Weather, Climate and Energy

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Abstract

By forecasting future weather conditions, researchers can predict the impact the weather has on an integrated energy system and how this can affect energy demand and electricity supply, as well as energy transmission capability. The aim of this Insight Series Paper is to discuss five research papers which describe methods used for weather forecasting through different time frames and historic case studies to highlight the importance of long- and short-term forecasting. The results indicate that by understanding climate-related effects within different time frames (either long- or short-term), energy suppliers can ensure enough energy is generated to meet demands and reduce the environmental impact. Furthermore, historic case studies allowed forecasters to better understand and support investment decisions to improve the predictability and support decision-makers in meeting their emission reduction targets by ensuring adequate energy is generated and reducing the impact on the grid.

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Energy Systems Integration Partnership Programme

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Context

The Energy Systems Integration Partnership Programme (ESIPP) is a research programme, funded by Science Foundation Ireland and industry, and delivered by a multidisciplinary team of researchers from University College Dublin, Trinity College Dublin, NUI Galway, the Economic and Social Research Institute (ESRI) and Dublin City University. The research programme has three strands: (i) addressing operational and technical aspects of the electricity and gas networks, (ii) identifying energy solutions for people in their homes and businesses, and (iii) informing energy policy and infrastructure investment to enable energy decarbonisation. Recent research at ESIPP has focused on methods to forecast weather conditions to facilitate the integration of renewable energy technologies and reduce demand on the grid.

The Insights Series aims to bring together research activities as part of ESIPP to provide information in a more accessible way. This series enables us to bring together different research findings to provide unique perspectives gained through a multidisciplinary research approach. Over the duration of the ESIPP project, researchers have published several papers on how weather forecasting can contribute towards predicting energy supply and demands.

Weather conditions are strong external drivers of integrated energy systems that simultaneously impact the demand and electricity supply as well as energy transmission capabilities (Rübbelke and Vögele, 2013). For example, changes in air temperature and wind speeds can influence energy demand for heating and cooling but can also cause fluctuations in electricity generation on timescales ranging from minutes to decades (Grams *et al.,* 2017; Sinden, 2007; Staffell and Pfenninger, 2018; Wild *et al.,* 2015). Similarly, in conditions where extreme precipitation produces floodwater, stress can be placed on pumping stations[1], leading to combined sewer overflows. Conversely, drought conditions can reduce hydroelectric power generation.

When generating energy, suppliers need to take into consideration the variability and limited predictability of renewable energy generation sources (Mason *et al.,* 2018). Long-term energy forecasting enables policymakers, planners and engineers to prepare for future energy needs by building and developing infrastructure in the most beneficial locations. However, predicting wind and solar resources on time-scales beyond the approximately ten-day limit of numerical weather prediction is currently impossible. However, significant progress has been made with regard to seasonal-scale prediction of large-scale atmospheric pressure patterns (Cradden *et al.,* 2017) that may permit the detection of upcoming seasonal scale low-wind conditions, particularly in winter. In addition, short-term energy forecasting is critical to energy production as it allows planners to know how much renewable energy will be available to meet demand. By better planning of load shifting during peak energy generation periods, forecasters can reduce demand on the grid by planning additional renewable energy generation during these time periods, in turn reducing greenhouse gas emissions as energy generated will be able to meet the current demands.

Research Description and Discussion

The five papers highlighted below discuss the importance of understanding long and short-term climate-related effects for weather forecasting to assess the energy demand and supply and why historic case studies can contribute to future analysis.

Study one forecasts wind and solar energy generation through different statistical and physical modelling approaches through short term (minutes to hours) to long term (hours to days) for both deterministic and probabilistic forecasting (Sweeney *et al.,* 2020). **Figure 1** provides a graphical representation of potential business models in renewable energy forecasting as it is often dependent on the needs, capabilities and budgets of the forecast user. Physical modelling is concerned with solving the governing equations of the atmosphere and generating forecasts for those atmospheric variables relevant for renewable energy run.

[1] A pumping station is an intermediate storage or collecting station used to supply water to canals, drainage of low-lying land and for the removal of sewage at processing sites.

Statistical modelling approaches 'bridge the gap' between the information from meteorological forecasts and observations (meteorological or power). This study discusses advances in forecasting for renewable energy technologies, uncertainty in forecasting, new industry challenges and new products required to aid decision making subject to risk constraints. Results of **study one** indicate that future forecasting will need to include probabilistic information specifically tailored to the end user and their decision-making problems, for example, statistical modelling and artificial intelligence. Short-term forecasting uses data from the renewable energy plants to forecast future values however improvements through better utilisation of other data sources, such as cloud imagery, radar, or weather typing could be made. Long-term forecasting includes numerical weather prediction (NWP) forecast data that could be utilised to improve modelling techniques to improve outputs.

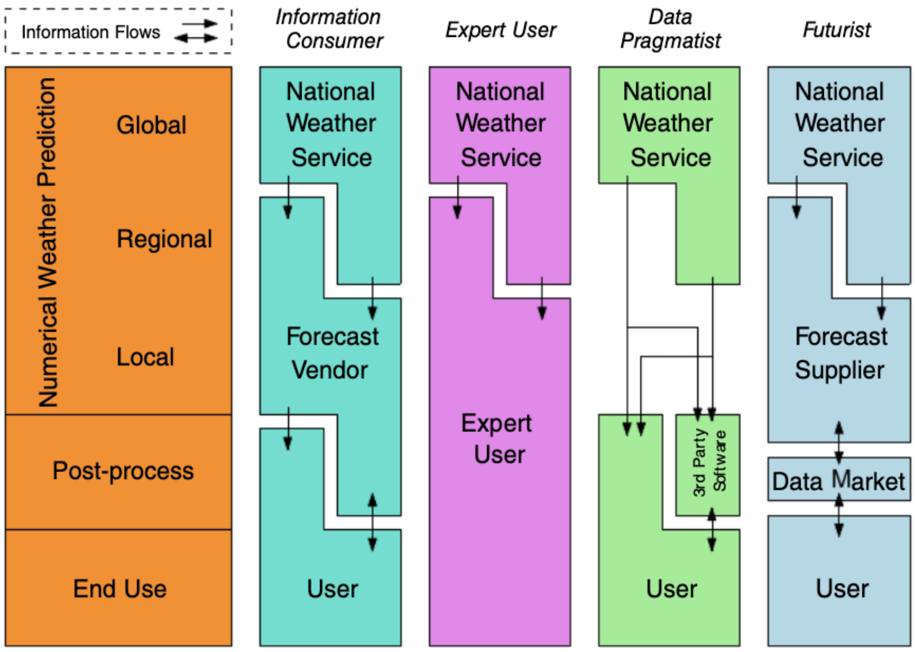

Figure 1: Graphical representation of potential different business models in renewable energy forecasting (Sweeney *et al.,* 2020).

To study climate-related aspects of power system operation with large volumes of wind generation, data with sufficiently wide temporal and spatial scope is required. The relative youth of the wind industry means that long term data from real systems are not always available. **Study two** uses a detailed aggregated wind power generation model using MERRA[2] reanalysis wind speed data that is verified against measured wind production data for the period 2001–2014 for Ireland (Cradden *et al.,* 2017). The model is used to hindcast hypothetical aggregate wind production over a 34-year period (between 1980 and 2013), based on existing installed wind capacity. Results indicate that the methodology was successful in representing aggregate power output in the middle years of the analysis period, after the total installed capacity had reached around 500MW. Variability on scales of greater than six hours is captured with one additional higher resolution wind dataset found to improve the representation of higher frequency variability. The results of the hypothetical aggregate wind production, based on existing installed wind capacity, highlighted that there was a relationship between several of the production characteristics including capacity factor, ramping and persistence, and two large-scale atmospheric patterns (the North Atlantic Oscillation (NAO) and the summer East Atlantic (EA) Pattern).

Study three discusses high resolution wind power statistical models fitted to meteorological data for Ireland (Carroll *et al.,* 2018a, 2018b). This study focuses on the number of hours when power is theoretically produced

[2] Modern-Era Retrospective analysis for Research and Applications (MERRA).

i.e., ignoring market and operational curtailment, which is a phenomenon called a 'wind power event' which occurs when wind speed exceeds the cut-in threshold of a wind turbine so that power is produced. The end of the event occurs when the wind speed drops below the cut-out threshold. Using a discrete Burr model, the number of consecutive hours of wind power availability was predicted, as well as the complement of the wind power availability events, wind droughts and when wind speed is insufficient to produce wind power. Results indicated that it took time resolutions of less than six hours to capture zero power and short bursts of wind power potential. These models provide insights for investors on potential wind power availability at different geographic locations.

Study four focuses on the winter periods between 2009–10 and 2010–11 in Ireland (Cradden and McDermott, 2018). During these time frames, electricity demand was relatively high, whilst wind generation capacity factors were low. These circumstances caused strains and difficulties on the electricity network resulting in a high level of dependence on wind energy. By understanding the atmospheric conditions associated with study periods, insights into the large-scale drivers for cold, calm spells can be made, and will help to evaluate if they are rare events. The influence of particular atmospheric patterns on coincidental winter wind generation and weather-related electricity demand is investigated here, with a focus on blocking in the North Atlantic/European sector. Results indicate that the 2010–11 period was found to be unusual in a long-term context as forecasting events, particularly at a seasonal level, are critical for optimal management of the system. This study provided a greater understanding of how atmospheric circulation patterns relate to wind generation, weather driven electricity demand and their coincidence in relation to Ireland's electricity system.

Most studies on the connections between large-scale atmospheric patterns and renewable energy resources have focused on wind speeds and directions, with fewer studies assessing their impact on incident short wave (SW) solar radiation, important for the solar energy industry. **Study five** focuses on the relationship between the winter period (December to February) of large-scale atmospheric circulation patterns and incident winter SW radiation in the Euro-Atlantic sector, focusing on the UK and Ireland (Correia *et al.,* 2020). In this sector, atmospheric teleconnections such as the NAO, the EA and the Scandinavian (SCAND) patterns reflect regional-scale sea level pressure anomalies which have effects on renewable energy resources at various time-scales. This study highlights the effect of land surface elevation and local orographic effects on modulating cloudiness and incident SW solar radiation. Results indicate the EA pattern exerts a weak control on winter SW radiation, although the western part of the Iberian Peninsula and adjacent Atlantic Ocean demonstrate significant positive correlations. High values of the SCAND pattern index result in higher than average winter SW radiation in northern Europe, although some regions exhibit the opposite behaviour. Inter-seasonal variations in the dominant atmospheric flow and moisture transport directions, steered by large-scale atmospheric pressure patterns, combined with orographic uplift and rainout effects on the windward side of hills and mountains, are interpreted to be the physical drivers of the observed zonal variations and correlation sign reversals between winter SW anomalies and the NAO index.

Key Insights and Application

The results from these studies highlight that as electric power systems move towards higher integration of renewable energy technologies, renewable energy forecasting will have an important role in preserving system stability (Sweeney *et al.,* 2020). Managing power systems with large amounts of decentralised renewable energy generation will require advanced forecasting skills for these energy sources, considering 'behind-the-meter' forecasting, and new representations for forecast uncertainty (Sweeney *et al.,* 2020)**.**

The future of forecasting for renewable energy depends on the availability of large data sets, and new sources of data being included, there is great potential to broaden the types and amount of data used in both statistical and physical modelling. Larger datasets can be used to drive novel approaches in statistical and machine learning, while making new sources of data available to NWP through new data assimilation processes that will improve forecast skill. By better understanding the history of unusual events through better data and forecasting models, forecasters will have a better understanding to support investment decisions to improve the predictability of results over different time frames and can be specifically tailored to the end user's targets. This provides policymakers with the best mix of energy and locations for the different renewable technologies.

Forecast modelling allows policymakers to estimate the energy required to meet demand, to determine what energy type would be most beneficial based on the expected weather projections and in turn reduce the impact on the grid and environment. Furthermore, businesses operating in this sector may see a change in business models as more individuals and businesses compete, with different combinations of skills, data and modelling being required for different products. The transaction of data itself may change with the adoption of blockchain technology, which could allow forecasting providers and end users to interact in a trusted, yet decentralised way.

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