

Power Systems Transformation:

Delivering Competitive, Resilient Electricity in High-Renewable Systems

July 2025 | Version 1.0



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Key messages from the report



Technical feasibility

► It is technically possible to operate stable power systems with very high shares of wind and solar generation (e.g., 70 to 80 %), provided that key investments are made in grid stability technologies and appropriate procurement is implemented.



Enabling policies and actions

► Delivering low-cost, high-wind and solar power systems will require:

- Setting a strategic vision supported by appropriate planning.
- Ensuring that key aspects of market design reduce investor risk and support efficient capital allocation by incentivising the deployment of grid and flexibility technologies.
- Implementing grid regulations that minimise delays in the connection and integration of new technologies into the system.
- Applying digital and AI-based capabilities to manage power systems more efficiently.
- Addressing potential supply chain and workforce bottlenecks.
- Enabling demand side flexibility through consumer engagement and product design.



Balancing electricity supply and demand

► Energy supply and demand can be balanced in high wind and solar systems using a range of already available storage and flexibility technologies:

- For short durations (up to eight hours), batteries are likely to be a low-cost solution, and demand-side flexibility (DSF) has significant potential.
- For medium-long durations, multiple increasingly cost-effective solutions are available.
- The highest costs will be associated with delivering ultra-long-duration balancing.



Total system costs

► Future total system costs per kWh in high wind and solar systems can be comparable to or lower than today's fossil fuel-based systems in almost all countries. These costs will be:

- Lowest in countries with strong solar resources and predominantly short-duration balancing needs (e.g., the low-latitude global sunbelt such as India, Thailand, Mexico, Australia).
- Highest in countries primarily dependent on wind and with significant long-duration balancing needs (e.g., the high-latitude global wind belt such as the UK, Japan, Germany).

In the near and medium term, transitional costs (e.g., from legacy contracts and initially expensive technologies) could be significant and must be carefully managed.



Last mile decarbonisation

► The final stages of power system decarbonisation will be the most expensive, especially in high-latitude, wind-dependent countries, given the higher costs of low-utilisation assets to ensure security of supply. Governments should strike a pragmatic balance between:

- Driving towards complete power system decarbonisation.
- Shifting the primary policy focus to accelerating electrification once a very low carbon intensity (e.g., below 30 grams per kWh) has been achieved.



Grid expansion and costs

► Major investments will be needed in both transmission and distribution grids, with total grid length and annual investment requirements expected to grow two to three times by 2050. However, costs can be significantly reduced through the deployment of innovative grid technologies (IGTs) and demand side flexibility (DSF).

Rapid electrification is essential to scale electricity demand in line with grid expansion, enabling lower grid costs per kWh.

Top actions for policymakers, businesses and investors



Strategic vision and planning

- ▶ Establish an integrated strategic vision that sets clear, time-bound targets for renewables, storage, flexibility, and grid infrastructure.
- ▶ Governments should develop whole-system planning frameworks to coordinate investments across generation, transmission, and flexibility. Planning should be based on a granular understanding of the specific balancing needs each country will face and should define the least-cost mix of flexibility options to address these.
- ▶ Clear institutional mandates and anticipatory investment strategies are essential to deliver infrastructure ahead of need and in line with electrification trajectories.



Market design

- ▶ Reform electricity market structures to enable emerging flexibility technologies compete on equal terms with incumbent assets.
- ▶ This requires ensuring full access to all relevant markets (wholesale, ancillary, capacity) and reforming existing markets, where necessary, to value and remunerate new technologies based on their contribution to system adequacy and reliability, not on legacy operational profiles.
- ▶ Introduce de-risking mechanisms such as two-way CfDs, long-term PPAs, or cap-and-floor contracts to lower the cost of capital for capital-intensive assets.
- ▶ Close innovation gaps through targeted public support for earlier-stage technologies with high system value.



Grid regulations

- ▶ Modernise regulatory frameworks to unlock timely investment in transmission and distribution infrastructure and accelerate project delivery.
- ▶ Streamline grid connection processes with transparent timelines and milestone-based queue management that prioritises viable projects.
- ▶ Reform grid fee structures to eliminate double-charging for storage and enable non-firm access models that reduce costs and connect assets faster.
- ▶ Regulations must support grid operators in deploying innovative grid technologies (e.g., dynamic line rating, smart transformers) that increase capacity utilisation and defer costly reinforcement.



Data and AI modernisation

- ▶ Leverage AI and advanced digital tools to improve power system planning, optimise grid operations, and enhance system stability and safety.
- ▶ AI-driven forecasting and scenario modelling enable better anticipation of demand, generation, and congestion patterns—supporting more efficient investment decisions.
- ▶ Real-time data and automation improve fault detection, system resilience, and the safe integration of variable renewables and distributed assets. Smart meters and digital controls are critical enablers of responsive demand and grid flexibility.



Supply chain and workforce

- ▶ Address critical bottlenecks by aligning national infrastructure plans with long-term demand signals to enable anticipatory investment in key technologies (e.g., transformers, HVDC systems, battery storage).
- ▶ Use public-private partnerships to expand manufacturing and installation capacity, and launch coordinated workforce strategies focused on grid engineering, digital operations, and flexibility deployment.



Consumers

- ▶ Build consumer trust in demand-side flexibility by ensuring transparency, data privacy, and user control, alongside strong consumer education on the benefits of participation.
- ▶ Design intuitive, automated, and interoperable flexibility products that reduce friction and cater to diverse user needs, enabling large-scale adoption across residential, commercial, and industrial users.
- ▶ Scale DSF through coordinated national and local action, supported by targeted policy, investment, and governance, including digital infrastructure, local flexibility markets, and public sector procurement standards.

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