this effort. They balance supply and demand across regions, integrate off-shore renewables and support multi-grid co-ordination.

By connecting areas with complementary energy profiles, inter-connectors enhance grid flexibility, lower costs through trading and unlock new markets. This is especially critical for integrating intermittent renewable energy sources.

In the European Union, transmission capacity is projected to increase from 90 GW in 2021 to 140 GW by 2030, thereby supporting greater cross-border electricity flows and regional co-ordination (IRENA, 2025c).

Figure 18 International transmission capacity expansion: Power sector



Source: (IRENA, 2025c).

Note: EU = European Union; GW = gigawatt.

An example of national integration is Ofgem's ASTI framework in the United Kingdom. This framework streamlines the regulatory and funding processes for large-scale transmission projects, including early approval of 26 critical transmission projects, valued at an estimated GBP 20 billion. It is estimated to save up to two years in the funding process (Ofgem, 2024). ASTI presents a shift towards a more co-ordinated network planning approach that prioritises high-value strategic infrastructure rather than sequential project-by-project assessments.

An example of an inter-country integration is the European Network of Transmission System Operators for Electricity (ENTSO-E), an association comprising 40 European TSOs from 36 countries, that is responsible for the co-ordinated operation of Europe's electricity grid – the largest inter-connected power system in the world (ENTSO-E, 2025a). Through ENTSO-E, the TSOs have standardised network codes, platforms and tools to facilitate the efficient operation of inter-connected transmission networks, as well as to identify key risks to ensure system stability. ENTSO-E has also developed a Ten Year Network Development Plan, which defines a co-ordinated vision for network development across Europe, aiming to meet net-zero development needs while maintaining cost efficiency and security (ENTSO-E, 2025b).

The Nordic Regional Coordination Centre (RCC) is another example of inter-country integration. It is an independent company owned by the TSOs of Finland, Sweden, Norway and Denmark. Its focus is on regional co-ordination to improve operational security and planning, which encompasses outage planning, adequacy forecasts and service operation of the common grid model. Ultimately, its goal is to maintain stable supply across the region in alignment with net-zero initiatives.

The global capacity of inter-connectors is expected to increase significantly, with a projected growth of 140% between 2020 and 2040. This surge is driven by the need to support the global expansion of renewable energy and to meet the increasing demand for electricity as economies become more electrified. However, regional discrepancies exist (McKinsey Global Institute, 2024):

- **Europe.** Europe is the most established market for inter-connectors, currently accounting for around 75% of the world's installed inter-connection capacity. The region aims to double this figure by adding approximately 230 GW by 2040, which would represent 62% of all announced capacity additions between 2021 and 2040. The European Union has also set a target for Member States to achieve inter-connections that enable at least 15% of the electricity generated be transmitted across the European Union.
- **Asia-Pacific.** Efforts to integrate energy networks across countries such as Australia, China, Singapore, the Lao People's Democratic Republic and India are expected to result in a nearly five-fold increase in inter-connection capacity by 2030 compared to pre-2020 levels. In Southeast Asia, the Association of Southeast Asian Nations Power Grid initiative is further promoting regional inter-connection, fostering cross-border electricity trade and enhancing system resilience among Member States.
- **Middle East and North Africa.** The planned expansion of inter-connector capacity in this region is projected to more than triple by 2030 compared to pre-2020 levels. Notable projects include the Saudi-Egypt link.

Despite the anticipated growth, several challenges must be addressed to unlock the full potential of global inter-connectivity. These include regulatory and governance hurdles, geopolitical uncertainties, financial and economic issues, as well as constraints related to technology, supply chains and human capital. Addressing these challenges requires strong co-operation and collaboration among all stakeholders, including governments, industry leaders and international organisations.



Box 7 Regional integration and distributed electrification in Africa: AfSEM and Mission 300

Africa offers a compelling example of a dual approach to regional co-ordination, blending large-scale inter-connection with distributed energy innovation. The **African Union's Single Electricity Market (AfSEM)** aims to establish one of the world's largest inter-connected power systems by unifying Africa's five regional power pools. Achieving this vision will require two critical steps: first, achieving full intra-regional integration by ensuring that every country is connected to its respective power pool; and second, establishing inter-regional connectivity across the continent. Progress is already underway, with the first inter-pool link between Zambia and the United Republic of Tanzania expected to become operational by 2027.

In parallel, the continent is advancing electrification through decentralised energy access. The **Mission 300 (M300)** initiative, launched in 2024 by the World Bank and African Development Bank, aims to provide electricity to 300 million people in Sub-Saharan Africa by 2030. Half of the beneficiaries would gain access through traditional grid expansion, while the other half would be served via distributed solutions such as community solar mini-grids. This underscores the continent's potential to leapfrog conventional transmission and distribution models, combining centralised grid extension from urban centres with decentralised systems that expand inward from rural areas. For instance, in Nigeria, hybrid approaches are already being implemented through partnerships between distribution companies and private developers to establish inter-connected mini-grids that blend both centralised and decentralised infrastructure.

Source: (African Union, 2025; World Bank, n.d.).

Recommendations to support cross-border co-ordination

1. **Optimise location.** Prioritise high-impact locations based on co-ordinated planning across countries, taking into account existing and planned generation sites, grid capacity and limitations, as well as proximity to key demand centres.
2. **Co-ordinate across borders.** Encourage co-operation among system operators to enable optimal cross-border flows for inter-connectors, and to minimise the impact on constraint costs (the additional system expenses incurred when grid congestion requires compensating some generators to reduce output and others to increase it elsewhere).
3. **Consider financial incentives.** Provide incentives for infrastructure investments through long-term support mechanisms, such as cap and floor arrangements, while minimising price differentials.
4. **Future-proof infrastructure.** Promote the adoption of new technologies, such as off-shore hybrid assets, to connect new off-shore developments directly to multiple markets to maximise flexibility and minimise infrastructure requirements.
5. **Set long-term, holistic, co-ordinated plans.** Any large-scale grid infrastructure project should be integrated into a broader, forward-looking, holistic and co-ordinated national or regional plan. This plan must consider new generation and demand, as well as cross-border development.
6. **Engage stakeholders.** Engaging stakeholders is essential and should commence early in the planning process. This engagement must continue at regular intervals throughout the build, operation and decommissioning phases of the project.



7. **Reshape the relationship between suppliers and developers.** In light of the cost increases and delays currently affecting supply chains, it is essential to move away from the traditional customer-supplier dynamic. Developing more strategic partnerships built on trust will facilitate the discovery of efficient solutions and may help mitigate potential supply chain risks that could delay otherwise a project.

3.4 Focus on system value

Electric grids span thousands of kilometres, impacting communities and natural ecosystems along the way. As the pace of grid development accelerates, the resulting impacts are felt more quickly and closer to communities, making social acceptance crucial. Raising public awareness of the role and benefits of grids is essential, alongside promoting education, training and job creation within this sector.

In the United States, one in three clean energy projects are delayed due to conflicts over public participation in the planning and development processes (Susskind *et al.*, 2022). Legal challenges further lengthen the permitting timelines, jeopardising economic viability and creating reputational risks. Research indicates that two-thirds of the public believe the advantages of infrastructure projects should be communicated more effectively, while a similar proportion feels that their worries are not being addressed by major energy companies. In the United Kingdom, following a recommendation by the Electricity Networks Commissioner, the transmission operators have united to support the Moving the Grid Forward campaign, which explains the need for grid upgrades and highlights their benefits.

Doorstep (National Grids, 2024) is a community engagement tool from National Grid Ventures that enables stakeholder engagement teams to better understand community concerns and sentiments. Their insights, in turn inform engagement strategies and communication design. Stakeholder engagement teams can communicate with communities in a simple, friendly and timely manner through web and app platforms. Testing on over 1 000 community members has shown 20-35% improvement in public sentiment and a 25-50% improvement in trust.

Adopting a system value approach to the expansion and modernisation of T&D networks provides a more holistic view on the broader impacts on system value dimensions, including CO₂ emission reduction, water footprint and jobs creation.



A collaboration between the Greater Houston Partnership, the Center for Houston's Future, Accenture and a consortium of companies, educational institutions and non-profits was established to actively identify skills gaps and assess skills transferability within local communities, particularly focusing on individuals from disadvantaged communities (Greater Houston Partnership, 2024). The strategy emphasises a skills matching process designed to connect people from these communities with well-paid, middle-skilled jobs in the hydrogen economy. This was followed by job matching efforts that help developers deliver on their commitments to improve local employment. This initiative serves as an example from a tangential industry that can be applied to grids, not only to help close the skills gap needed for developing the required infrastructure but also to deliver system value benefits. For example, estimates from Houston, Texas, where the study was conducted, suggest a potential 60% increase in earnings for disadvantaged communities.

Recommendations for wider system value:

1. **Mandate early and continuous public participation** to build a culture of trust in clean energy infrastructure. Encourage new methods of engaging with communities to reach wider audiences.
2. **Record and transparently report system value benefits** to highlight the wider benefits of grid infrastructure, such as local community employment, security of supply and carbon emission reduction.
3. **Strengthen education programmes** that emphasise the broader benefits of expanding the grid system and its role in the energy transition, highlight potential career paths and build long-term public support.
4. **Incorporate wider system value elements into planning proposals and assessments**, promoting nature-positive design.
5. **Encourage developers** to actively provide upskilling opportunities and make investments that support the local economy.



3.5 Policy best practices

The existence of the Conference of the Parties, the Paris Agreement and the United Nations Framework Convention on Climate Change underlines the critical role of policy in achieving net zero. To effectively tackle challenges related to grid investment, a holistic and integrated policy approach is essential across planning, financing, regulatory incentives, digitalisation, supply chains and capacity building.

Below are global examples of progressive policies in these areas.

Planning

Germany's NEP (Netzentwicklungsplan Strom) uses multi-scenario forecasting for renewable integration and demand growth to assess network expansion needs for the year and define its annual development plan.

Financing

The Green Energy Corridor in India, a critical transmission infrastructure initiative to integrate renewable energy into the national grid secures funding from the government (40%) and international investors (a 40% loan from KfW Germany) as well as equity from state transmission utilities (20%) (Impriindia, 2025).

Regulatory incentives

In the United Kingdom, Ofgem has introduced a new Accelerated Strategic Transmission Investment (ASTI) framework to finance major on-shore transmission projects necessary for achieving the government's 2030 targets. This initiative provides earlier access to funding, thereby speeding up project delivery.

Digitalisation

Digital and analytics trends are transforming grid operations across both T&D systems. In transmission, the availability of comprehensive and centralised asset data enables risk-based asset maintenance, improving efficiency and reliability. Meanwhile, in distribution, the integration of smart grids and smart pipes, equipped with sensors and controls, enhances system visibility and enables transactive controls, paving the way for more dynamic and responsive grid management.

Innovation

The rapid roll-out of innovation plays a key role in policy terms boosting the efficiency of electricity grids. In Scotland, SSEN Transmission has achieved a global first with its Aquila project, first introduced at COP26 in Glasgow (SSEN Transmission, 2025). This project has successfully demonstrated a software interface that enables multi-vendor inter-operability for high-voltage direct current (HVDC) systems, allowing equipment from different manufacturers – such as control systems and main circuits – to operate seamlessly together. This eliminates the need for costly alternating current/direct current conversion when transferring power between systems. Additionally, SSEN Transmission is also installing the largest dynamic line rating system in the United Kingdom, which increases the amount of power flowing through overhead lines, thereby enhancing the efficiency of the electricity grid.



Supply chains

According to UNEZA's statement on *Building a Resilient and Diverse Clean Energy Technology Supply Chain*, the massive expansion of renewables and grids will exert significant pressure on global clean energy technology supply chains. These supply chains involve the sourcing of materials, manufacturing, transportation and installation of technologies that generate, transmit, convert, store or consume clean energy, including wind turbines, solar panels, batteries, HVDC systems and transformers (UNEZA, 2024).

Developers can send strong long-term signals to the manufacturing industry and the entire supply chain to invest in the required inputs. This can be facilitated through detailed logistical planning, such as outlining substation requirements, and through co-operative ordering or alliances between distribution network operators and TSOs to provide strong market signals.



**Box 8 UNEZA supply chain recommendations for policy makers: Power grids**

Leverage global supply chains and free trade to the extent possible. Political decisions significantly influence the development of clean energy supply chains. Governments are increasingly focused on strengthening domestic resilience through on-shoring, friend-shoring, and trade or tariff barriers, alongside financial incentives driven by industrial policy. While local manufacturing capacity is expanding, it is crucial for policy makers to ensure that manufacturers continue to leverage global supply chains. A functioning global system, rooted in free trade to the extent possible, will be critical for scaling up key grid technologies, such as transformers and HVDC converter stations, and for enabling a timely renewable energy rollout.

Ensure forward looking, integrated power system development planning combined with multi-project approvals and permitting to enable the deployment of renewable energy alongside the grid development, refurbishment and modernisation required to meet global climate and energy goals. While some regions already engage integrated planning, it is often conducted at the national level and then consolidated into regional ten-year plans. There is a need for longer-term (20-25 years), strategic regional plans that consider cross-sectoral demand and cross-border requirements. Policy makers must facilitate this planning approach to enhance investment visibility, guide supply chain capacity and support anticipatory investments, ultimately lowering long-term costs and easing supply chain pressure. By basing actions on such plans, shifting from single to multi-project approvals and permitting will accelerate development at the needed scale and pace.

Enhance the resilience of land, sea and air infrastructure. Major disruptions to these infrastructure caused by changing climate conditions or geopolitical factors will create a ripple effect across global supply chains, leading to cost increases and delivery delays. In the G20 countries alone, land transport infrastructure currently moves over 66 billion tonne-km per day (BCG, 2023). As supply chain capacity ramps up, and the physical size of equipment, such as transformers, increases, the associated transport infrastructure must develop at the same speed and scale. Policy makers must ensure that railways, roads and ports are specifically planned, built and operated to enable the seamless transportation of critical and heavy grid technologies, without introducing unnecessary barriers.

Establish standards and common technical specifications to facilitate improved supply chain resilience; however, implementation is crucial. These standards and specifications promote safety, security and interoperability; encourage infrastructure investment and accelerate delivery. However, manufacturers currently face nearly as many unique design requests as there are projects. The broader adoption of international standards, along with streamlined tendering, could enable modularisation, reduce design variations and ease pressure on component supply and engineering capacity. However, these benefits are contingent on effective implementation. Policy makers and regulators must play a key role in promoting the use of these standards in procurement.

Policy makers and regulators must maintain a healthy skills supply chain. More than 66 million people were employed in the energy sector in 2021, representing nearly 2% of global formal employment (World Economic Forum, 2022c). Clean energy jobs now constitute over half of this total. However, the sector is facing a growing skills gap as it navigates large-scale grid and generation expansions alongside rising complexity. Policy makers must focus on four key areas: university education, vocational education and training, cross-industry transitions through reskilling and upskilling, and migration (Clean Energy Council, 2022). Anticipating workforce needs, making the sector attractive to youth and aligning education systems accordingly will be crucial. Furthermore, reskilling efforts should be supported through energy transition skills academies. In some regions, migration can expand the talent pool. Policy makers must also ensure that enabling infrastructure – such as housing, schools and retail – is in place where significant energy employment is anticipated.

Encourage policy, regulatory and business model innovation. The concept of innovation extends beyond technology; it also encompasses leveraging new and innovative business models, as well as policy, regulatory and financing strategies. For example, *programmatic procurement* and *capacity reservation contracts*, recently implemented by companies such as Tennet (European Union), SSE (United Kingdom) (SSE, 2023) and Grid United (US), can help tackle some short-/medium-term supply chain challenges. These agreements provide developers with supply certainty and provide manufacturers with long-term visibility to invest in capacity and secure inputs.

Utilising common frameworks and specifications where appropriate reduces design variation and alleviates pressure on engineering resources, enabling faster delivery and scalability. Policy makers and regulators must create an enabling environment for these innovations to thrive. Innovation can also include circularity, the use of recycled materials or the strengthening of local value chains. Market actors, particularly regulated utilities, should be given the flexibility to adopt such models and be recognised through tariff support or similar mechanisms.



The SINCO.GRID project, a collaboration between Slovenia and Croatia, aims to enhance grid resilience through the deployment of smart grid technologies such as virtual cross-border control centres and dynamic thermal rating systems. These technologies improve frequency control, reduce congestion and improve grid resilience (Sincrogrid, 2025).

The North American Electric Reliability Corporation (NERC) CIP-013-2 mandates that utilities develop and implement supply chain risk management plans to safeguard against cybersecurity threats and ensure reliability of the bulk electric system (NERC, n.d.).

Cross-industry collaboration

Permitting is one of the most significant bottlenecks in the advancement of renewable energy projects and grid infrastructure. This cross-industry challenge requires a collaborative solution. WindEurope, Amazon Web Services and Accenture are working together to create a digital permitting solution – EasyPermits (Wind Europe, 2025). EasyPermits is a cloud-based, serverless online designed to address the three main challenges in the permitting administrative process – namely, information management, collaboration and process transparency. For instance, EasyPermits delivers standardised application templates to ensure that adequate information is shared, promotes the standardisation of workflows and clear milestones, and allows for progress monitoring throughout the entire process. Community members can also access a dedicated view that offers transparency and access to key information, facilitating collaboration and supporting the social licence.

4. Conclusion

Achieving global energy transition goals, particularly those outlined in the COP29 pledges, requires not only ambition but also co-ordinated, sustained action. The scale and complexity of the necessary transformation in both grid infrastructure and energy storage systems calls for cross-sectoral co-operation, policy innovation and financial mobilisation.

To support this momentum, the following cross-cutting recommendations are essential:

1. **Long-term planning and revisiting historic policies in light of changing market dynamics.** Co-ordinated, forward-looking and holistic power system planning is required facilitate the deployment of renewables, as well as the grid development, refurbishment and modernisation needed to achieve global climate and energy goals.
2. **Streamlining the permitting process through enhanced engagement.** Permitting timelines, especially in transmission, can delay investment by up to a decade. Streamlining these processes and introducing early and continuous public participation will build trust and accelerate project implementation.
3. **Cross-vector operations, such as NESO, across electricity and energy.** Integrated system planning across electricity and other energy carriers (e.g. hydrogen, heating) is essential to support efficient infrastructure development and long-term system flexibility.
4. **Collaboration among developers to provide supply chain signals, and between countries for cross-border integration.** Developers and countries should co-ordinate to send clear, long-term signals to supply chains, and promote joint infrastructure planning across borders to unlock flexibility and avoid bottlenecks.
5. **Incorporating system value to enhance public acceptance and future-proof development through economic opportunity and broader benefits.** Considering the dimensions of system value, such as job creation, community benefit funds and wider legacies, CO₂ reduction and human health benefits, can support community acceptance and deliver broader societal gains.
6. **Exploring new financing opportunities, particularly to send strong signals to the market over price certainty and to crowd in private investment.** Regulatory certainty, stable revenue mechanisms and public funding can help reduce risk for private sector investors and unlock capital for large-scale infrastructure projects.

In conclusion, the pledges made at COP29 represent a shared global vision. Delivering on them will require sustained international co-operation, the exchange of best practices and collective support for globally adopted targets. UNEZA remains committed to accelerating global progress by facilitating dialogue, enabling knowledge sharing and fostering aligned efforts across its members and partners.



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Annex 1. Selected energy storage projects implemented by UNEZA members in 2024-2030

Company name	Delivery year (any year from 2024 to 2030)	Country	Capacity of modernised or new project (MWh)	Short description
Iberdrola	2025	Spain	The project includes a hybrid battery with a power output of 15 MW and a storage capacity of 7.5 MWh.	Iberdrola's Torrejón-Valdecañas complex is an innovative project in Spain, notable for its pioneering integration of hybrid battery storage and reversible pumping. With a capacity of 225 MW, including a 15 MW/ 7.5 MWh battery, and up to 210 GWh of combined storage, it serves as a key infrastructure for stabilising the grid, reducing carbon dioxide emissions, and supporting the energy transition while generating local economic impact.
Contemporary Amperex Technology Co. Limited (CATL)	September 2023	United States	1 800 MWh	As the world's largest battery storage facility, the Desert Peak Energy Storage Project employs CATL's innovative containerised liquid cooling energy storage system, EnerC. This project's energy storage capacity is 1.8 GWh, sufficient to support the daily electricity consumption of 259 200 households. With CATL's advanced EnerC energy storage system and new-generation battery cells, the project has significantly improved energy density and installation efficiency, surpassing industry average standards for overall performance. Furthermore, in terms of safety, the EnerC system has an IP55 protection rating and includes fire protection equipment, enabling it to withstand extreme weather conditions and safety risks in California, while operating safely and reliably for up to 20 years.



Ingrid Capacity	2024	Sweden	211 MW/ 211 MWh	Southern Sweden BESS Portfolio #1 (14 sites) <i>Status:</i> Operational (commissioned 2024). <i>Use-cases:</i> Frequency services, local congestion management, energy shifting, electricity trading. <i>System value:</i> Rapid flexibility near load centres; supports renewable integration.
	Under construction	Finland	70 MW/ 140 MWh	Nivala BESS <i>Status:</i> Under construction. <i>Use-cases:</i> Frequency and congestion relief, electricity trading, renewable integration.
	Under construction	Sweden	172 MW/ 280 MWh	Southern Sweden BESS Portfolio #2 (13 sites) <i>Status:</i> Under construction, operational in 2025/2026. <i>Use-cases:</i> Frequency services, local congestion management, energy shifting, electricity trading. <i>System value:</i> Rapid flexibility near load centres; supports renewable integration.
Dubai Electricity & Water Authority (DEWA)	2025	United Arab Emirates	1 500 MWh	DEWA is developing a pumped storage hydro-electric power plant in Hatta, which will utilise water from the Hatta Dam and a newly constructed upper reservoir in the mountains. This highly efficient system achieves up to 78.9% efficiency in power generation and storage, and can respond to electricity demand within 90 seconds. The 250 MW station has a storage capacity of 1 500 MWh and a lifespan of 80 years, making it the first facility of its kind in the Gulf Cooperation Council region. Operational tests began in January 2025, and the plant began generating clean energy from water in April 2025.
EDP Renewables	2026	Spain	72 MWh	The Las Lomillas project is a hybrid plant incorporating wind, solar and storage, located in Cuenca, Spain. The storage system includes a 36 MW and 72 MWh lithium-ion battery, co-located with an existing 50 MW wind farm and a 39 MWp photovoltaic plant. The project will enhance system flexibility, profit from curtailment opportunities and provide ancillary services.



Orsted	2026	United Kingdom	300 MW/ 600 MWh	As the first large-scale UK BESS, this project is situated alongside Ørsted's Hornsea 3 Offshore Wind Farm, near Norwich, Norfolk. The system will have a capacity of 600 MWh and a power rating of 300 MW, which is equivalent to the daily power consumption of 80 000 UK homes. It is expected to become operational by the end of
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Note: Each company is welcome to add as many projects as possible line by line or provide aggregated data in one line. BESS = battery energy storage system; MW = megawatt; MWh = megawatt hour; MWp = megawatt peak.



Annex 2. Selected grid projects implemented by UNEZA members in 2024-2030

Company name	Delivery year (any year from 2024 to 2030)	Country	Voltage level	Modernisation or new grid length (km)	Short description
Scottish and Southern Electricity Networks (SSEN) Transmission	2029 onwards	United Kingdom	3 × 400 kV overhead lines. 4 × 525 kV HVDC subsea connections + Associated substations/ converter stations Additional reinforcements: 275 kV (Argyll and Kintyre), 132 kV (Skye), 220 kV high-voltage alternating current subsea link (Orkney-Caithness, 2028)	~500 km overhead line (Scotland) ~1 200 km subsea HVDC cable (incl. links to England) ~100 km underground HVDC cable	SSEN Transmission is currently upgrading the transmission system in the north of Scotland through its “Pathway to 2030” investment programme. This initiative is a combination of new on-shore and subsea electricity transmission projects as well as upgrades to existing network infrastructure, which will increase the amount of renewable electricity connected to the grid, especially from off-shore wind. These projects will play an important role in meeting the clean energy targets set by the UK and Scottish governments, unlocking homegrown low-carbon electricity generation necessary for a cleaner, more secure and affordable electricity system for both current and future generations. *The majority of Pathway to 2030 projects are expected to be completed by 2030, alongside current in-flight projects. Eastern Green Link 2 and 3 are being developed as a joint venture with the National Grid, with Eastern Green Link 2 due for delivery in 2029, and Eastern Green Link 3 in 2033.



Kazakhstan Electricity Grid Operating Company (KEGOC)	2021-2027	Kazakhstan	500 kV overhead transmission line	604.3 km	The KEGOC West Kazakhstan Power System Interconnection Project involves the construction of a 500 kV overhead transmission line from the Karabatan Switching Point to the Ulke Substation, spanning a total length of 604.3 km. This project will connect the Western Zone to the main section of Kazakhstan's Unified Power System via national territory, with implementation
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Note: Each company is welcome to add as many projects as possible line by line or provide aggregated data in one line. HVDC = high-voltage direct current; km = kilometre; kV = kilovolt.



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