

The Power of Transformation

Wind, Sun and the Economics of Flexible Power Systems

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- **The additional cost to reach high shares of variable renewable energy (VRE) critically depends on how well the system is adapted as a whole.** This finding is the result of detailed economic modelling at hourly time resolution for a test power system.
 - When allowing for full transformation of the entire system (Transformed case), a share of 45% VRE in annual electricity generation (15% solar PV, 30% onshore wind) increases total system costs of the test by USD 11/MWh, compared to a share of 0% of VRE. This corresponds to an increase of about 10%-15%. A lower share of 30% VRE increases total system costs by USD 6/MWh, or about 7%.
 - The transformation includes a re-optimised mix of dispatchable power plants as well as additional flexibility in the form of demand side response using thermal energy storage. It also assumes an optimised strategy for managing grid infrastructure.
 - The model uses current wind and solar PV technology costs and a CO₂ price of USD 30/tonne.
 - In the extreme and purely hypothetical scenario that a share of 45% is added overnight without changing the power plant mix and optimising grid infrastructure (Legacy case), total system costs increase by as much as USD 33/MWh, or about 40%.
- The revised **IEA Flexibility Assessment Tool (FAST2)** assesses the **technical ability** of power systems to absorb higher shares of VRE, **given today's levels of system flexibility** in different case-study regions.
 - Penetration levels of 25% (inflexible systems, e.g. Japan) to 40% (flexible systems, e.g. Brazil) of annual generation are technically feasible. The analysis assumes presence of sufficient grid capacity.
 - These shares can be increased further (reaching levels above 50% in flexible systems) if a small amount of unused VRE generation is accepted (curtailment).
 - However, mobilising system flexibility to its technical maximum can be considerably more expensive than least-cost system operation.
- **Countries with the highest annual share of wind and solar PV generation as of the end of 2012** were Denmark (34%), Portugal (23%), Spain (20%), Ireland (15%), Germany (12%) and Italy (11%).
 - Medium-term estimates (to 2018) expect VRE shares in electricity generation in these countries to be approximately: Denmark (45%), Ireland (30%), Portugal (25%), Germany (20%), Spain (20%) and Italy (15%).
 - India, Japan and Brazil are projected to have annual generation shares of around 5% in 2018, up from less than 2% in 2012.
 - Looking further ahead to 2035, the IEA *World Energy Outlook* scenario featuring the most aggressive deployment of wind power and solar PV (the 450 Scenario) sees VRE shares in power generation respectively at 31% in Organisation for Economic Co-operation and Development (OECD) Europe, 20% in the United States, 19% in Japan, 16% in India and 7% in Brazil.
- The lessons of *The Power of Transformation* **depend** on whether a country has a **stable power system** – where power demand is stable or falling – or a **dynamic power system** – characterised by high demand growth and/or short-term need to replace old assets.
 - Countries with stable power systems should seek to maximise the contribution from existing flexible assets and consider accelerating system transformation by decommissioning or mothballing inflexible capacities that are surplus to the system.
 - Countries with dynamic power systems should approach system transformation as a question of holistic, long-term system development from the outset. This requires the use of planning tools and strategies that appropriately represent the potential of VRE for a cost-effective, low-carbon energy system.

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- There are **four fundamental flexible resources** that can facilitate VRE integration by increasing the flexibility of the power system: flexible power plants, grid infrastructure, storage and demand side integration. A simplified metric, the **levelised cost of flexibility (LCOF)** assesses the cost of the different flexible resources:
 - **Flexible generation.** Reservoir hydro and certain gas power plants are extremely flexible technically and they are among the cheapest options available. The additional cost to obtain flexibility from these sources ranges from USD 1/MWh to USD 5/MWh.
 - LCOF can be much higher if inflexible technologies are used to ramp generation up or down quickly and frequently or if flexibility provision leads to a reduction in the capacity factor, in particular for power plants that were designed to operate around the clock.
 - **Grid infrastructure** is the only flexibility option which brings a significant double benefit: it is a precondition for connecting more distant resources, and it helps smooth the variability of wind and solar PV by aggregating their output over larger areas (which can be exposed to diverse weather conditions).
 - Transmission can be a relatively low-cost option, as low as USD 2/MWh; its LCOF shows a high sensitivity to utilisation rate and is higher if subsea or underground cables are used.
 - The additional costs for accommodating small-scale solar photovoltaic (PV) generation on the distribution level are moderate - as low as USD 1/MWh for a PV system size featuring 2.5 kilowatt per household – if the grid is planned properly from the onset. Costs for retrofits may be considerably higher.
 - **Electricity storage** can provide a broad range of different services, but it remains roughly ten times more expensive than other options.
 - In exceptionally favourable cases, pumped hydro plants can deliver flexibility for USD 20/MWh, if existing reservoir hydro power plants can be used. Costs for new plants range from USD 30/MWh to more than USD 200/MWh.
 - Battery technologies are typically more expensive than pumped hydro storage. For example, using lithium-Ion batteries may cost at least USD 200/MWh to more than USD 800/MWh.
 - **Demand-side integration** holds the promise of providing flexibility cost-effectively. Including the cost for smart meters, distributed thermal storage can deliver flexibility for as little as approximately USD 7/MWh. Once communication and control infrastructure is in place and demand-response capabilities have been streamlined into design of appliances, additional costs can be negligible.
- The cost for providing flexibility paints only half of the picture. The **value of the flexibility service** that each source can provide is equally important. If a high-cost resource provides a very high-value type of flexibility, it can still be cost-effective. Using two different economic simulation tools, *The Power of Transformation* investigates the **cost benefit** of the **different flexible resources**.
 - **Demand-side integration** (in particular distributed thermal storage) shows superior cost-benefit performance compared with other flexibility options. However, a degree of uncertainty exists regarding its full potential in real-life applications.
 - Cost-benefit profiles of **storage** are less favourable, reflecting higher costs. However, where multiple benefits align (e.g. avoiding grid investments, providing reserve capacity), storage can be cost-effective today. Potential cost reductions for storage merit further investigation.
 - **Interconnection** allows a more efficient use of distributed flexibility options and generates synergies with storage and demand-side integration (DSI). Modelling for the North West Europe case study shows favourable cost-benefit of significantly increased interconnection.
 - Cost-benefit analysis of retrofitting existing **power plants** to increase flexibility shows a wide range of outcomes, driven by project-specific costs.