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A time series-based approach for renewable energy modeling

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ABSTRACT

Despite the growing literature on renewable energy sources, causal relationships between the variables that are selected as inputs of the models proposed in forecasting studies have not been investigated so far. In this paper, a novel approach to decide prediction input variables of wind and/or temperature forecasting models is suggested. This approach uses time series techniques; more specifically, Granger causality and impulse-response analyses between some meteorological variables. To conduct our study, wind speed, temperature and pressure data obtained from different regions of Turkey are employed. The results suggest that bidirectional causal relationships exist between these variables and that short-run dynamics differ with respect to location (inland versus coastal area). From this, it is concluded that renewable energy models must be built accordingly to improve prediction accuracy.

Contents

1. Introduction

The usage of renewable sources such as solar and wind are exponentially increasing day by day. Accordingly, with the increasing attention being paid by energy industries, governments, non-governmental institutions or the general public to issues relating to the use and development of renewable energy technologies, the research in this field has experienced a remarkable impetus in recent years. As will be discussed later, one of the avenues that has been investigated by researchers is the prediction of renewable energy generation. A major challenge that the scholars in this area have to face is that since meteorological variables carry stochastic behavior, it is not straightforward to determine which variables carry the most important information to predict another one. In other words, whatever the prediction method employed the output of the prediction depends to some extent on some *a priori* assumptions on the relationship between the meteorological variables involved in the analysis. Consider the following example to clarify further this point. From a statistical viewpoint, in a clear region, temperature data and solar radiation data should be strongly correlated. However, in a

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cloudy region, the correlation between the two is likely to be less apparent. In this perspective, it becomes clear that, for a specific region, if the existence of a possible relationship between meteorological variables is investigated and in the case of a relationship, if the nature of this relationship can be determined in terms of causality before a prediction model is developed and estimated, then both the accuracy of the model and the performance of the prediction can be improved. That is to say, a pre-analysis method should be developed and used before the prediction step. This is what the present paper aims to achieve. Therefore unlike the previous articles, in this study a pre-analysis methodology is suggested to test for the existence of a relationship between the methodological variables (both predicted variables and those used for prediction) and to explore the causal nature of this relationship.

Essentially the method presented in this study consists of using time series techniques to assess the inter-relationship between a number of variables for renewable energy sources. In fact the use of such techniques has been receiving considerable attention in recent years especially with the increased focus on energy demand forecasting (see [1] for a recent review of this literature). The approach proposed in this paper differs from the exiting literature in that it focuses on both the possible causal chains among the meteorology-related variables and the magnitude of their deviations from the steady-state at each point in time. Our idea is that; a variable (for example, in our case, temperature or pressure) should be used for forecasting another (for example wind speed), only if there is a causality running from the former to the latter. In a seminal paper, Granger argues that this causality technique can be used for determining whether one time series variable is useful in forecasting another and as discussed below, in its general form, it provides a cross-disciplinary framework for studying different relationships in different contexts [2].

It should be noted that the econometric methods used in this study are not new in the economics literature. However, it appears that the idea of using time series techniques with meteorological data is new in renewable energy literature. More specifically, the novelty of this paper is that it shows the way in which the information required for renewable prediction studies can be obtained using Granger causality procedure. The present analysis goes further by providing simulations of generalized impulse response functions (GIRFs) which makes it possible to trace out the transmission mechanisms revealed by the meteorological data used in the analysis. More precisely the GIRFs are used to determine the effect of a shock to any one of the variables on the current and future movements in others. Hence, this final analysis provides further evidence on the short-run dynamic linkages among these variables and how each of them responds to shocks by the other variables in the model.

In view of the above, this paper contributes to two strands of the literature which have been unconnected so far. First, although its main objective is not to make a prediction, it still falls into the literature on renewable prediction since it provides an econometric procedure that enables a coherent model construction for predicting energy resource data and a better understanding of the dynamics of the relationships between the renewable energy sources. In other words, using the causality tests and GIRFs proposed herein, one would be able to decide ex ante on the variables that should be involved in the prediction analysis. Second, the present study adds to the growing body of empirical literature on Granger causality. Using time series analysis as a pre-analysis of renewable prediction, the paper enriches the application fields of Granger causality and GIRFs.

The organization of the rest of the paper is as follows. Section 2 gives a review of previous work on renewable energy prediction. Section 3 is divided into two parts: while in Section 3.1 the data used in the study are presented and discussed, in Section 3.2 the proposed method mentioned above is described and a very brief review of the econometric literature using time series techniques is included. The empirical results are illustrated and analyzed in detail in Section 4. Finally, the conclusion and future works are mentioned in Section 5.

2. Literature review

As mentioned in the previous section, accurate prediction models are of vital importance for energy related issues. Therefore a lot of prediction models developed, tested and published previously. In this section deliberately selected ones are reviewed.

Benghanem et al. developed an artificial neural network (ANN) for daily solar radiation modeling [3]. Soares et al. applied a perceptron neural-network (NN) technique to estimate hourly values of the diffuse solar radiation [4]. Azadeh et al. presented an integrated ANN approach for predicting solar global radiation by meteorological variables [5]. Cao and Lin proposed diagonal recurrent wavelet neural networks to forecast hourly and daily global solar irradiance [6]. In a similar study, Mellit et al. combined wavelet theory and neural networks and proposed a Wavelet-network model to predict daily total solar radiation [7]. In that study, various numbers of total solar radiation data were taken as inputs and different structures were developed. Hocaoglu et al. developed a novel hourly solar radiation forecasting methodology [8]. In a different study, a novel two dimensional modeling procedure is proposed [9]. Since photovoltaic sizing algorithms gives more accurate sizing results in case model generated data used as presented in [10], Hocaoglu developed novel analytical models for photovoltaic based system sizing algorithms and compared modeling performances with previously developed analytical models [11]. In another study, a different ANN based model was developed for the prediction of solar energy potential in Nigeria [12]. In that study meteorological geographical inputs were used in prediction. Behrang et al. used daily mean air temperature, relative humidity, sunshine hours, evaporation, and wind speed values to predict daily global solar radiations [13]. According to an extensive and in-depth review of the literature on the use of artificial intelligence (AI) in photovoltaic system modeling by Mellit et al., AI techniques provide the possibility for sizing PV-systems with reasonable accuracy even in the case of a lack of complete data [14]. A more general review of solar energy modeling and prediction techniques can be found in Khatib et al. [15] and also in Besharat et al. [16].

On the other hand, for wind speed prediction, Salcedo-Sanz et al. proposed a method to improve the accuracy of the wind speed prediction systems based on exploiting diversity in the input data of the neural networks [17]. Kavasseri and Seetharaman used fractional f-Autoregressive Integrated Moving Average (f-ARIMA) models to predict day-ahead wind speed forecast [18]. Louka et al. used Kalman filtering to improve wind speed forecast accuracy [19]. In another study, a history based method is developed to predict short-term ahead wind speed [20]. Mohandes et al. used support vector machines in the same topic [21]. Grassi and Vecchio suggested a two-hidden layer neural network to predict the wind energy output [22]. From the same perspective Haque et al. proposed soft computing models (SCMs) “augmented” by a similar days (SD) method which is found to lead to an increase in the level of performance of wind speed forecasting technique [23] (see also [24] for a review of the use of ANN in this field). In a different study, temperature values are employed as model inputs and accurate wind prediction results are obtained using hidden Markov models [25]. Cadenas and Rivera compared ARIMA and ANN models in wind speed predictions [26].

In most of the previous studies, the prediction model inputs are decided intuitively. In this work, the necessity of a pre-analysis for prediction models is emphasized and a novel approach is suggested. This approach consists of using a time series analysis on