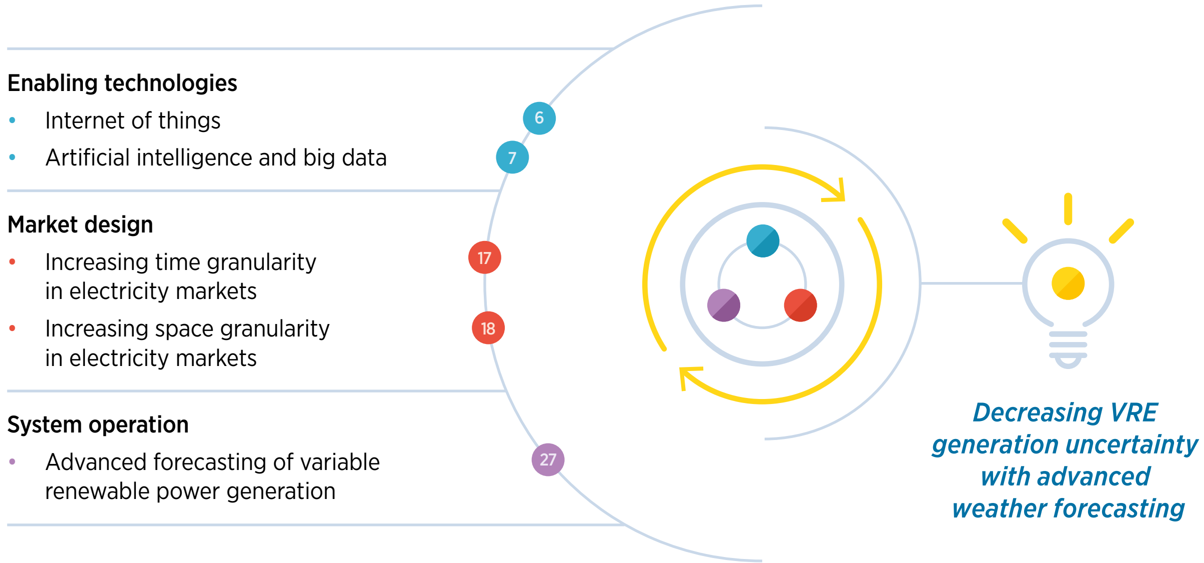
SOLUTION I

Decreasing VRE generation uncertainty with advanced weather forecasting

Figure: Synergies between innovations for decreasing uncertainty of VRE generation with advanced forecasting



At the system operation level, effective VRE forecasting is crucial to integrate wind and solar resources into the grid, especially at high penetration levels. As one of the most cost-effective tools available to system operators, advanced forecasting helps reduce the uncertainty associated with VRE generation, providing support in operation planning to counteract its variability. Better forecasting does not remove the need for action, it just gives longer to plan. Accurate forecasting can help improve unit commitment and dispatch efficiently and reduce reliability issues, hence reducing the amount of operating reserves needed in the system. Also, it permits VRE to be used to provide system services such as operating reserves. For example, through blade pitching, wind turbines can provide upward and downward reserve. When system services can be obtained also from VRE, the power system can integrate more VRE (IRENA, IEA and REN21, 2018).

High-quality weather forecasting can accurately predict output on a two- to six-hour interval, greatly improving system reliability. Today, forecast errors typically range from 3% to 6% of the rated capacity an hour ahead and from 6% to 8% a day ahead on a regional basis (as opposed to for a single plant). In comparison, errors for forecasting load typically range from 1% to 3% a day ahead (Lew *et al.*, 2011). Even slight improvements in generation forecasting have the potential to result in large operational and economic benefits. *(Key innovation: Advanced forecasting of variable renewable power generation)*

Thanks to enabling technologies, advanced weather forecasting models now take into consideration site-specific parameters and real-time data gathered from advanced meteorological devices. By using the significant processing power afforded by modern ICT, such as cloud-based computing, improved mathematical models (which produce forecast results for 5 or 15 minutes instead of an hour) and artificial intelligence, together with the big data collected on past weather patterns and generation outputs, accuracy and locational resolution of VRE generation forecast could be improved. Some other weather forecast models also use advanced cloud-imaging technology, sky-facing cameras to track cloud movements, and sensors (installed on the turbines) to monitor wind speed, temperature and direction. *(Key innovations: Artificial intelligence and big data; Internet of Things)*

A successful example is the EWeLiNE, a machine-learning-based software used in Germany. It uses artificial intelligence and the data from solar sensors, wind turbine sensors and weather forecasts to predict power generation. It therefore helps minimise losses due to surplus power generation and intermittency in the renewable energy integrated system. Another example is Utopus Insights, a company based in New York and India that is focused on improved forecasting for the electrical grid using machine learning as a way to respond to renewable energy growth, which poses a significant challenge to balancing supply and demand. Along with predicting and managing peak loads, the Utopus Insights software will anticipate icing events that can knock down power lines, block solar panels and cause wind turbines to emit unpleasant sounds (Polhamus, 2017).

- **Market design** would need to adapt in order to best capture the benefits of improved forecasting. Improved weather forecasting can be used to update commitment and dispatch and transmission schedules more frequently. This enables better scheduling of the system and reduces the need for expensive operating reserves. Accurate solar and wind generation forecasts could give conventional generators sufficient time to ramp up or down, thereby reducing emissions and balancing the system cost-effectively.

Increasing time and space granularity in the wholesale market helps to capture the value of advanced weather forecasts for VRE generation in the market and dispatch schedule. ERCOT, in Texas, has reduced the dispatch time intervals from 15 minutes to 5 minutes, allowing updates in generation schedules until 10 minutes before the actual power dispatch. This change in the rule helps to minimise forecast error and to reduce wind curtailment due to better accuracy in forecasts (Bridge to India, 2017). *(Key innovations: Increasing time granularity in electricity markets; Increasing space granularity in electricity markets)*

88% → 94%
ACCURACY in renewable power generation forecast

30%
IMPROVEMENT in accuracy for solar irradiation forecasting

Impact of better forecasting through digital technologies:

- **Artificial intelligence can improve the renewable energy generation forecast from 88% to 94%.**

Digital technologies, such as machine-learning algorithms, when applied to weather and power plant output data, can increase the accuracy of renewable forecasts to up to 94%, from around 88% across the industry. Most of these systems are in the pilot phase. In addition, retrofitting digital systems can improve VRE integration by allowing operational data to be provided directly to operators (BNEF, 2017).

- **30% improvement in accuracy for solar irradiation forecasting when using artificial intelligence.**

In 2015 a project by IBM and a team of partners, developed through the US Department of Energy's SunShot Initiative, was able to show an accuracy improvement of 30% for solar forecasting due to the building of a better solar forecasting model using deep-machine-learning technology. The self-learning weather model and renewable forecasting technology, named Watt-Sun, integrated large sets of historical data and real-time measurement from local weather stations, sensor networks, satellites and sky-imaging cameras (NREL, 2015a).

10 % REDUCTION in wind curtailment

USD 60 MILLION SAVINGS due to 37% improvement in wind forecast

UP TO USD 146 MILLION SAVINGS due to 50% improvement in short-term wind forecast

Impact on VRE curtailment:

- **10% reduction in wind curtailment from a 670 MW solar-wind facility enables powering of 14 000 homes.**

IBM created the Hybrid Renewable Energy Forecasting (HyRef) solution for the Chinese State Grid's Jibei Electricity Power Company Limited to perform advanced data analysis and improve wind power predictions for a 670 MW solar-wind energy facility. HyRef uses weather modelling capabilities, advanced cloud-imaging technology and sky-facing cameras to track cloud movements, along with wind turbine sensors, weather forecasts and images of clouds to forecast power outputs for periods ranging from 15 minutes to a month in advance. The technology has helped integrate more renewable energy into the grid through a reduction in wind power curtailment of 10%. This additional energy can power approximately 14 000 homes (NREL, 2013).

Impact on cost savings:

- **USD 60 million in savings between 2009 and 2016 for an investment of USD 3.8 million that improved forecasted wind generation by 37.1% in Colorado, US.**

Colorado utility Xcel Energy calculated that a 37.1% improvement in wind generation forecasting saved the utility's customers USD 60 million between 2009 and 2016. The forecast was made based on surface-level measurements when the average wind turbine hub could be 80-100 metres above the ground. Also, some measuring stations were around 50 km away from the turbines. The improvement in forecasting was achieved by deploying a state-of-the-art wind forecasting system that was specific to each farm and that provided hub-height speeds and was updated every 15 minutes. Its wind production displaces approximately 11.7 million tonnes of carbon dioxide emissions annually (Baskin, 2016; RAL, 2014).

- **Between around USD 5 million and USD 146 million in annual cost savings (capacity reserve, frequency regulation reserve and production cost savings) for improved short-term wind forecasting in California.**

A study done for the California Independent System Operator (CAISO) shows that improved short-term wind forecasting in the CAISO market can result in annual total cost savings (capacity reserve, frequency regulation reserve and production cost savings) of approximately USD 5 million to USD 146 million considering various scenarios (NREL, 2015b). In a low-wind scenario, a total of 7 299 MW of available wind capacity is expected, and in a high-wind scenario a total of 11 109 MW of available wind capacity is expected. The time-based variability in the wind speed determines the instantaneous penetration level and the degree to which the forecasting accuracy influences the actual dispatch of generation.

Wind scenario	Forecast improvement	Annual savings (USD millions)
Low	10%	5 050
High		25 100
Low	25%	14 800
High		62 900
Low	50%	34 700
High		146 000

Source: NREL, 2015

IMPLEMENTED SOLUTION

Germany is using advanced weather forecasting to reach its renewable energy target

Since 2012 the Deutscher Wetterdienst (German Meteorological Service) has been working on optimising its weather forecasts for renewable energy applications within the two research projects EWeLiNE and ORKA, funded by the Federal Ministry for Economic Affairs and Energy (BMWi). Based on the findings of the ORKA project in December 2015, this successful co-operation was continued in a new project, ORKA2, implemented in January 2016. The working field has been expanded through prediction of the current-carrying capacity of power lines.

In the EWeLiNE project, the German Meteorological Service and the Fraunhofer Institute for Wind Energy and Energy System Technology are working with the three German transmission system operators: Amprion GmbH, TenneT TSO GmbH and 50 Hertz Transmission GmbH. Their goal is to improve the weather and power forecasts for wind turbines and solar PV plants and to develop new forecast products focusing specifically on grid stability. EWeLiNE takes real-time data from solar panels and wind turbines around Germany and feeds it into an algorithm that uses machine learning to calculate the renewable energy output for the next 48 hours. Researchers then compare the real data with EWeLiNE predictions to refine the algorithm and improve its accuracy.

PerduS, another research project funded by the BMWI, was launched in March 2016. It focuses on Saharan dust outbreaks and on improving weather and PV power forecasts during such weather situations, thereby supporting the incorporation of an increasing share of renewable energy into the German power mix (DWD, 2018). For example, on 5 April 2014, a large day-ahead Germany-wide PV power forecast error, on the order of 10 GW, occurred. During this and preceding days, Saharan dust was transported to Germany.

SUMMARY TABLE: BENEFITS AND COSTS OF DECREASING VRE UNCERTAINTY THROUGH ADVANCED WEATHER FORECASTING

Decreasing VRE generation uncertainty with advanced weather forecasting	**Low**	**Moderate**	**High**	**Very high**
BENEFIT				
Potential increase in system flexibility			●	
Flexibility needs addressed	from minutes to weeks			
COST and COMPLEXITY				
Technology and infrastructure costs		●		
Required changes in the regulation framework		●		
	regulation can incentivise this solution, *e.g.*, providing VRE balance responsibility would improve their forecast			
Required changes in the role of actors	●			
Other challenges	• availability of historical weather data for small players			

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**).