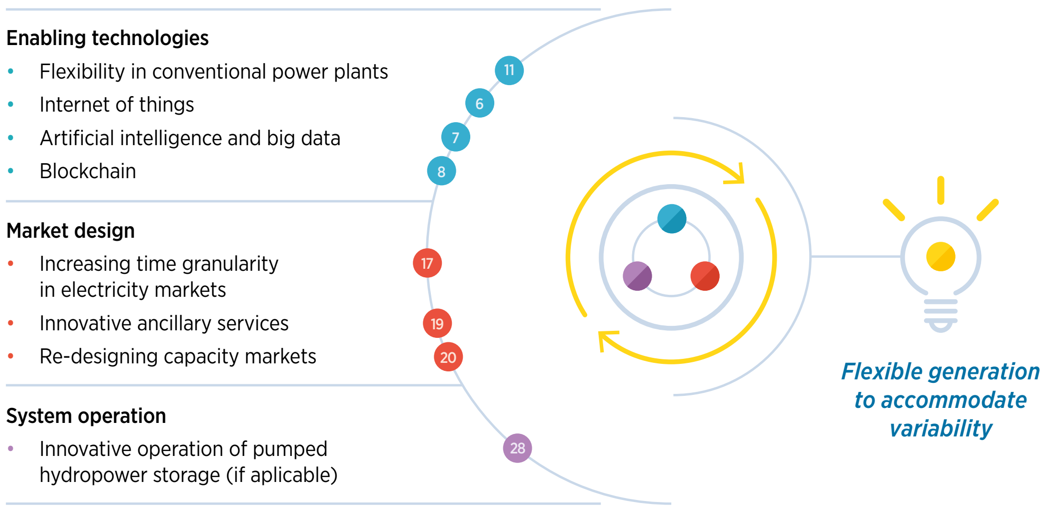
SOLUTION II

Flexible generation to accommodate variability

Figure: Synergies between innovations for increased flexible generation



At the operation level, supply-side resources that are quick ramping and that have short time activation and short reaction time can add great flexibility to the grid. Typically, hydropower and gas-fired plants offer such fast ramping and fast reaction times. Hydro plants have the capability to react instantaneously, at zero costs. However, for gas-fired plants, the flexibility cost increases with the steepness and the length of the ramp, and they are greatly exposed to gas fuel costs, particularly for markets reliant on imported liquefied natural gas (LNG). Pumped hydro storage plants can provide a great degree of flexibility in terms of both supply (firm electricity as needed) and demand (pumping to refill reservoirs in times of excess supply). *(Key innovation: Innovative operation of pumped hydropower storage)*

On the technology side, with technical enhancements, the normally inflexible generating technologies also can contribute to system flexibility (Jacobs *et al.*, 2016). At the power plant level, operational flexibility is characterised by three main features: the overall bandwidth of the operation (turndown ratio, ranging between minimum and maximum load); the speed at which the net power feed-in can be adjusted (ramp rate); and the time required to attain a stable operation when starting from a standstill (start-up time) (Agora Energiewende, 2017). Research has shown that coal power plants, although traditionally believed to be relatively inflexible, can in fact provide flexible output, supported by the necessary technical and operational upgrades (Cochran *et al.*, 2013) and if the owner is incentivised or forced to run at a capacity utilisation rate average that is well below the optimal design rate of 70-85%. Both India and Australia are examining retrofits to existing fleets to accommodate lower utilisation rates and more flexible ramping management. *(Key innovation: Flexibility in conventional power plants)*

Regarding market design, encouraging power plants to operate as balancing loads, rather than as base loads, will require new revenue streams that compensate operators for making these changes and incurring extra costs in plant operation. For example, the transition of a coal power plant from base load to balancing load implies that operators will likely have to invest in new equipment, while facing lower annual capacity factors and more frequent forced outages. Innovative market regulations need to be designed in order to adequately remunerate and incentivise operators to run such plants for balancing, while also maintaining profits.

A way to achieve this is through increasing the time granularity in wholesale energy markets. This better reflects the conditions at a particular time and remunerates efficient response from the existing generators. Trading products or contracts with shorter intervals, as well as trading as close as possible to real time, helps to internalise in the price the value of flexibility, thus creating value for the flexible sources that are capable of responding in near-real time by ramping up or down easily. The more reflective the prices are of the short-term demand-and-supply conditions, the better are the price signals sent to the generators that can quickly alter their output when needed by the system. Increases in the shares of wind and solar generation will increase the volumes of intraday trading necessities and the need to adjust production schedules to the most recently updated forecast. This requires the market time frame (both the settlement period and gate closures) to adapt to fully exploit the potential of renewable energy sources and the flexible behaviour of other existing generators in the system, to counteract the VRE generation.

On the day of delivery, where intraday markets are in place, participants must submit their bids for supply and demand for any given trading interval, also called the settlement period. Market participants can trade up to a certain point before the settlement period, called the gate closure. One of the examples with a low time granularity is Germany where the gate closure is between 5 and 30 minutes before the start of the physical delivery for a 15-minute settlement period (EPEX SPOT, 2019), while in England the gate closure is 16 to 19 minutes before the 30-minute settlement period (IEEFA, 2018). A narrower gate closure would reduce forecasting errors for renewable generation and minimise the amount of costly reserve generation that must be contracted to respond to unpredicted variability. *(Key innovation: Increasing time granularity in electricity markets)*

In real time, system operators use primary, secondary or tertiary reserves to handle the real-time deviation in forecasted demand and supply. Such ancillary service products need to be adapted to increase the system's flexibility, incentivise fast response and ramping ability, and remunerate each of the services accordingly. For instance, PJM Interconnection, a transmission system operator in the US, has developed different frequency regulation products for the slower conventional resources and the faster battery storage resources. Also, opening the market to all new actors, including small players and distributed energy resources, and making all actors responsible for balancing the system could improve the system flexibility. Marginal pricing of balancing energy and the removal of price caps will allow prices to reflect the real value of electricity. This also will provide the correct incentives to invest in flexibility and to offer balancing energy and reserve services. *(Key innovation: Innovative ancillary services)*

Through capacity market mechanisms, sufficient reliable firm capacity can be assured if 1) such capacity mechanisms are designed in a way to allow the equal participation of all flexibility service providers, such as demand-side response, interconnectors and storage operators, and 2) such mechanisms are designed as a response to real identified adequacy concerns. However, for a future system with a high share of VRE, flexibility in the system is required due to the variability introduced by these renewable sources. By introducing flexibility requirements in capacity market products, investments in power plants can be incentivised. *(Key innovation: Redesigning capacity markets)*

- A system where energy is traded more quickly, closer to real time and in shorter increments, is more difficult to manage and requires a greater degree of automatisation. **Enabling technologies**, such as digital systems, can monitor remote generators and automatically send simple instructions and corrections to the operators. Data reporting from generators and power exchanges can inform grid operators' expectations and allow them to make better decisions on energy and service procurement. ICT developments and advanced control centres will unlock opportunities and have the potential to change the way that energy systems are operated, providing greater flexibility to the system.

Until recently it was costly to put in enough sensors, transmit high-frequency data, store the large volume of data, perform smart analytics of the data and tune the process for optimal performance. These constraints are being overcome as digital technologies unleash a “full digitalisation” of the process. It makes the grid intelligent and flexible, giving it the capability to manage variability and uncertainty. On the operations end, the Internet of Things can increase the generation flexibility by lowering the minimum capacity factor and increasing the ramp rate. *(Key innovations: Artificial intelligence and big data; Internet of Things)*

Impact of increased time granularity in the wholesale markets:

- **Integration costs in the US are lower with faster dispatch: USD 0/MWh to USD 4.40/MWh in areas with five-minute dispatch, compared to USD 7/MWh to USD 8/MWh in areas with hourly dispatch.**

Five-minute dispatch is currently the norm for independent system operators throughout the US, serving more than two-thirds of the national load. With faster dispatch, load and generation levels can be more closely matched, reducing the need for more expensive regulating reserves. Five-minute scheduling was adopted not to enable renewable generation integration, but because it reduces power system operating costs. Five-minute scheduling has helped reduce regulation requirements to below 1% of peak daily load. Integration costs prove to be lower in areas with faster dispatch. For example, integration costs have ranged from USD 0/MWh to USD 4.40/MWh in areas with five-minute dispatch, compared to USD 7/MWh to USD 8/MWh in areas with hourly dispatch (WGA, 2012).

- **An additional 15-minute intraday call auction increased the efficiency of the German electricity intraday market and helps set a clear price signal; refurbishments of coal power plants helped to increase flexibility and increase renewable generation share.**

In December 2014 EPEX launched an additional 15-minute intraday call auction at 3 p.m. on the day before (D-1). This helped optimise the constraints due to the hourly product in the day-ahead and intraday markets. This is a uniform price auction for the 96 quarters for the following day. It has increased the efficiency of the German electricity intraday market and helps set a clear price signal. The variation of the price also has decreased since the implementation of the 15-minute intraday call auction (EPEX SPOT, n.d.). Hard coal power plants are adjusting their output on a 15-minute basis to participate in the intraday market. Upgrades at Weisweiler power plant reduced minimum load by 170 MW and 110 MW at two generation units and increased the ramp rate by 10 MW/minute. Retrofits of the Bexbach power plant reduced the minimum load from 170 MW to 90 MW. These retrofits, and operating the plants flexibly, increases operation and maintenance costs. However, these increases are small compared to the fuel savings associated with higher shares of renewable generation in the system (Agora Energiewende, 2017).

- **The need for balancing power is reduced by several hundred GWh a year when the gate closure is reduced from 75 minutes to 15 minutes before delivery.**

For instance, RWE’s transmission system operator Amprion in Germany revealed in documentation provided to the energy regulator that if the 75-minute period could be reduced to just 15 minutes before delivery, the need for balancing power in its zone alone could be reduced by several hundred GWh a year.

USD 262 MILLION SAVINGS by introducing a new ancillary service product

70 % Procurement COSTS SAVINGS for TSOs

200 % INCREASE in VRE due to new players providing ancillary services

Impact of innovations in the ancillary service market:

- **National Grid, the transmission system operator in the UK, could save USD 262 million by introducing a new ancillary service product.**

Grid operators have to deal with increasing volatility due to a growing share of wind and solar power. The deployment of the sub-second Enhanced Frequency Response by National Grid in the UK is expected to provide National Grid with greater control over frequency deviations, resulting in potential cost savings of GBP 200 million (USD 262 million) (KPMG, 2016).

- **Allowing renewable energy generators, battery storage systems and industrial loads to provide ancillary services could lead to 70% procurement costs savings for transmission system operators and to a 200% increase in VRE installed capacity.**

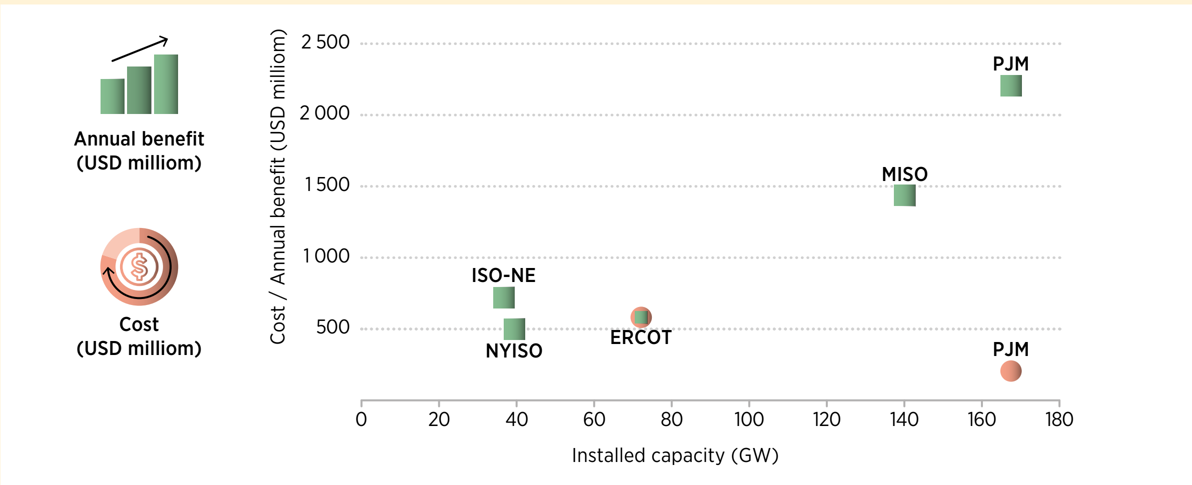
In Germany, alongside conventional generators, renewable energy generators, battery storage systems and industrial loads also were allowed to participate in the balancing markets in 2009. In the period from 2009 to 2015 the balancing market size (in GW) decreased by 20%, the ancillary service procurement costs for transmission system operators decreased by 70%, while in the same period the system stability increased and the installed capacity of VRE increased by 200%. This indicates that allowing alternative energy resources to participate in ancillary service markets can help increase system stability while reducing costs (Wang, 2017).

Impact of zonal or nodal prices:

- **Investment in transitioning to a nodal pricing system has been recovered within one year of operation by different independent system operators in the US.**

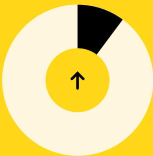
Nodal pricing system implemented in US resulted in better congestion management, improved grid reliability, increased retail access and competition, reduced transition costs, improved planning and better co-ordination with regulatory agencies (Eto *et al.*, 2005). Investment in transitioning to a nodal pricing system has been recovered within one year of operation by different independent system operators, as the figure below illustrates.

Figure: Costs and benefits of nodal pricing

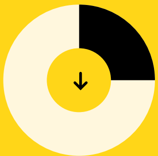


ISO-NE = Independent System Operator – New England; NYISO = New York Independent System Operator; ERCOT = Electric Reliability Council of Texas; MISO = Midcontinent Independent System Operator; PJM = Pennsylvania – New Jersey – Maryland Interconnection.

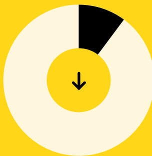
Source: Neuhoff and Boyd, 2011.



8 %
INCREASE in RE generation due to digitalisation



25 %
CURTAILMENT REDUCTION due to digitalisation



10 %
COST REDUCTION in operation and maintenance due to digitalisation

Impact of digitalisation on the wholesale market:

- **Digital system implementation and data analytics led to an 8% increase in renewable energy generation, a 25% reduction in curtailment and a 10% reduction in operation and maintenance costs.**

General Electric estimates that by implementing digital systems and data analytics, renewable energy operation and maintenance costs can be reduced by 10%, production increased by 8% and curtailment cut by 25% (Neuhoff and Boyd, 2011).

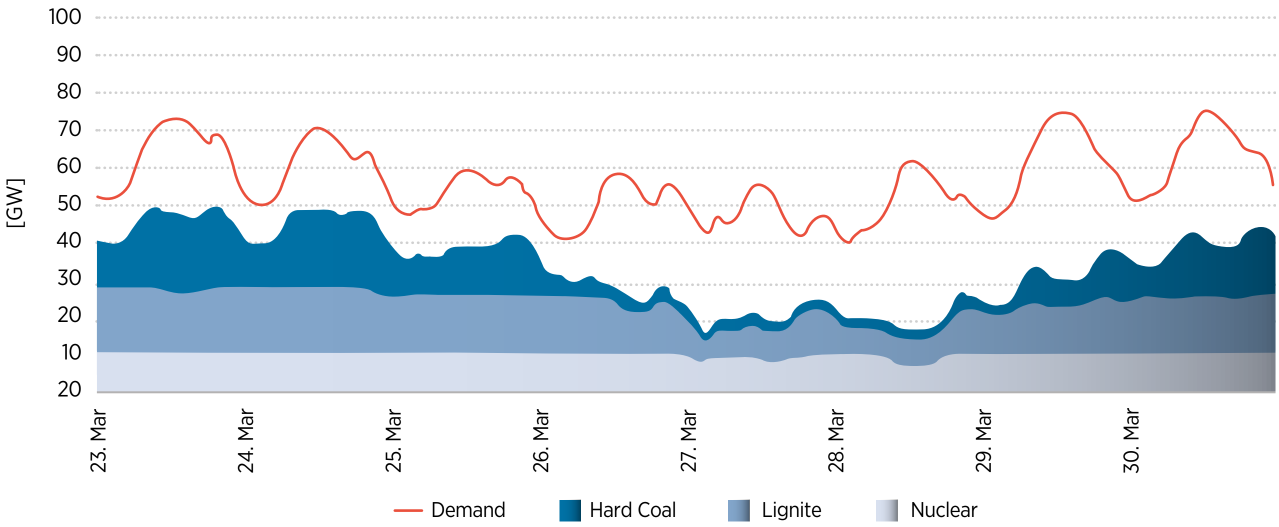
IMPLEMENTED SOLUTION

Increased flexibility of coal power plants and market design in Germany

- Operators of existing coal power plants can technically provide much more flexibility than is often believed. In countries such as Germany and Denmark, targeted retrofit measures have been implemented on existing power plants, greatly enhancing their technical flexibility. Furthermore, effective market incentives – including intraday electricity markets – have been introduced in order to remunerate the provisioning of flexibility. Such measures have enabled renewable generation to be integrated more easily and in an economically efficient way, thus limiting wasteful curtailment.

State-of-the-art hard coal power plants can operate at minimum load levels of 25% to 40% of the nominal load. State-of-the-art lignite power plants can achieve minimum loads of 35% to 50% of the nominal load. By contrast, power plants built 10 to 20 years ago in industrialised countries had minimum load levels of 40% (hard coal) to 60% (lignite). Retrofitting can reduce minimum loads even further. In Germany, for example, minimum load levels of 12% have been achieved (Agora Energiewende, 2017). The next figure illustrates how hard-coal-fired power plants, and to some extent lignite-fired power plants, are already providing significant operational flexibility in Germany, adjusting their output to the variation in renewable energy feed-in and demand.

Figure: Power generation from nuclear, hard coal and lignite power plants and demand in Germany, 23 to 30 March 2016



Source: Agora Energiewende, 2017.

Whether, and to what extent, flexibility retrofitting measures are profitable varies on a case-by-case basis in relation to the plant characteristics and the market environment (*e.g.*, age of the plant, market share of renewables, general market design, remuneration options for flexibility). However, it has been seen that flexibility retrofitting is likely to be profitable in Germany when the market is properly designed to remunerate the flexibility. The introduction of short-term electricity markets and the adjustment of balancing power arrangements are important measures for remunerating flexibility. The introduction of a 15-minute-based intraday market incentivised the retrofits of coal plants.

In Germany, some power plant operators deliberately push flexibility, even though this reduces the plant's life. This relates in part to the shift in energy policy away from coal over the coming decades. It also explains the relatively higher flexibility of German power plants compared to other countries.

In systems with high shares of wind and solar PV, conventional plants must serve the load that is not covered by variable renewables – that is, the residual load curve. Therefore, the operation of these plants has to be significantly more flexible, and a proper market design should be adapted. The need for flexibility and the challenges faced by conventional power plants in Germany are illustrated in the figure.

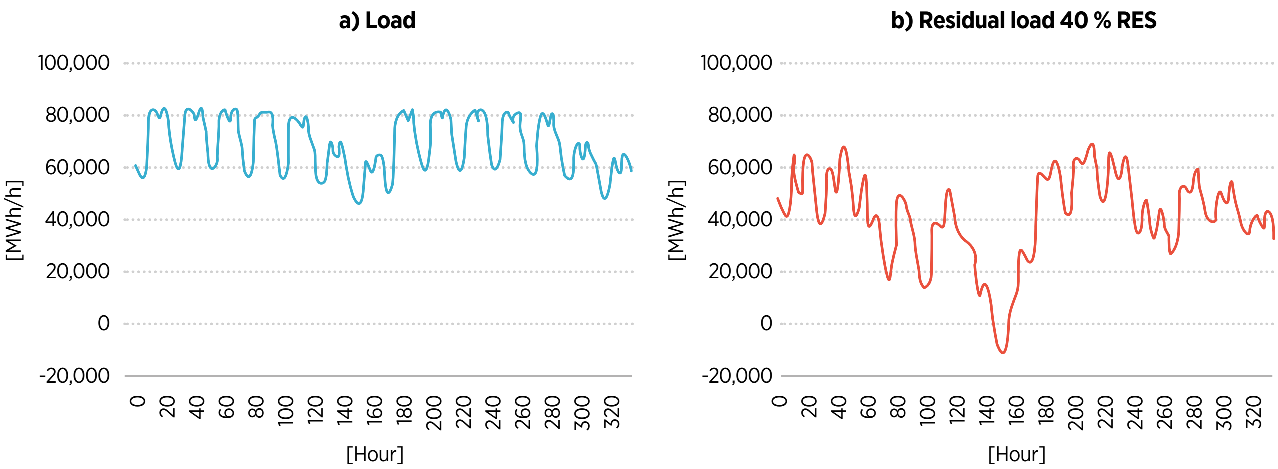
Market design and flexibility providers in Denmark

In Denmark, the development of the electricity market is the foundation for the integration of VRE. It allows for better balancing of VRE over a large market area by incentivising the increase in thermal power plant flexibility, and through the establishment of dynamic and close-market coupling.

Denmark has been part of the Nordic power market since 2000. The Danish generation mix consists of wind and thermal sources, with the thermal power plant fleet almost exclusively comprising combined heat and power production. As the share of VRE increased, the role of CHP plants changed from being the main base load of the power system to becoming a key source of system flexibility.

The default ramping ability in a thermal power plant built to deliver a continuous amount of power is typically 1% of maximum power output per minute. Danish thermal power plants are built or retrofitted to ramp on average 4% per minute, in response to the demand for flexibility in the production fleet, expressed through power price fluctuations throughout the day. Improved ramping properties allow the plant to increase or decrease participation in the market more quickly and to follow the volatility in power prices. Similarly, the minimum load is as low as 15% in some Danish thermal power plants, whereas the

Figure: Flexibility requirements in Germany. Example load curves for two weeks during winter in Germany



Source: Agora Energiewende, 2017.

standard load, if the plant is not optimised, is 30% to 40% (Energinet, 2018).

A number of issues in the market design influence flexibility. Some of the most important characteristics of the Nordic market design are listed in the figure below.

An advantage of a very low minimum load on thermal power plants is that they can participate in the day-ahead market with minimum load, say 20%, and then participate in the intraday and balancing markets with the remainder of the plant capacity. If there is a great demand for flexibility, the prices are likely to be higher in the intraday and the balancing markets. Therefore, plants with higher levels of flexibility will be able to minimise the production sold at low prices and maximise the production at high prices, yielding higher profits (Energinet, 2018).

Flexibility incentivised in California's power market

- California's independent system operator, CAISO, has proposed several changes in the power market to incentivise system flexibility due to large solar PV generation. One of the changes being proposed is in the day-ahead market, to change the granularity from 1 hour to 15 minutes[2] (CAISO, 2018a). The reduction in scheduling intervals would allow power-generating resources to follow the load curve as forecasted by CAISO more closely. CAISO also may be able to reduce procurement from the real-time market, especially during morning and evening ramping times.

In November 2016 CAISO implemented a separate flexibility ramping product on the ancillary service market: Flexible Ramp Up and Flexible Ramp Down Uncertainty Awards, which are products to procure ramp-up and ramp-down capability for 15-minute and 5-minute time intervals through the ancillary service market. The product is procured in terms of megawatts of ramping required in a five-minute duration, and any resource capable of fulfilling the ramping requirement can participate. The price for providing ramp-up service is capped at USD 247/MWh, and the price for providing ramp-down service is capped at USD 152/MWh (CAISO, 2018b).

Following CAISO's successful implementation, the New York Independent System Operator (NYISO) also proposed a similar flexible ramping product as part of its 2018 Master Plan (Avallone, 2018).

Figure: Key characteristics of the design of the Nordic market

	DAY-AHEAD	INTRADAY	BALANCING
Market type	Auction/Marginal pricing	Continuous bid matching	Prioritised bid activation/mix of marginal price and pay ad bid
Minimum product size	1 MW	1 MW	5 MW
Gate closure time	12-35 hours	60 minutes	45 minutes
Bid linking	Yes	No	No
Validity periods	60 minutes	60 minutes	60 minutes
Settlement of imbalances	1 hour (2-price model)		

Source: Energinet, 2018.

2 Other changes proposed include combining Integrated Forward Market (IFM) and Residual Unit Commitment (RUC), and procurement of imbalance reserves that will have a must-offer obligation to submit economic bids for the real-time market.

SUMMARY TABLE: BENEFITS AND COSTS OF FLEXIBLE GENERATION TO ACCOMMODATE VARIABILITY

Flexible generation to accommodate variability	Low	Moderate	High	Very high
BENEFIT				
Potential increase in system flexibility				
Flexibility needs addressed	from seconds to hours			
COST and COMPLEXITY				
Technology and infrastructure costs	refurbishment of thermal plants			
Required changes in the regulation framework				
Required changes in the role of actors				
Other challenges	• Effective flexible generation needs improved modelling tools to account for flexibility related parameters such as ramps, turndown ratio, start-up time, and simulations will need lower time resolution to capture variability.			

This document is extracted from a longer report:

IRENA (2019), ***Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables.*** International Renewable Energy Agency, Abu Dhabi (**ISBN 978-92-9260-111-9**).

The full report and related materials are available on the IRENA website (**www.irena.org**).