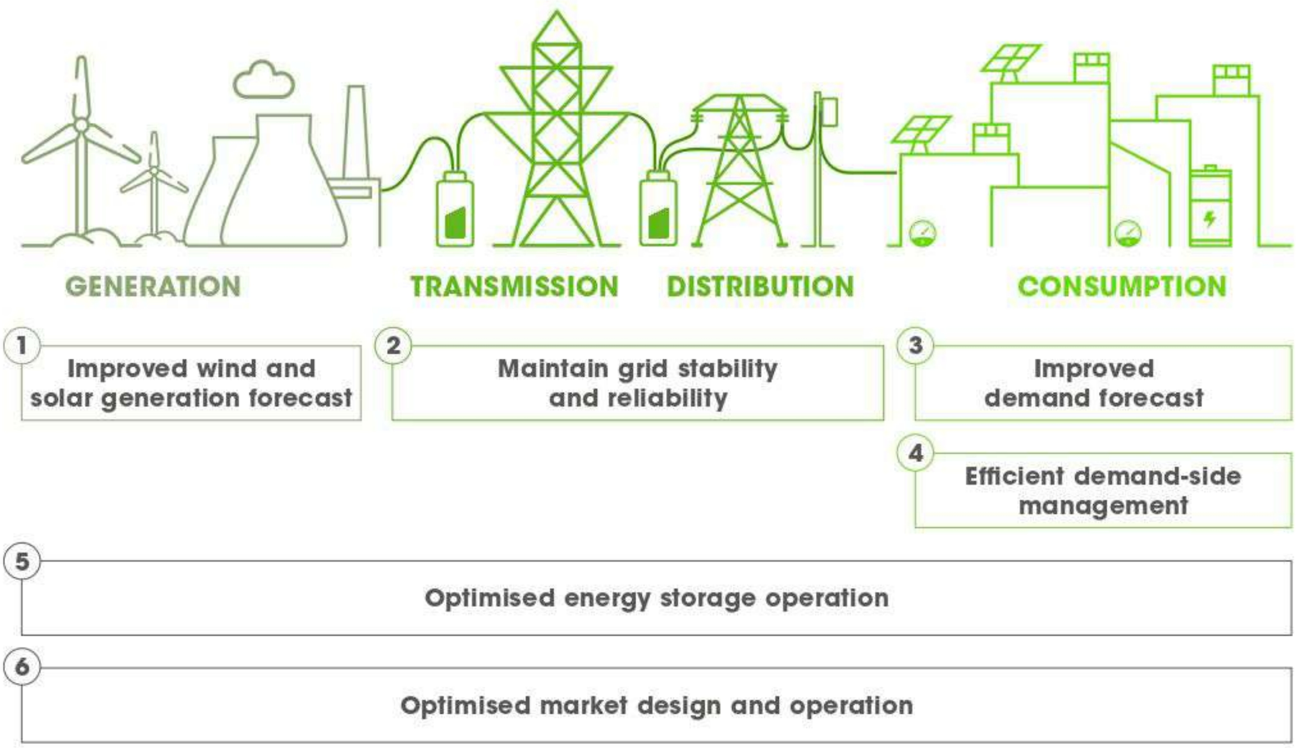
# AI`S CONTRIBUTION TO POWER SECTOR TRANSFORMATION

The power sector is undergoing a major transformation with the increased deployment of renewable energy technologies (solar PV and wind) that provide variable energy supply, distributed energy resources (DERs)[5], bidirectional flow of electricity, large flows of data collected by IoT and other devices, increased use of energy storage, and the evolving role of utilities and consumers. Many system operation decisions are still taken and enacted manually, or with a basic level of automation, because of the small number of automatically controllable resources. However, the developments mentioned above would allow for a larger number of automatically controllable resources responding to needs from several stakeholders (*e.g.* consumers, generators, transmission and distribution operators, retailers). This advanced level of control enables optimisation of the system with more distributed resources while maximising system flexibility and reducing the cost of operating a system with high shares of VRE. Thus, the role of AI and big data is evolving from a facilitating and optimising tool to a necessity for smart and fast decision making.

As previously discussed, AI and other digital technologies can support the renewable energy sector in a variety of ways. Most of the advances currently supported by AI have been in advanced weather and renewable power generation forecasting and in predictive maintenance. In the future, AI and big data will further enhance decision making and planning, condition monitoring, inspections, certifications and supply chain optimisation and will generally increase the efficiency of energy systems. However, this brief focuses on facilitating greater integration of VRE into power systems, where six main categories of application for AI can be identified, as shown in Figure 3.

Emerging applications of AI for VRE integration




**Note:** The categories listed are not exhaustive but identify concrete areas where AI is, at present, being used or tested for VRE integration.

## 1. Improved renewable energy generation forecast

Improved weather forecasting is one of the main AI applications that will improve the integration of renewables into the power system. Solar and wind generation provide an enormous amount of data, and renewable technologies have benefited from sensor technology being long established. Big data and AI can produce accurate power generation forecasts that will make it feasible to integrate much more renewable energy into the grid (MIT, 2014). For example, in 2015, IBM was able to show an improvement of 30% in solar forecasting while working with the US Department of Energy's SunShot Initiative. The self-learning weather model and renewable generation forecasting technology integrated large datasets of historical data and real-time measurement from local weather stations, sensor networks, satellites and sky image cameras (IBM, 2015).

Accurate VRE forecasting at shorter time scales can help generators and market players to better forecast their output and to bid in the wholesale and balancing markets, while avoiding penalties. For system operators, accurate short-term forecasting can improve unit commitment, increase dispatch efficiency and reduce reliability issues, and therefore reduce the operating reserves needed in the system.

A successful example is that of EWeLiNE, a research project using machine learning-based software in Germany, finished in 2017, and Gridcast, a follow-up project. Through AI, both projects forecasted power generation using data from solar sensors, wind turbine sensors and weather forecasts, which helped minimise curtailment of excess power generation.

## 2. Maintain grid stability and reliability

By providing accurate demand and supply forecasts, AI can further optimise the operation of the system, in particular in the context of decentrazlised systems with bidirectional electricity flow, which increases complexity in power systems.

Power distribution grid operators are confronted with great challenges because the number of decentralised energy generation systems, such as solar PV, has grown rapidly. The deployment of renewable energy technology leads to fluctuations and irregular peak loads in the power grid. AI can ensure that the power grid always operates at optimal load and can optimise the energy consumption of customers. Ideally, the electricity generated by the solar PV system in the home or within the neighbourhood grid would be consumed.

For example, in Riedholz, Switzerland, four companies (Adaptricity, AEK, Alpiq and Landis+Gyr), together with the Canton of Solothurn, are testing how AI solutions can ensure future grid stability and minimise investments in costly grid expansion in a pilot project called SoloGrid. The project investigates how GridSense, an algorithm that learns user behaviour through AI, can 1) control the primary electricity consumers, such as heat pumps, boilers, household batteries and charging stations for electric vehicles, and 2) integrate measurement data from solar PV systems for optimal grid operation. The algorithm continuously measures parameters such as grid load, consumption and generation, including weather forecasts and electricity prices, and optimises the generation and consumption of power. The technology reduces peak loads in the power grid, balances the loads and stabilises the distribution grid (Warren, 2019).

Grid congestion at the transmission and distribution level is an important factor that slows the integration of wind and solar PV electricity into power systems. AI can increase the capacity of the power grids and reduce the need for new lines through better use of existing lines as a function of weather conditions. This is the case in, for example, the dynamic line rating projects implemented by the company Ampacimon or being investigated at the Karlsruhe Institute of Technology in the "PrognoNetz" project (KIT, 2019). AI-based systems, using large amounts of weather data, can ensure optimal use of existing power grids by adapting operation to the weather conditions at any time and therefore reducing congestion.

AI can also improve safety, reliability and efficiency in the power system by automatically detecting disturbances. The technology can enable automated data processing in real time and detect cases of emergency or appliance failure. As an example, researchers have provided AI models with examples of typical system outages to allow the algorithm to gradually learn to distinguish – and precisely categorise – normal operating data from defined system malfunctions. The algorithm was able to make split-second decisions on where there was an anomaly or fault, as well as the type and location of that disturbance. If one power plant should fail, an abrupt spike can be expected in the load placed on the other power plants. The increased load slows down the generators, and the frequency decreases. This calls for rapid (less than 500 millisecond [ms]) countermeasures, because if the frequency sinks below a threshold value, the operator may be forced to cut off sections of the grid for the sake of system stability. Since the algorithm can reach a decision within 20–50 ms, there would be sufficient time to implement the appropriate fully automated countermeasures. The algorithm is ready to be implemented, according to researchers, and work continues on the control and regulation of the relevant countermeasures (Fraunhofer, 2019).

## 3. Improved demand forecast

Accurate demand forecasting, together with renewable generation forecasting, can be used to optimise economic load dispatch as well as to improve demand-side management and efficiency.

Consumers produce an increasing stream of data that comes through the power grid itself. There has been a significant push to install smart meters that are able to send the information to utility providers as often as hourly. From this data, AI can predict not only network load but also consumption habits, and can accurately draw a consumption pattern for each consumer. This becomes even more relevant with the current deployment of DERs, such as electric vehicles, heat pumps and solar PV panels, which change the traditional load shape entirely.

BeeBryte, for example, is a French startup that uses AI to predict a building's thermal energy demand in order to produce heating and cooling at the right times, maintaining comfort and temperature within an operating range set by the customer. This can result in savings of up to 40% on utility bills thanks to a combination of efficiency gains and load shifting to periods when electricity is cheapest, when renewable electricity is available in the system (BeeBryte, 2018).

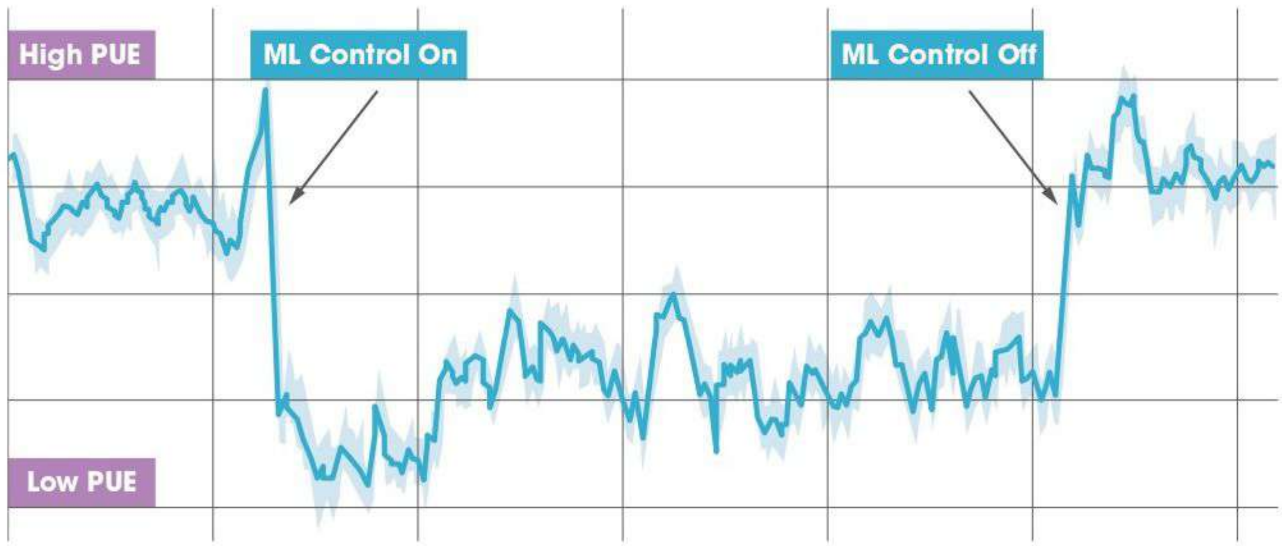
Understanding the consumer's habits, values, motivations and even personality further bolsters the balancing and effectiveness of a smart grid. It also allows policies to be created more effectively and enables an understanding of the human motivations associated with renewable energy adoption and how to possibly change consumer behaviour to optimise the whole energy system (Jucikas, 2017).

## 4. Efficient demand-side management

Demand-side management is witnessing a myriad of AI and big data activity, with advancements being made in demand response, energy management systems and overall energy efficiency. Using weather forecasts, occupancy, usage, energy prices and patterns identified in consumer behaviour, AI can optimise the energy management of a consumer's house, reducing their electricity bill.

Google's DeepMind AI, for example, reduced the energy used for cooling at one of Google's data centres by 40% in 2016 (a 15% overall reduction in power usage) using only historical data collected from sensors within the data centre (*e.g.* temperatures, power, pump speeds, setpoints) to improve data centre energy efficiency. The AI system predicts the future temperature and pressure of the data centre over the next hour and gives recommendations to turn the consumption on or off. The graph below shows a typical day of testing, including when Google turned the machine-learning recommendations on and off (Evans and Gao, 2016).

**Figure 4:** Machine-learning recommendations (on and off) on a typical day




**Source:** Evans and Gao (2016).

ML = machine learning; PUE = power usage effectiveness. The data centre industry uses the measurement PUE to measure efficiency. A PUE of 2.0 means that for every watt of computing power, an additional watt is consumed to cool and distribute power to the IT equipment. A PUE closer to 1.0 means nearly all the energy is used for computing.

In 2018, DeepMind took these innovations to the next level. Instead of its recommendations being implemented by people, DeepMind's AI system now directly controls data centre cooling, while remaining under the expert supervision of data centre operators. This cloud-based control system now delivers energy savings in multiple Google data centres (Gamble and Gao, 2018).

IBM has shown similar results using their machine-learning techniques (IBM, 2018a). Additionally, Grid Edge, an UK based company, reduced energy consumption in shopping centres and airports and provided energy managers the ability to better manage energy usage through the prediction of weather and of customer or new aircraft movements.

## 5. Optimised energy storage operation

Energy storage systems, in the form of large-scale batteries, aggregated small batteries ("behind the meter") or plugged-in electric vehicles, are emerging as key enablers for renewable energy integration. AI can help operate these technologies in a more efficient way, maximising renewable electricity integration (including the reduction of generation forecast errors), minimising prices for electricity consumed locally and maximising returns for the owners of the storage system. For large-scale energy storage systems, this includes decisions on storing excess renewable electricity in a network of batteries and discharging the batteries to meet demand at a later point in time, while considering forecasted demand, renewable energy generation, prices and network congestion, among other variables.

As storage batteries can be activated quickly and can be used to manage excessive peaks and minimise the back-up energy needed from diesel generators, coal-fired power plants or other peaker plants, AI can be used to predict and make energy storage management decisions.

The speed and complexity of managing energy storage systems in a dynamic environment, encompassing many variables, requires advanced AI. AI research is studying decision making on a scale and with a complexity that surpasses that of a human operator, especially for networks of thousands of mixed energy storage units (electrical, thermal, etc.) installed at the end consumer side, at households or industrial installations.

In addition, AI can help estimate and extend the useful life of a storage unit by applying predictive logic algorithms to the charging and discharging data. Owners will deploy their storage pack according to the compensation for the services provided by the battery, as well as the impacts these services have on the state of health of the batteries. California-based company Stem has developed Athena, which uses AI to map out energy usage and allow customers to track fluctuations in energy rate to more efficiently use storage.

In Australia, for example, Tesla's Hornsdale battery was a wake-up call, according to United States-based software-as-a-service platform provider AMS. By using AI, versatile battery storage systems can optimise opportunities to purchase electricity from the grid when prices are low and then to sell back to the market when prices are high. The Hornsdale battery has operated via an autobidder developed by Tesla, which has allowed the project to capture the best revenue streams to a degree that could not have been achieved by human bidders alone. "Relative to a human trader, algorithmic bidding software can increase the revenues of a battery by about five-times", according to AMS. In its first year of operation, the Hornsdale battery generated an estimated $24 million in revenue, while also providing between a $40 and $50 million reduction in frequency control ancillary service costs, savings that are ultimately to the benefit of consumers (Mazengarb, 2019). Cost savings such as these are likely to lead to an influx of algorithm development aimed at operating batteries in the most lucrative way.

## 6. Optimised market design and operation

Sophisticated models based on AI are also being deployed to optimise close to real-time market operations. Such optimisation relies on the analysis of large streams of diverse data to enable rapid response to market changes.

Intraday trading is particularly useful for adjusting to unforeseen changes in power production and consumption by putting market mechanisms to use before control reserves become necessary. This allows a power plant operator who suddenly loses production in a single block to buy additional power from other participants on the market and maintain the balancing group. Intraday trading is therefore a key component for direct marketing of power produced by renewable energy when quickly changing weather results in an unplanned shortfall or surplus of power from solar or wind power plants. The speed and complexity of operating intraday markets in a dynamic environment that encompasses many variables can be beyond a human operator; this would be an ideal application for advanced AI.

When coupling different markets to create regional markets, the complexity in market operations increases even more. An AI-based algorithm called EUPHEMIA was developed to calculate day-ahead electricity prices across Europe and allocate cross-border transmission capacity on a day-ahead basis. EUPHEMIA is used daily to compute in a coupled way day-ahead electricity prices for 25 European countries (Austria, Belgium, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom), with an average daily value of matched trades over EUR 200 million (NEMO Committee, 2019).

In terms of market design, AI can increase time granularity in electricity markets and enable real-time markets. The use of AI is being explored to support trading and dispatch decisions for generation assets in the close to real-time trading markets, focusing on when the generators should commit to trade to maximise the option value of flexible capacity. An example is Origami Energy, a startup company based in Cambridge, United Kingdom, using AI to predict asset availability and balancing mechanism market prices in near real time to successfully bid in the frequency response markets.

With the use of advanced analytics and machine learning, various operational optimisation problems can be solved and new insights for medium- and long-term strategy can be derived – such as to forecast when an asset will be available, the value of flexibility and how an asset should best be used to derive most value (Pöyry, 2018).

## Other AI applications in the power sector

In addition to directly supporting the integration of VRE, AI can be used in other applications for power systems. These include increased visibility into energy leakage, consumption patterns and equipment functioning status. For instance, predictive analytics can take sensor data from a wind turbine to monitor wear and tear and predict with a high degree of accuracy when the turbine would need maintenance. Strategy in targeting where to deploy the real-time sensing is also necessary. For example, some assets last a very long time and outlast the sensors several times over.

With the help of AI, GE in Japan succeeded in enhancing wind turbine efficiency, reducing maintenance costs by 20% and increasing power output by 5% (Nikkei, 2017). McKinsey's Utilityx achieved maintenance and replacement cost savings of 10–25% through predictive maintenance (McKinsey & Company, 2019). Uruguay's National Agency for Research and Innovation and the Uruguay Ministry of Industry, Energy and Mining are also exploring AI for the predictive maintenance of wind power plants in a project conducted jointly with the utility UTE and the School of Engineering of the University of the Republic[6].

Where such markets are in place, AI could also enhance the integrity of the electricity market as well as transparency in the regulator's tasks of monitoring and investigating the trading activity. For example, the European Agency for the Cooperation of Energy Regulators (ACER) uses a market surveillance system called ARIS, which automatically screens and analyses the data collected to identify anomalies that might constitute cases of market abuse according to European legislation (ACER, 2015).