The quality of weather information for forecasting of intermittent renewable generation

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Abstract

The weather forecasts are affecting different aspects of our everyday life. Nowadays, thanks to many tools and methods we are able to predict meteorological phenomena. It is possible, with a level of uncertainty, to take control over the unpredictability of the future weather conditions. Unfortunately, the predictions of the future meteorological variables are far from perfection, and it is confirmed not only by scientific research but also by every-day experience. Hence, the quality of the weather predictions has to be evaluated. Especially, as this information is critical for numerous sectors, amongst which the renewable energy sector may be distinguished. Nowadays, an accurate prediction of the power output of intermittent renewable energy sources (RES) is highly dependent on weather and climate conditions. Thus, the energy decision- makers have to depend on the quality of the obtained weather information. However, there are no commonly accepted standards that would allow for the evaluation of the quality of information gained from different sources. The aim of this paper is to provide a critical overview of the currently used assessment methods of the quality of weather forecasts. The main focus is put on the methods and criteria for evaluation of weather information that is used for predicting power output from intermittent RES.

1. Introduction

Weather forecasting is based on predicting the state of the atmosphere in the future. Nowadays, thanks to many tools and methods we are able to predict meteorological phenomena. Thus, it is possible, with a level of uncertainty, to take control over the unpredictability of the forthcoming weather conditions. Moreover, progress in measuring techniques, computing and information technology had a huge impact on the quality and the usefulness of weather forecasts [17].

The various energy production units, different consumption patterns and the energy system in general have different technical, legal and even behavioural constraints [14]. To plan ahead for the future energy production and consumption, energy specialists, like any other analysts, rely on a system of equations [30]. According to [58], the choice of the appropriate forecasting model relies on four characteristics: the forecast horizon, the availability of historical observation data, the level of data aggregation and finally on the amount and quality of the external information, amongst which the weather and climate information plays a significant role [36]. Unfortunately, as confirmed by both the research and the everyday life experience, the predictions of the future meteorological variables are far from perfection. Often, even the seemingly best weather forecast may prove to be inaccurate when conditions change unexpectedly [28, 32]. Hence, the quality of the weather predictions has to be impartially evaluated. Especially, as this information is critical for numerous sectors, amongst which the renewable energy sector may be distinguished.

An accurate prediction of the power output of intermittent renewable energy sources - RES (especially wind and solar power) is highly dependent on weather and climate conditions. Consequently, the currently used forecasting methods of energy generation are relying on weather forecasts. Thus, the energy operators have to depend on the quality of the obtained weather information. However, the problem of assessing the quality of weather forecasts for the use

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of energy forecasting is very complex. In the context of RES, a number of questions arises: (1)What is the real usefulness of the weather forecasts provided? (2)What is the most appropriate forecasting horizon? (3)How far in advance should the weather forecast for a particular day be published in order to be useful and reliable for forecasting RES output? (4)What are the sector relevant measures of the quality of the weather forecasts?

The paper is structured as follows. Section 2 presents the general weather information quality terms. Additionally it provides a critical overview of the currently used types of forecasts and methods of their quality assessment. Section 3 focuses on the topic of how significant is the weather information in renewable energy sector. Moreover, it addresses the forecasting horizons and their operational usability in the context of weather and climate variables that influence the RES performance. Section 4 discusses the information attributes relevant to the quality assessment of weather forecast and the needs of the renewable energy sector. The main findings are summarized in the concluding Section.

2. The weather information and its quality

2.1. The quality of information

ISO 8402 standard defines the quality term as all features and characteristics of a product or service used to satisfy identified or anticipated needs [44]. In this sense, the quality of the information should be understood as the satisfaction degree of the user requirements. Therefore, quality should be estimated from the perspective of the needs of the entity, which relies on it. Thus, it is necessary to specify the information recipient [1]. The latter is the one that imposes his requirements, and determines the manner in which information can be evaluated. This involves determining the quality of information by using the evaluation of attributes (features) connected to the information. In the literature, one can find many attempts to define the attributes of information [23, 43, 62]. However, these publications do not differ significantly from one another. The differences arise mainly from the fact that there are various configurations in the set of features or different names for information attributes are used, but in fact they are understood similarly. It is worth to emphasize that even the information itself, due to the widespread use in various fields of science and life, does not have a common definition. It is also assessed differently depending on the context of its application.

In general, the quality of information may consist of many elements, such as its reliability, timeliness, security, usefulness etc. Nevertheless, there are no commonly accepted standards that would allow for the evaluation of the information quality [23]. Section 2.2 provides a critical overview of the currently used types of forecasts and methods of their quality assessment.

2.2. Forecast types and verification methods

According to [51] data used in forecasting may occur in various types (nominal, ordinal, interval and ratio). Moreover there are different forecasting methods that can be applied to generate the prognosis. These forecasting approaches can be divided by their nature, space-time domain or specificity. Table 1 presents a classification scheme, proposed by [32], of verification methods assigned to a particular forecast type and grouped by three aforementioned categories.

Category	Forecast type	Appropriate verification methods
nature of forecast	deterministic	visual, dichotomous, multi-category, continuous, spatial
	probabilistic	visual, probabilistic, ensemble
	qualitative	visual, dichotomous, multi-category

space-time domain	time series	visual, dichotomous, multi-category, continuous, probabilistic
	spatial distribution	visual, dichotomous, multi-category, continuous, probabilistic, spatial, ensemble
	pooled space and time	dichotomous, multi-category, continuous, probabilistic, ensemble
specificity of forecast	dichotomous	visual, dichotomous, probabilistic, spatial, ensemble
	multi-category	visual, multi-category, probabilistic, spatial, ensemble
	continuous	visual, continuous, probabilistic, spatial, ensemble
	object- or event-oriented	visual, dichotomous, multi-category, continuous, probabilistic, spatial

Table 1: A classification scheme for forecast verification methods.

According to Table 1 there are seven categories of verification methods: visual, dichotomous, multi-category, continuous, spatial, probabilistic and ensemble. Apart from their applicability to the specific forecast type, it worth to examine both pros and cons of these approaches. Visual or "eyeball" verification methods are one of the simplest. Among others, time series plots, maps, histograms, box plots, scatter plots, reliability diagrams can be distinguished. These methods are based on a human judgment during graphical comparison of presented forecast and observations. Main advantage of this group is that they provide the simplest way to quickly verify the model accuracy. However, this approach is not quantitative and thus there is a room for individual interpretations and subjectivity. As such, these are the biggest disadvantages of the visual verification methods.

The next groups - dichotomous and multi-category verifications can be described together since both are using contingency tables and dichotomous contingency tables. As the latter is a special case of a multi-category verification table. The contingency table method is based on a table where the frequency of forecasts and observations are placed in the appropriate cells [39]. Each row and column represents one of the category (in dichotomous contingency table case categories are "yes" and "no") [38]. In general it is easy to diagnose the nature of forecast errors, but it is difficult to summarize the error by using "one number method". Luckily, there are many statistics that can be used to evaluate error in the contingency table, such as: accuracy, Heidke skill score, Hanssen and Kuipers discriminant, Gerrity score, bias score, probability of detection (hit rate), false alarm ratio and many others [6, 50].

The most commonly utilized verification methods belong to the continuous variable verification category. These approaches are: mean error, multiplicative bias, mean absolute error (MAE), root mean square error (RMSE), mean squared error (MSE), absolute mean percentage error, linear error in probability space, stable equitable error in probability space, correlation coefficient or anomaly correlation [50]. During the error interpretation it is widespread to use just two methods - MAE or RMSE, rather than MSE. The former two are measured in the same data units as the observational data. Thus, it is easier to interpret their scores unlike to the MAE approach. Also, the RMSE is better than MAE if we want to put an emphasis on the forecast outliers, but in few studies this method is criticized due to this feature [3, 65]. Two atypical verification methods: correlation coefficient and anomaly correlation are usually used to check the linear association and phase difference between observations and forecasts. These methods are sensitive to outliers, but say nothing about forecast bias [21, 64].

Another category is based on a probabilistic verification methods. The probabilistic forecast is in fact a value between 0% and 100%. The usefulness of this method can be observed only when there is a significant amount of probabilistic forecast generated [50]. From the probabilistic category we can distinguish brier score, brier skill score [37], relative operating characteristic [34], ranked probability score, ranked probability skill score and relative value [45].

The spatial and ensemble verification methods form the last category. Among many others, such approaches may be distinguished: intensity-scale verification [9], discrete cosine transformation [12], fraction skill score [46], spatial multi-event contingency table [4], neighbourhood verification method [15], CRA verification [16], method for object-based diagnostic evaluation [7], cluster analysis [33], displacement and amplitude score [24], correspondence ratio [52], likelihood skill measure, Nash-Sutcliffe efficiency coefficient [41], alpha index [25], quantile-based categorical statistics and many others [50]. In the following sections the focus is put on the significance of the weather information in a particular energy sector – renewable energy. Moreover, the attributes of weather forecasts quality are identified and the appropriate verification methods proposed.

3. The significance of weather information in renewable energy sector

The irregular production of electricity in RES and their constantly increasing integration with the power grid is currently being one of the major challenges for the energy system operators. It is a known fact that the process of generating energy from this sources is random and problematic in the face of maintaining the security of the network.

The crucial requirements towards RES power forecasting are defined by the forecast horizons that determine the operational, practical usage of the forecasts and are demanded by the electricity value chain participants. Table 3 presents the most commonly industry-requested forecasts.

Forecast horizon	Granularity	Operational usability
Intra–Hour: 15 minutes to 2 hours	30s to 5 min	Management of variability and ramping events
Hour Ahead: One to max 9 hours	Hourly	Transactions on intraday energy markets, load following forecasting, congestion management
Day Ahead: One to 3 days	Hourly	Operational planning, switching sources, short-term power purchases, reserve planning, system balancing, programming backup, ancillary services
Medium-term: 7 days to max 2 months	Daily	Plant optimization, risk assessment, congestion management
Long-term: One to more years	Monthly and annual	Targeting return on investments

Table 2: Forecasting horizons in renewable energy sector (general approach) and their operational usability [26, 28, 32]

Undoubtedly, the most important forecasting horizons for managing the RES output are the hour and day ahead time spans. It might be said, with a great deal of confidence, we may say that the most valuable weather forecasts are in situ and remote observations. Apart from the time horizon, an accurate prediction of the power output of intermittent RES is highly dependent on weather conditions (wind speed, wind direction, radiation, cloudiness, storms etc.). Consequently, the currently used forecasting methods of energy generation are relying on weather forecasts and climate predictions. It is worth to mention that weather attributes are highly dependent on the geographical localization. Table 3 summarizes the dependencies between RES technology and main meteorological variables that have an effect on the amount of generated power.

Renewable energy source	Weather / climate variable
Solar power	Radiation affected by latitude and clouds, air temperature
Wind power	Wind speed, wind direction, wind gust, icing, storms
Hydropower	Precipitation (rain, snow), evaporation, surface slope, air temp.
Biomass power	Temperature, precipitation, insolation
Wave and tidal power	Wind

Table 3:Weather and climate variables influencing the RES performance.

The energy forecasting of the specific time scales, presented in Table 2, and the relevant weather variables distinguished in Table 3, imposes various requirements to the applicable data sources, weather forecasting models, forecasting techniques that can convert available data into high quality RES power forecasts [26, 28]. In general, the weather forecast can be derived using such techniques like Numerical Weather Prediction (NWP), statistical models, satellite-based forecasting or total sky imager–based cloud cover (Sky Image Processing in general), discussed in detail in [17, 28, 58].

4. The characteristics of the weather forecasts' quality and its value for the renewable energy sector

The issue of quality assessment of weather information was widely discussed in meteorology. Throughout the years, a variety of evaluation techniques has been developed and applied [19, 21, 32, 56, 57]. Due to the number of forecast quality measures, in order to avoid confusion, their use must be obvious, easy to calculate and their statistical significance should be testable [56]. In the book [21] one can find a detailed list of common assessment metrics with full discussion of their advantages and limitations. Mailer et al. [32] pointed out that the literature on assessment of forecast quality is largely written to meet the needs of forecasting models developers. However, the evaluation of the quality of weather forecasts in the case of various sectors and users is still to be performed.

Referring to the forecast verification methods presented in Section 2.2., it can be said that renewable energy sector has to use such methods to determine the forecast quality. For example, in the case of wind speed forecasting the most commonly used verification methods are root mean squared error [48, 49, 59, 63] and mean absolute error [5, 20, 40, 47]. In many studies both methods are used and compared, because of the RMSE advantage and disadvantage at the same time – outliers sensitiveness. Equally often the mean absolute percentage error (MAPE) is used in different studies [27, 29, 59, 63]. This method has the such advantage that it abstracts from data units and it is easy to compare different research results. In some studies another verification methods are used like brier score [2], but less frequently than other methods. The situation looks very similar in the case of solar radiation forecasting, scientist mainly use mean absolute percentage error [11, 42, 53, 54] and RMSE verification methods [11, 18, 42]. In noticeably smaller number of studies was used mean square error or mean absolute error [53, 60]. Some researchers use the less popular methods such as ranked probability score or contingency table, but always with support of more popular verification methods [55, 60]. What is interesting, almost no one is using more advanced verification methods for spatial forecasts, generally in that case MSE or RMSE are used with support of the visual methods.

Having in mind the applicability of different forecasts' verification methods commonly used in the renewable energy output forecasting, we can know characterize the main attributes of a weather information. Out of the set of information attributes, mentioned in Section 2.1, we have distinguished these relating directly to the characteristics of weather forecast and the needs of decision-makers from the renewable energy sector. Table 4 presents the relevant attributes of information and their short description.

Information attributes	Description
Completeness	Information is complete if it is reliable and useful. Completeness of information does not mean that all needed information is given in a specific situation. In other words, the scope of the information should be relevant to the problem [1].
Accuracy	Information accuracy decides whether the information is accurate and convergent enough with reality. The consumer must find the data accurate. For example, the data should be correct, objective and come from reputable sources [62].
Correctness	It is strongly linked to accuracy of information. Correct information should be free from errors, mistakes and distortions. It should not be biased.
Timeliness	Timeliness is connected with the information subject which is up-to-date if it describes the present (or last possible to identify) state of some reality. Timeliness may refer to the time when information is received by the recipient or the state of reality when it was created [1]. Information should not be outdated or obsolete.
Relevancy	Relevancy is the information validity assigned to it by the user. Thus, information relevance depends on the user. Therefore, it is a subjective quantity. It can be considered on four dimensions: temporal, personal, geographical and economical [1].
Utility	Information is useful if it meets the needs of the recipient. Utility is connected with the recipient, not the sender. Therefore, the same information may be useful for some recipients, and for others – useless. Moreover, the same information may be useful for some recipient in certain circumstances but in others not [1].

Table 4: Attributes of information relevant to quality assessment of weather forecast and the needs of renewable energy sector

Attributes listed in Table 3 allow for measuring and estimating the information quality. According to [21] these measures must be defined, so they can be quantified. It should be remembered that the overall quality is affected above all by the quality of the data, which is used to forecast the weather, local dependencies and ground limitations.

It is worth to empathize that no single verification measure provides complete information about the product quality [56]. Moreover, the literature shows that not always good quality of weather forecast reflects in a simple manner on its value to the users [31]. There are also different studies showing how various information attributes can affect the forecast value for the user [26, 31, 35]. According to Milligan et al. [35] the most accurate forecast gives the highest benefit from the power resource, but improving accuracy to 100% declines marginal benefits. On the other hand, the forecast accuracy strongly depends on the local conditions at the forecast site [26] and surprisingly the biased forecasts could be more valuable to the power generator than unbiased ones [31] depending on a type and time of day on power markets. Therefore, the importance of "fitness for use" concept that is also widely adopted in the quality literature [10, 13, 22, 62] should be emphasized. Having that in mind, we have decided to take the consumer "fitness for use" in the conceptualization of the underlying aspects of weather information quality.

5. Conclusions

Even though the energy sector is one of the major users of weather information there are still changes that should be made to better meet the consumer needs and to achieve the highest possible quality of the weather predictions.

In this paper we focused on the quality of the weather information and its impact on the RES forecasting. The findings from the critical literature review have led us to a place where we can undoubtedly say that despite many attempts no standardized approach towards assessing the real quality of the weather forecasts has been yet introduced. There are actually three mainly used methods to validate the quality- RMSE, MAPE and MSE. However, the accuracy of prediction which may help evaluate the offers of the forecast service companies is actually a matter of subjectivity. Therefore, apart from different attributes that can describe the quality of the weather information, there is one particularly important – utility. As such we can define "quality of weather information" as the fit for use by information users, in our case: the decision-makers from the renewable energy sector.

6. References and Bibliography

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