Received: 19 February 2020 | Revised: 23 July 2021 | Accepted: 17 August 2021 | Published on: 29 August 2021

DOI: 10.1002/joc.7359

REVIEW

International Journal of Climatology RMetS

Seasonal and subseasonal wind power characterization and forecasting for the Iberian Peninsula and the Canary Islands: A systematic review

Susana Bayo-Besteiro[1] | **Michael García-Rodríguez**[1] | **Xavier Labandeira**[2] | **Juan A. Añel**[1]

[1]EPhysLab & CIM-UVigo, Universidad de Vigo, Vigo, Spain

[2]REDE, Universidad de Vigo, Vigo, Spain

Correspondence
Susana Bayo-Besteiro, EPhysLab & CIM-UVigo, Universidad de Vigo, Vigo, Spain.
Email: sbayo@uvigo.es

Funding information
Government of Spain, Grant/Award Number: RYC-2013-14560; Xunta de Galicia, Grant/Award Number: D431C 2017/64-GRC; Naturgy Chair

Abstract

Renewable energy has a key role to play in the transition towards a low-carbon society. Despite its importance, relatively little attention has been focused on the crucial impact of weather and climate on energy demand and supply, or the generation or operational planning of renewable technologies. In particular, to improve the operation and longer-term planning of renewables, it is essential to consider seasonal and subseasonal weather forecasting. Unfortunately, reports that focus on these issues are not common in scientific literature. This paper presents a systematic review of the seasonal forecasting of wind and wind power for the Iberian Peninsula and the Canary Islands, a region leading the world in the development of renewable energies (particularly wind) and thus an important illustration in global terms. To this end, we consider the scientific literature published over the last 13 years (2008–2021). An initial search of this literature produced 14,293 documents, but our review suggests that only around 0.2% are actually relevant to our purposes. The results show that the teleconnection patterns (North Atlantic Oscillation [NAO], East Atlantic [EA] and Scandinavian [SCAND]) and the stratosphere are important sources of predictability of winds in the Iberian Peninsula. We conclude that the existing literature in this crucial area is very limited, which points to the need for increased research efforts, that could lead to great returns. Moreover, the approach and methods developed here could be applied to other areas for which systematic reviews might be either useful or necessary.

KEYWORDS

Iberian Peninsula, seasonal forecast, systematic review, wind power

1 | INTRODUCTION

During 2020, even though the world energy demand decreased by 4.5%, global consumption of renewable energy increased by more than 9% compared to 2019 (BP, 2021). In 2017–2020 the capacity of renewable energy had increased by 28% and in 2020 the renewable energy share of electricity capacity was 36%

(International Renewable Energy Agency, 2021). This trend has been guided by the need to move away from an energy model based on fossil fuels to one with a limited carbon footprint to tackle the problem of global climate change. Renewable energy has a central role to play in the transition towards a low-carbon society. Thus, many countries have been investing in R&D and deployment of renewables over the last few decades. At the same time, limited attention has been devoted to the crucial effects of weather and climate due to their impact on demand and supply, as far as the generation and operational planning or renewable energy are concerned. One of the technologies to have experienced a major boost over the last few decades has been that of wind energy. Europe installed 14.7 GW of new power capacity in 2020 and now has 220 GW of wind power capacity. Wind power covered 16% of the electricity demand of the European Union (EU+UK) in 2020. Spain is second only to Germany, with an installed capacity of 27 GW, and Portugal has an installed capacity of 5 GW. Spain and Portugal represent 4.37% of the installed capacity in wind power around the world, and the Iberian Peninsula (IP) thus makes a significant contribution in this area (Komusanac *et al.*, 2021). During 2020, 22% of the average annual electricity demand in Spain was met by wind power, and for Portugal the figure was 25% (Komusanac *et al.*, 2021). Weather and climate forecasting for wind as applied to wind power has seen an increased relevance over the last few years in this region. The TSO (Transmission System Operator, for Spain Red Eléctrica Española) now considers wind generation to be a core part of the daily power supply rather than simply an additional source (Government of Spain, 2015).

The rapid growth of wind power over the last few years, coupled with the expectation of the future development of the EU to comply with the terms of the Paris Agreement (United Nations, 2015), now makes it necessary to improve the capacity of the various climate services in use across the EU. This is the goal of several recent efforts (Goodess *et al.*, 2019). Among these, accurate weather forecasting is of the outmost importance in making the appropriate geographical selection of the areas to be exploited, to decide which wind farms could increase their capacity, or to identify the proper operating conditions for power production. This is of great relevance given the spatiotemporal variability inherent in the production of renewable energy linked to climate and weather, and the problems associated with energy storage related to the use of this resource.

Wind forecasting for energy generation and the operation of power systems is mainly focused on the immediate short-term of seconds to minutes, the short-term of hours to two days, and the medium term of 2–7 days (Foley *et al.*, 2012). Therefore, the resulting information is only of value for short-term decision-making. When it comes to the long-term planning of renewables, with the aim of planning maintenance regimes (Wen-Yeau, 2014), it is necessary to consider seasonal and subseasonal weather forecasts. Therefore, for forecasting power production, meteorological and climate models are critical. Despite the extensive development of these fields over the last decades, significant gaps persist in the application of meteorological and climate models in the energy sector in terms of our knowledge and understanding of these areas (Añel, 2015).

Literature reviews are often useful for obtaining a global and objective perspective of a given subject. Systematic reviews are not common in the geosciences, but are regularly applied in other scientific disciplines. An example of a systematic literature review in geosciences is a recent study of big data for solar photovoltaic electricity generation forecasting (de Freitas Viscondi and Alves-Souza, 2019). This is especially important in fields in which these reviews can lend support to strategic decision-making, for example, when this decision-making is related to climate services. One recent review was aimed at mapping the global landscape of research on climate services (Larosa and Mysiak, 2019). In the UK, the Met Office commissioned a literature review of weather- and climate-related sensitivities and risks for an energy system highly geared towards renewable (Dawkins, 2019). This review was compiled by the National Infrastructure Commission (NIC) in support of the work of the EU Commission on low-carbon energy generation, to provide recommendations made in the NIC Assessment.

Given all the issues described above, the objective of the present study is to analyse the existing literature systematically, and to provide a broad picture of the state-of-the-art in wind and wind power forecasting at seasonal and subseasonal scales for the IP and the Canary Islands (CI). The final goal of this study is to provide a concise review of the state of the art, useful to make decisions from the knowledge for the point of medium-range and long-term planning of wind power farms.

The remainder of this paper organized as follows. First we describe the methodology we use; then we present our results, followed by discussion, before offering some key conclusions from this work.

2 | METHODS

The term "Systematic" is synonymous with the idea of following a rigorous methodology. Therefore, our first step was to design a search methodology compliant with the requirements of comprehensiveness, precision and reproducibility (Sturm and Sunyaev, 2017). A properly systematic literature review cannot be considered to be biased because it cannot contain any subjective views.

The literature reviewed here was obtained from scientific sources available on the internet, and our review was based on search strings that we considered to be representative of the topic at hand. A search string is the combination of characters, numbers and symbols inserted by a user into a search engine to find results that reflect the terms of the search. A search of this kind returned several papers that matched the search criteria. Our main source of literature was Google Scholar (Google, 2021). We used Google Scholar because it has been argued to be the optimal choice (Falagas *et al.*, 2008) compare with PubMed (US National Library of Medicine National Institutes of Health, 2020), Scopus (Elsevier, 2020) and Web of Science (Clarivate Analytics, 2020).

To prove our preceding point, we selected two databases: Google Scholar and Scopus, and applied the same search string to both. As shown in Table 1, Google Scholar is more effective than Scopus because it returns a more comprehensive set of results. Google Scholar offered results that include scientific papers, reports, books and doctoral dissertations (search as of September 18, 2018).

A string is a sum of two or more search terms; for example, for this research "Iberian Peninsula" is a search term and "forecast"+"Iberian Peninsula" is a search string. Google Scholar offers some particular benefits for improving any search. The search terms were applied to obtain results that contained exact terms only, to avoid less relevant results that showed some other variation of the same words. In our case, to increase the degree of restriction we used "+" to concatenate different terms in the search string, "or" to include other search terms that met our criteria and "-" to exclude terms that were not of interest. In this systematic review, we considered results for the period 2008–2020. Although improvements in seasonal forecast over the recent years are a key reason to focus our study initially for the last 10 years, probably it is more accurate to say that in fact is also relevant for stakeholders, as the more recent periods offer more useful information for planning.

In our search, the filter "-" was used with the search terms "neural networks" and "short term." "Neural networks" and "short term" were selected because it has been proved that the research in neural networks is not a good analytic tool for the seasonal forecast (Salcedo-Sanz *et al.*, 2009; Swiatek and Dutka, 2015) and short-term results are not relevant in seasonal and subseasonal forecast (Zhang *et al.*, 2014). Therefore, not removing these results from the search would result in a large number of works to check mostly irrelevant for this review. In this study, we used four strings to obtain four different groups of results: wind power forecasting and wind forecasting, each one for the IP and the CI. The four strings and the target of each string are shown in Table 2.

For each result, according to the previous criteria, we obtain a list of links with the search results of Google Scholar. In this list, Google Scholar indicates what of them are books. Books are discarded from this review and not downloaded since we consider that the primary source of cutting edge scientific evidence in the field is in other formats: papers, technical reports or theses. After that, we download every link obtained, in most cases, it corresponded to a document in PDF format. The number of the documents downloaded for each search string is shown in Table 2.

We compiled in a list (including titles and links) all the documents that we avoided to download: It includes the documents whose link does not allow download (e.g., corrupted files and broken links) and the books.

It also happened that some of the downloaded documents were duplicates. In such cases they were removed to avoid redundancy. Next, every document was screened using software developed ad hoc, called ReadPdf, that let us in to classify automatically the files downloaded based on several criteria explained below. "Readpdf" is implemented in Java (Schildt, 2014) under General Public License version 3 (GNU, 2007) assuring high standards of scientific computational reproducibility (Añel, 2011; Añel, 2017). This code is included as supplementary electronic material and is available via Git repository (https://gitlab.com/mgrodriguez3/readpdf). A "readme" file is included with detailed information on what the program does, and the steps to follow to run it.

ReadPDF performs a complete, fast and accurate reading of a series of keywords from each of the documents analysed. In our case, we use it to discard papers that are "false positives." For example, they deal with the region of interest, but they are focused on a different topic. For our work the keywords selected were: aerosol, NO_2, Australia, Malaysia, Britain, rainfall, wind and dust. These words have been selected based on preliminary

TABLE 1 Comparison of the number of results for the same search for SCOPUS and Google Scholar

Search strings	SCOPUS	Google Scholar
Wind power seasonal forecast	102	63,500
Wind power seasonal forecast Iberian peninsula	0	2,020
Wind seasonal forecast	916	141,000
Wind power seasonal forecast Iberian peninsula NAO	0	389
Wind seasonal forecast Iberian peninsula NAO	0	797

TABLE 2 Identifier of the search string, target and number of results obtained

Number of string	Search string		Number of results
1	"Wind power"+"seasonal"+"forecast"+"Iberian peninsula" OR "Spain" OR "Portugal"- "neural networks"-"short term"	Studies about seasonal wind power forecasting for the Iberian Peninsula	1,326
2	"Wind power"+"seasonal"+"forecast"+"Canary Islands" - "neural networks" -"short term"	Studies about seasonal wind power forecasting for the Canary Islands	119
3	"Wind"+"seasonal"+"forecast"+"Iberian peninsula" OR "Spain" OR "Portugal" -"neural networks" -"short term"	Studies about seasonal wind forecasting for the Iberian Peninsula	9,560
4	"Wind"+"seasonal"+"forecast"+"Canary Islands"-"neural networks"-"short term"	Studies about seasonal wind forecasting for the Canary Islands	709

screening of several documents. For example, in many cases, wind and solar power are studied together; therefore, we separated the two terms in our searches to avoid to discard relevant works. Dust, aerosol and NO_2 were selected to discard literature focused on the study of aerosols and polluting particles. Rainfall was discarded because the works dealing with it did not provide relevant information on wind power. We also found many studies of wind forecasting focused on Malaysia and Australia but clearly they are not relevant to our region of interest.

Applying these filters, they allowed us to classify all documents analysed and documents focused on wind and wind power into three categories: accepted, discarded and corrupted. For it, a series of checks were carried out that allowed categorizing each file in its corresponding category:

- Documents containing aerosol, NO_2, Australia, Britain or Malaysia are discarded.
- Documents containing rainfall but not wind are discarded.
- Documents that contain dust but do not contain wind are discarded.
- Documents with a format distinct to PDF are classified as corrupted. Also, documents are classified in this category when it does not observe the basic structure of a PDF.
- The remainder documents pass the previous filters successfully, and therefore are classified as accepted.

It should be noted that in the analysis of each file by Readpdf, the list of references is not taken into account to avoid that keywords from cited works cause the removal of a document that is relevant for our systematic review.

Therefore, ReadPdf allows quick and unambiguous filtering to obtain the final results for this systematic review. Then, all the files in the corrupted category were reviewed manually to classify them into one of the other two categories. At this point, the scientific literature of the accepted category underwent full-text review to obtain the final results.

3 | RESULTS

The application of the methodology resulted in an initial set of 14,293 documents (the sum of the documents that we download and those that we avoid downloading). From those, after applying all the filters as explained previously, we obtained 37 documents of which 13 were duplicates. Therefore, in the end just 24 documents (roughly 0.2% of the initial set) were considered relevant to this systematic review. Of these, 23 were scientific papers and one was a MSc thesis.

We avoided downloading 2,579 documents. 1,711 correspond to books, 80 are theses, 673 are papers and 115 are links to broken webpages, not-scientific documents or web pages in a language other than English. We have checked the titles of the 80 theses and 673 papers. When the title revealed that a document could be relevant for our review, we looked for it and checked its content. As a result, we had into account seven additional papers. However, all of them were discarded too as they did not provide useful information.

A total of 11,714 downloaded documents have been analysed and classified using Readpdf. For the string 1 (1,326 documents), ReadPdf discarded 548 of them and 34 were manually reviewed. After that 14 documents met all the requirements. Equally for the string 2 (119 documents), ReadPdf discarded 50 of them, and 5 were manually reviewed. After that, no document met all the specifications that were sought. For the string 3 (9,560 documents), ReadPDF has dropped 5,263 files. Subsequently, 296 documents have been manually reviewed, obtaining 23 files that meet all the specifications that were sought. Finally, for the string 4 (709 documents) ReadPdf discarded 407 of them and 20 were manually reviewed. Again, no document met all the specifications that were sought (see Figure 1). Those documents discarded manually after passing the ReadPDF filter correspond to false positives. They were automatically selected because they meet the search strings and criteria but actually do not contain relevant information for this review.

4 | GLOBAL PICTURE OF THE STATE-OF-THE-ART

In 17 of the works reviewed, seasonal wind forecasting was considered (Table 3), and a further seven related to seasonal wind power forecasting (Table 4). Only seven papers were focused on the CI (Table 3). To determine how many corresponded to each region, we considered studies carried out in our region of interest or on other wider regions that included it. We also found four papers in which specific subregions of the IP were considered (Figure 2).

The results obtained include references to several different methodologies for evaluating the seasonal forecasting of wind and wind power. To get a global view and to classify the information in a way that was relevant and easy to understand, we decided to classify the results according to these methodologies. We thus divided these into Climatic Patterns, Statistical Models, Regional Models, and Stratosphere (Table 5) as discussed in the subsections below.

5 | CLIMATIC PATTERNS

In this section, we consider patterns of climate variability. Such patterns are useful from the point of view of stakeholders because they allow classifying meteorological situations that involve similar behaviour of different variables, among them wind. The predictability of these patterns at seasonal and subseasonal scales is limited; however, it is worthwhile compared to a total lack of information. Because of it, research on them related to winds and for application the wind power sector has been extensive from multiple points of view, for example, Burningham and French (2013), Couto *et al.* (2015), Correia *et al.* (2017), Cradden *et al.* (2017), Grams *et al.* (2017) and Zubiate *et al.* (2017). Indeed, some models have shown a reasonable skill in forecasting some of these patterns. For example, Lledó *et al.* (2020) analysed the methodology to produce a seasonal forecast of four patterns:

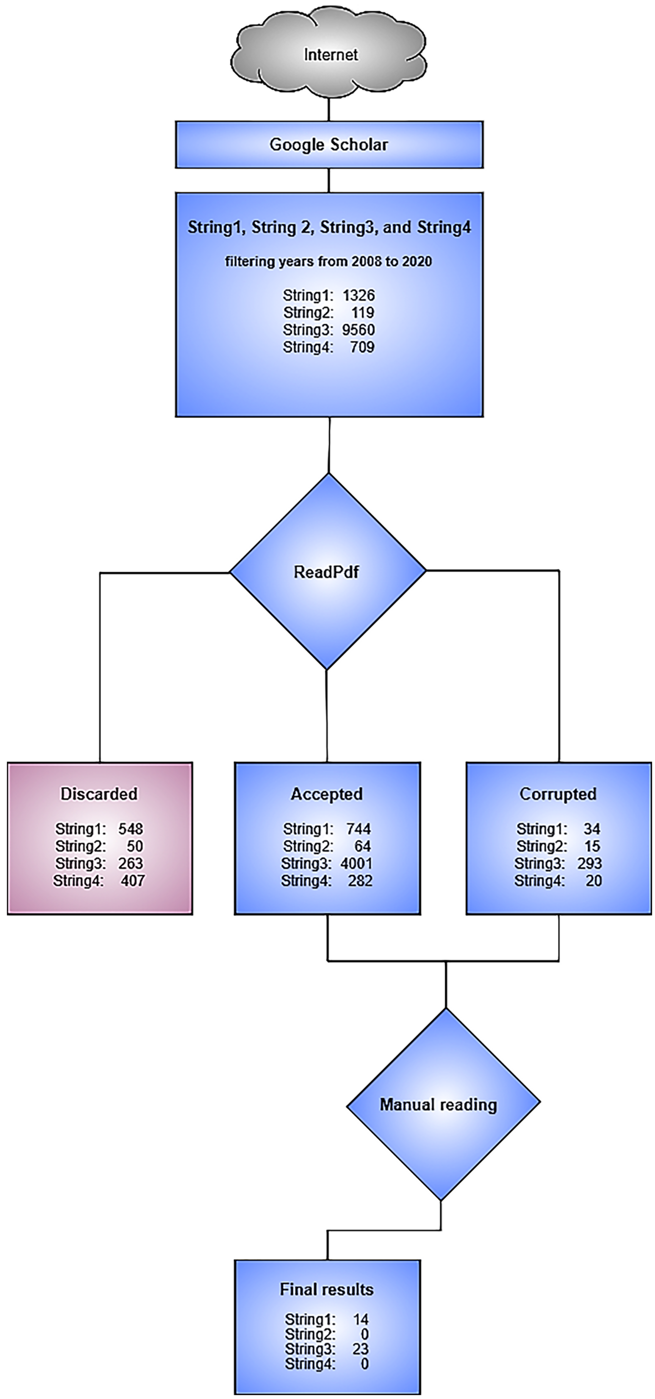

FIGURE 1 Search strategy and number of results obtained for strings 1, 2, 3 and 4. "Manual reading" means reading the selected scientific literature [Colour figure can be viewed at wileyonlinelibrary.com]

The North Atlantic Oscillation (NAO) (Hurrel, 2003), East Atlantic (EA) (Wallace and Gutzler, 1981), East Atlantic/Western Russia (EAWR) (Lim, 2015) and Scandinavian pattern (SCAND) (Barnston and Livezey, 1987). They showed that these patterns can be simulated by some seasonal prediction systems. Taking into account the results obtained

TABLE 3 List of studies on wind seasonal forecasting considered here following systematic search and review

Region	*N*	References
Iberian Peninsula	17	Martín *et al.* (2011a, 2011b), Katsafados *et al.* (2011), Chávez-Arroyo *et al.* (2013), Montávez *et al.* (2014), Landelius *et al.* (2016), Walz *et al.* (2018), Scaife *et al.* (2014), Scoccimarro *et al.* (2011), Jimenez *et al.* (2010), Lledó *et al.* (2020), Jimenez *et al.* (2008), Beerli *et al.* (2019), Della-Marta *et al.* (2009), Peña *et al.*, 2011, Büeler *et al.* (2020) and Ramon *et al.* (2021)
Canary Islands	7	Lledó *et al.* (2020), Chávez-Arroyo *et al.* (2013), Landelius *et al.* (2016), Scaife *et al.* (2014), Scoccimarro *et al.* (2011), Büeler *et al.* (2020) and Ramon *et al.* (2021)

TABLE 4 List of studies on wind power seasonal forecasting considered here following systematic search and review

Region	*N*	References
Iberian Peninsula	7	Santos *et al.* (2015), Jerez *et al.* (2013), Ravestein *et al.* (2018), Beerli *et al.* (2017), Santos-Alamillos *et al.* (2014), Monteiro Correia (2015) and Van der Wiel *et al.* (2019)
Canary Islands	0	

from the studies considered here, we find that for spring (March–May) the variability of regional wind over the IP is dominated by the Scandinavian pattern (SCAND) (Barnston and Livezey, 1987), North Atlantic Oscillation (NAO) (Hurrel, 2003) and East Atlantic (EA) (Wallace and Gutzler, 1981) pattern (Martín *et al.*, 2011a).

SCAND is linked to above-normal wind gusts over the IP, and NAO is correlated with maximum wind speeds in the area (Martín *et al.*, 2011b).

EA explains winter wind storms in the north and northwest of the IP and NAO explains these in other areas. In regions where NAO dominates, simple use of the forecast NAO can improve regional predictions of winter storms (Scaife *et al.*, 2014).

The relationship between the variability of wind power and climate patterns was evaluated for Portugal in an MSc thesis. Their influence on the wind power systems in this region was quantified. Over Portugal, NAO, EA and SCAND dominate the seasonal variability of wind power (Monteiro Correia, 2015).

An accurate prediction of the average wind speed and wind velocity is possible using statistical-dynamical downscaling of surface wind fields for long-term periods through the use of empirical orthogonal functions (EOFs) (Chávez-Arroyo *et al.*, 2013). A particularly noteworthy improvement of this methodology is the better representation of temporal variability, which is 30% better than the industry-standard method (Rife *et al.*, 2013).

There exists a spatial balancing pattern between the wind energy resources in the northeastern region of Andalusia and the Gibraltar area. This pattern was found in the annual and seasonal analysis, being more robust in winter (Santos-Alamillos *et al.*, 2014).

The optimal locations of wind farms in the IP are the Ebro valley (northeast of the IP), coastal areas in the southwest, and some mountain ranges in the northwest (Jerez *et al.*, 2013).

In the future (and under climate change) the NAO will continue to be the main pattern driving wind power variability for the IP (Ravestein *et al.*, 2018).

Daily surface wind fields for the region of Navarra can be classified into six different weather patterns. These patterns show seasonal dependence. Therefore, it is possible to know in advance the behaviour of the wind according to the season of the year. The northwestern winds are the dominant pattern (60.9%) followed by the southeastern circulations (30.5%). The location of the stationary subtropical high-pressure centre over the Azores islands has a strong influence in the surface flows of this region (Jiménez *et al.*, 2008). The strong wind events in Catalonia (northeast of the IP) can be classified into six regional weather patterns. These events are characterized by the presence of the Azores high over the west of Europe cause the most of wind gust is in the northern region from the northeast. However, when the Azores high is located more in the south the most of winds gust are from the northwest and the extreme winds affect the whole region (Peña *et al.*, 2011).

In the region of the Ebro Valley (northeast of the IP), the days with the Atlantic Ridge pattern (Vautard, 1990) have higher than normal wind power production. Along the west coast of the IP have an increase in average wind power the days with the NAO pattern. The days with the Scandinavian Blocking (Vautard, 1990) regime have lower than normal wind power in the northwest coast of the IP (Van der Wiel *et al.*, 2019).

The strong Madden–Julian Oscillation (MJO) (Zhang, 2005) events have an impact on surface wind speed over the IP and the CI during January, February and March. It is possible to verify a positive wind speed anomaly in the north of the IP and a negative wind speed anomaly in the CI 15 days after phase 1 of the strong MJO event. Ten days after phase 2 it shows a positive anomaly of wind speed in

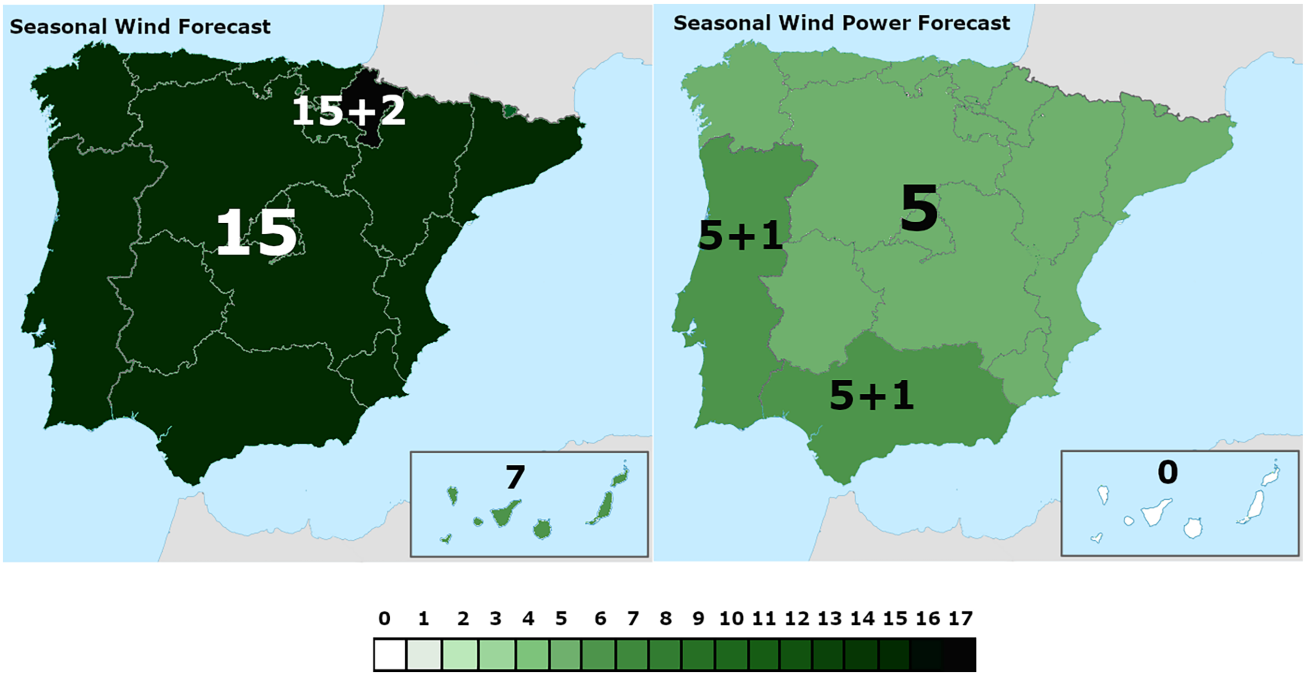

FIGURE 2 Number of papers obtained addressing seasonal prediction of wind (left) and wind power (right) by region in the IP and the CI. Spain is shown divided into administrative "autonomous regions" because research tends to focus specifically on these. The CI are included in the lower right-hand corner of each figure [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 5 Classification of results according to methodologies used

Methodologies	*N*	References
Climatic patterns	13	Martín *et al.* (2011a, 2011b), Walz *et al.* (2018), Scaife *et al.* (2014), Monteiro Correia (2015), Chávez-Arroyo *et al.* (2013), Santos-Alamillos *et al.* (2014), Jerez *et al.* (2013), Ravestein *et al.* (2018), Lledó *et al.* (2020), Jimenez *et al.* (2008), van der Wiel *et al.* (2019) and (Peña *et al.* (2011)
Statistical models	2	Della-Marta *et al.* (2009) and Ramon *et al.* (2021)
Regional models	6	Landelius *et al.* (2016), Katsafados *et al.* (2011), Jimenez *et al.* (2010), Montávez *et al.* (2014), Santos *et al.* (2015) and Scoccimarro *et al.* (2011)
Stratosphere	3	Beerli *et al.* (2017), Beerli *et al.* (2019) and Büeler *et al.* (2020)

the north of the IP. Five days after phase 3 it shows a positive anomaly of wind speed in the east of the IP and the CI. During the phase 4 it is reported a negative anomaly in two small regions of the IP (the Ebro valley and the south-east of the IP) and a positive anomaly in Gran Canaria and Tenerife islands (Lledó and Doblas-Reyes, 2020).

6 | STATISTICAL MODELS

The 10-m wind from reanalysis should not be considered as a useful tool to approach wind storms over Europe, because their return periods show very low correlations, at least for ERA-40 (Della-Marta *et al.*, 2009).

Hybrid models (combination of climatic patterns obtained from downscaling and statistical methods) show mixed changes in predictability one and 2 months ahead for near-surface wind speed compared to downscaled forecasting of climatic patterns alone. Correlations of the near-surface wind speed increase in the range of 0.2–0.4 for the south of the IP and the CI. On the other hand, they can decrease up to 0.2 for the north of the IP (Ramon *et al.*, 2021).

7 | REGIONAL MODELS

2D downscaling and analysis of the 10-m wind provide some detailed information for mountainous areas for Europe (Hirlam Council, 2020). The increased wind speeds reported in the analysis depend on a combination of orographic and synoptic effects. It is found that "During the winter, there is more synoptic activity in north-western Europe, and the synoptic activity is shifted towards the southern and southeastern parts of Europe during the summer." In areas with high-terrain of the IP during the winter there is more synoptic activity than in the summer. In the CI there is more synoptic activity in the summer than in the winter (Landelius *et al*., 2016).

Wind speed forecasts using WRF (NCAR, 2020) for the Mediterranean region overestimate the wind speed by up to 1.5 $m{\cdot}s^{-1}$ during the evening hours, while the forecast error remains almost constant (2.5–3 $m{\cdot}s^{-1}$) over the entire time of the forecast. In the IP, only over the central plain shows a moderate underestimation of the surface wind speed, for the remaining regions of the IP the model overestimates the surface wind speed. The results suggest that autumn and winter are the seasons that contribute the most to the systematic overestimation (Katsafados *et al*., 2011).

Meridional wind variability for Navarra is more accurately reproduced by WRF with a 2 km spatial resolution than zonal wind variability. The simulated wind variability for the Ebro valley, the mountain stations, and the northern valleys are similar to observations; the temporal variability is not well-reproduced in the central zone (Jimenez *et al*., 2010).

MM5 (Grell *et al*., 1994) reproduces wind variability in the central plains of the IP better than for the Pirineos mountains and the Mediterranean. The analysis of trends shows a reduction in wind speed during the winter and an increase in summer (Montávez *et al*., 2014).

Two papers contain descriptions of the use of regional models of the seasonality of wind and wind power: The highest values of daily mean wind power were found in winter over northern and eastern Iberia, particularly at high elevations and in coastal regions. Southern Andalucia shows high wind power throughout the year, whereas the Ebro valley and the central-western coast shows high wind power in summer. The projections show enhanced autumn wind power in southern Andalucia (Santos *et al*., 2015).

The study of the seasonal trends in extreme events in wind speed shows that over the land surface, there are no substantial differences between winter and summer (Scoccimarro *et al*., 2011).

8 | STRATOSPHERE

Exists a strong relationship between the lower stratospheric circulation for a month ahead and wind power generation in Europe. This relationship is due to episodes of troposphere-stratosphere coupling, which lead to prolonged periods with positive or negative NAO conditions. In normal conditions, the results show that the predictability is not higher than usual for the IP (Beerli *et al*., 2017). However, the ECMWF subseasonal forecast system shows forecast skill for the 10-m wind speed in the IP following strong and weak stratospheric polar events (Büeler *et al*., 2020).

The Scandinavian Trough (ScTr), the Greenland Blocking regime (GL), the Zonal regime (ZO) and the European Blocking Regime (Eu BL) (Vautard, 1990) influence the studied regions. In winter (DJF), high wind events in the IP (100-m wind speed greater than the 93% percentile) are dominated by the ScTr during strong polar vortex conditions. However, during weak and neutral polar vortex conditions, they are dominated by the GL. Low wind events (100-m wind speed lower than the 7% percentile) are dominated by the ZO during strong and neutral polar vortex conditions; however, in weak polar vortex conditions, Eu BL is the dominating pattern (Beerli and Grams, 2019).

9 | CONCLUSIONS

In this study, we performed a systematic review of the scientific literature on the application to wind power prediction of seasonal and subseasonal forecast for the IP and the CI. We focused on research works published for the years 2008–2021. We studied a total of 14,293 documents and filtered them both automatically and manually. This resulted in a total of 24 scientific documents that were relevant for this review.

It must be noted that our methodology is conceived to accomplish a systematic review without to leave apart existing relevant literature. The software tools here used for it perform very well on this. But it is also that they do not prevent the possibility that a few papers with some relevant bits of information are left out. The reasons for it are problems with the format of the documents to analyse, their indexing by search engines or keywords. In such a case, our expertise and knowledge of the field are key. Notwithstanding, the number of cases of not automatically included useful works is minimum, and does not prevent reaching a complete review of the state-of-the-art that contains all the main ideas and relevant information in the field.

The main results from these works can be summarized as follows:

As expected, NAO, EA and SCAND are the main patterns that explain the variability in springtime in the IP. SCAND is the most important pattern linked to the wind speed anomaly in the springtime, followed by NAO. The patterns that explain the winter wind storms are EA in the north and northwest and NAO in the other parts of the IP. For the Mediterranean region, NAO and wind energy are correlated, with a coefficient of circa −0.6. Besides, the Atlantic Ridge pattern has an influence on the production of wind power in other regions of the IP; however, it is secondary to others.

Also, three studies relevant to this work were not chosen by our search algorithms, because of several reasons (mainly lack of discussion using the selected keywords): Grams *et al*. (2017) reveal that the Atlantic Ridge is a pattern related to positive wind anomalies in the northwest of the IP. This is relevant because, during this regime, Spain increases the mean wind power generation. Zubiate *et al*. (2017) characterize the effect of the interaction between the above mentioned three weather patterns on the variations of wind speed. Their results showed that the distribution of positive or negative anomalies of wind speed into de the IP not only depend on the phase of the NAO but for each NAO phase it is necessary to assess the behaviour of the other patterns (EA and SCAND). Torralba *et al*. (2021) find that there is potential in the predictability of atmospheric circulation patterns over the Euro-Atlantic sector for the wind power sector. That said, there is a margin for improvement, mainly from a better representation of the sea-level pressure in the seasonal prediction systems.

The works that studied the regional weather patterns for a specific region into the IP obtained good results. However, the orography imposes severe limitations to their validity. Even so, these results allow us to relate a weather pattern with the maximum of wind speeds in the region and the predominant wind direction into it. This information can be very useful for the energy sector to improve energy efficiency and yields of wind farms.

The stratosphere exhibits longer predictability time scales than the troposphere, beyond 2 weeks for most of the seasonal forecast models. Comparisons with nine models conclude that, currently, the ECMWF model presents a very high skill regarding predictability in the stratosphere and troposphere on subseasonal time scales (Domeisen *et al*., 2020a). Also, results show that during the boreal winter, the changes in the features of the stratospheric polar vortex are an important source of predictability for wind and wind power in Europe. In particular, strong and weak stratospheric polar vortex events can be linked with wind speeds at surface levels through climatic patterns. Improvements in this field are evident using hybrid models, although of limited application.

On the other hand, the impacts on the stratospheric polar vortex of phenomena like El Niño–Southern Oscillation (ENSO) (Neelin *et al*., 1998), Quasi-Biennal Oscillation (QBO) (Baldwin *et al*., 2001) and MJO can have a role on seasonal predictability, as they affect the European weather regimes. However, usually the papers that studied these issues do not provide specific information on surface wind or wind power for the region of interest (Cassou, 2008; Domeisen *et al*., 2015) and, therefore they have not been considered here. It is also known that seasonal forecast models can represent the weakening of the polar vortex depending on the phase of the precursors like (QBO) ENSO and MJO (Domeisen *et al*., 2020b).

Other results in the study of seasonal forecast models showed that the Monthly Predictor System obtained for the S2S project ECMWF could predict the wind speed 2 weeks in advance in the IP (Soret *et al*., 2019). The skill for surface wind using the ECMWF System4 prediction system is modest in the IP but when looking at the wind capacity factor shows a slight increase of skill in the north of this region (Lledó *et al*., 2019). GloSea5 successfully reproduces the influence of the NAO on European Climate, leading to skilful forecast of wind speed and wind power (Clark *et al*., 2017).

Also, it seems clear that regional models allow us to forecast the seasonal wind variability and seasonal wind power for different regions in the IP. However, there is a lack of studies in the literature covering the IP and the CI in particular, and the only studies covering these islands are designed for wider spatial domains. This is relevant because energy supply in the CI relies heavily on wind power, with 56 installed farms totalling 447 MW (Wind Business Association, 2020) and a wind-pumped hydropower station, Gorona del Viento-El Hierro, which is a ground-breaking system and unique in the world (Gorona del Viento, 2021). There is no doubt that the energy security demands better knowledge and more focused studies of the wind resources for this region.

We are aware of ongoing efforts to improve the status of seasonal and subseasonal forecasting such as SECLI-FIRM (The Added Value of Seasonal Climate Forecasting for Integrated Risk Assessment) (SECLI-FIRM, 2020). Another projects are the S2S4E (S2S4E Project, 2020, p. 4) and the Copernicus initiative (The C3S Energy Operational Service, 2020) which will create an operational climate service in the seasonal and subseasonal forecast to convert the findings in this area to actual application in renewable energies (including wind power).

As a general conclusion, we believe that given the relevance of wind power for future energy planning and the exploitation of resources in the region, there is a lack of studies (or at least of published literature) on seasonal forecasting of wind and wind power for the IP and the CI. Moreover, it seems that there are many good research results on wind and its seasonal and subseasonal forecast. Still, only a few seem to go a step beyond in the form of knowledge transfer and research papers applied to the needs of stakeholders. Given the central role of wind power in current renewable energy capacities and in future moves towards a low-carbon society, our results suggest that increased efforts in this area could lead to significant advances, which are both necessary and feasible.

ACKNOWLEDGEMENTS

This research has been funded by the Naturgy Chair at the Universidade de Vigo. The EPhysLab is supported by the Xunta de Galicia under the project D431C 2017/64-GRC "Programa de Consolidación e Estructuración de Unidades de Investigación Competitivas" co-funded by the European Regional Development Fund (ERDF). During part of the work here developed Juan A. Añel was supported by a Ramón y Cajal Grant by the Government of Spain (RYC-2013-14560).

ORCID

Susana Bayo-Besteiro https://orcid.org/0000-0003-1875-4364
Michael García-Rodríguez https://orcid.org/0000-0003-4172-5107
Xavier Labandeira https://orcid.org/0000-0003-2952-058X
Juan A. Añel https://orcid.org/0000-0003-2448-4647

REFERENCES

Añel, J.A. (2011) The importance of reviewing the code. *Communications of the ACM*, 54, 40–41. https://doi.org/10.1145/1941487.1941502.

Añel, J.A. (2015) On the importance of weather and climate change for our present and future energy needs. *Contemporary Physics*, 56, 2–3. https://doi.org/10.1080/00107514.2015.1006251.

Añel, J.A. (2017) Comment on "Most computational hydrology is not reproducible, so is it really science? By Christopher Hutton et al.". *Water Resources Research*, 53, 2572–2574. https://doi.org/10.1002/2016WR019285.

Baldwin, M.P., Gray, L.J., Dunkerton, T.J., Hamilton, K., Haynes, P. H., Randel, W.J., Holton, J.R., Alexander, M.J., Hirota, I., Horinouchi, T., Jones, D.B.A., Kinnersley, J.S., Marquardt, C., Sato, K. and Takahashi, M. (2001) The quasi-biennial oscillation. *Reviews of Geophysics*, 39, 179–229. https://doi.org/10.1029/1999RG000073.

Barnston, A.G. and Livezey, R.E. (1987) Classification, seasonality and persistence of low frequency atmospheric circulation patterns. *Monthly Weather Review*, 115, 1083–1126. https://doi.org/10.1175/1520-0493(1987)115<1083:CSAPOL>2.0.CO;2.

Beerli, R., and Grams, C.M., (2019). Stratospheric modulation of the large-scale circulation in the Atlantic–European region and its implications for surface weather events. *Q J R Meteorol Soc*, 145, 1–19. https://doi.org/10.1002/qj.3653.

Beerli, R., Wernli, H. and Grams, C.M. (2017) Does the lower stratosphere provide predictability for month-ahead wind electricity generation in Europe? *Quarterly Journal of the Royal Meteorological Society*, 143, 3025–3036. https://doi.org/10.1002/qj.3158.

BP. (2021) *Statistical review of world energy 2021*. BP p.l.c. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-full-report.pdf

Büeler, D., Beerli, R., Wernli, H. and Grams, C.M. (2020) Stratospheric influence on ECMWF sub-seasonal forecast skill for energy-industry-relevant surface weather in European countries. *Quarterly Journal of the Royal Meteorological Society*, 146, 3675–3694. https://doi.org/10.1002/qj.3866.

Burningham, H. and French, J. (2013) Is the NAO winter index a reliable proxy for wind climate and storminess in northwest Europe? *International Journal of Climatology*, 33, 2036–2049. https://doi.org/10.1002/joc.3571.

Cassou, C. (2008) Intraseasonal interaction between the Madden–Julian Oscillation and the North Atlantic Oscillation. *Nature*, 455, 523–527. https://doi.org/10.1038/nature07286.

Chávez-Arroyo, R., Lozano-Galiana, S., Sanz-Rodrigo, J. and Probst, O. (2013) On the application of principal component analysis for accurate statistical-dynamical downscaling of wind fields. *Energy Procedia*, 40, 67–76. https://doi.org/10.1016/j.egypro.2013.08.009.

Clarivate Analytics. (2020) Web of Science. https://clarivate.com/products/web-of-science/. [Accessed 21 July 2021].

Clark, R.T., Bett, P.E., Thornton, H.E. and Scaife, A.A. (2017) Skilful seasonal predictions for the European energy industry. *Environmental Research Letters*, 12, 1–9. https://doi.org/10.1088/1748-9326/aa94a7.

Correia, J.M., Bastos, A., Brito, M.C. and Trigo, R.M. (2017) The influence of the main large-scale circulation patterns on wind power production in Portugal. *Renewable Energy*, 102, 214–223. https://doi.org/10.1016/j.renene.2016.10.002.

Couto, P., Costa, L., Rodrigues, V., Lopes, V. and Estanqueiro, A. (2015) Impact of weather regimes on the wind power ramp forecast in Portugal. *IEEE Transactions on Sustainable Energy*, 6, 934–942. https://doi.org/10.1109/TSTE.2014.2334062.

Cradden, L.C., McDermott, F., Zubiate, L., Sweeney, C. and O'Malley, M. (2017) A 34-year simulation of wind generation potential for Ireland and the impact of large-scale atmospheric pressure patterns. *Renewable Energy*, 106, 165–176. https://doi.org/10.1016/j.renene.2016.12.079.

Dawkins, L.C. (2019) *Weather and Climate Related Sensitivities and Risks in a Highly Renewable UK Energy System: A Literature Review*. Met Office. Available at: https://www.nic.org.uk/publications/weather-and-climate-change-risks-in-a-highly-renewable-uk-energy-system-literature-review-by-met-office/. [Accessed 21st July 2021].

de Freitas Viscondi, G. and Alves-Souza, S.N. (2019) A systematic literature review on big data for solar photovoltaic electricity generation forecasting. *Sustainable Energy Technologies and Assessments*, 31, 54–68. https://doi.org/10.1016/j.seta.2018.11.008.

Della-Marta, P.M., Hubert Mathis, H., Frei, C., Liniger, M.A., Kleinn, J. and Appenzeller, C. (2009) The return period of wind storms over Europe. *International Journal of Climatology*, 29, 437–459. https://doi.org/10.1002/joc.1794.

Domeisen, D.I.V., Butler, A.H., Charlton-Perez, A.J., Ayarzagüena, B., Baldwin, M.P., Dunn-Sigouin, E., Furtado, J. C., Garfinkel, C.I., Hitchcock, P., Karpechko, A.Y., Kim, H., Knight, J., Lang, A.L., Lim, E.-P., Marshall, A., Roff, G., Schwartz, C., Simpson, I.R., Son, S.-W. and Taguchi, M. (2020a) The role of the stratosphere in subseasonal to seasonal prediction: 1. Predictability of the stratosphere. *Journal of Geophysical Research: Atmospheres*, 125, e2019JD030920. https://doi.org/10.1029/2019JD030920.

Domeisen, D.I.V., Butler, A.H., Fröhlich, K., Bittner, M., Müller, W. A. and Baehr, J. (2015) Seasonal predictability over Europe arising from El Niño and stratospheric variability in the MPI-ESM seasonal prediction system. *International Journal of Climate*, 22, 256–271. https://doi.org/10.1175/JCLI-D-14-00207.1.

Domeisen, D.I.V., Butler, A.H., Charlton-Perez, A.J., Ayarzagüena, B., Baldwin, M.P., Dunn-Sigouin, E., Furtado, J. C., Garfinkel, C.I., Hitchcock, P., Karpechko, A.Y., Kim, H., Knight, J., Lang, A.L., Lim, E.-P., Marshall, A., Roff, G., Schwartz, C., Simpson, I.R., Son, S.-W. and Taguchi, M. (2020b) The role of the stratosphere in subseasonal to seasonal prediction: 2. Predictability arising from stratosphere–troposphere coupling. *Journal of Geophysical Research: Atmospheres*, 125, e2019JD030923. https://doi.org/10.1029/2019JD030923.

Elsevier. (2020) Scopus. https://www.scopus.com. [Accessed 21st July 2021].

Falagas, M., Pitsouni, E., Malietzis, G. and Pappas, G. (2008) Comparison of PubMed, Scopus, Web of Science, and Google Scholar: strengths and weaknesses. *FASEB J*, 338–342. https://doi.org/10.1096/fj.07-9492LSF

Foley, A.M., Leahy, P.G., Marvuglia, A. and McKeogh, E.J. (2012) Current methods and advances in forecasting of wind power generation. *Renewable Energy*, 37, 1–8. https://doi.org/10.1016/j.renene.2011.05.033.

GNU. (2007) GPLv3 License. https://www.gnu.org/licenses/gpl-howto.es.html. [Accessed 2nd August 2019].

Goodess, C., Troccoli, A., Acton, C., Añel, J.A., Bett, P., Brayshaw, D., De Felice, M., Dorling, S., Dubus, L., Penny, L., Percy, B., Ranchin, T., Thomas, C., Trolliet, M. and Wald, L. (2019) Advancing climate services for the European renewable energy sector through capacity building and user engagement. *Clim Serv*, 16, 100139. https://doi.org/10.1016/j.cliser.2019.100139.

Google. (2021) Google Scholar https://scholar.google.es/. [Accessed 21st July 2021].

Gorona del Viento (2021) Cómo funciona la Central Hidroeólica?. Available at: https://www.goronadelviento.es/ [Accessed 22nd July 2021].

Government of Spain (2015) Boletín Oficial del Estado. Available at: http://www.boe.es. [Accessed 20th June 2021].

Grams, C., Beerli, R., Pfenninger, S., Staffell, I. and Wernli, H. (2017) Balancing Europe's wind-power output through spatial deployment informed by weather regimes. *Natural Climate Change*, 7, 557–562. https://doi.org/10.1038/nclimate3338.

Grell, G.A., Dudhia, J. and Stauffer, D.R. (1994) *Description of the fifth-generation Penn State/NCAR mesoscale model (MM5)*. University Corporation for Atmospheric Research. NCAR technical note NCARTN-398 STR, 117 pp.

Hirlam Council. (2020). Hirlam EURO4M reanalysis. Available at: http://www.euro4m.eu/ [Accessed 11th September, 2020].

Hurrel, J.W. (2003) North Atlantic and Artic Oscillation. In: *Enciclopedia of Atmospheric Sciences*. National Center for Atmospheric Research.

International Renewable Energy Agency. (2021) *Renewable capacity statistics 2021*. Abu Dhabi: International Renewable Energy Agency.

Jerez, S., Trigo, R.M., Sarsa, A., Lorente-Plazas, R., Pozo-Vázquez, D. and Montávez, J.P. (2013) Spatio-temporal complementarity between solar and wind power in the Iberian Peninsula. *EGU General Assembly*, 40, 48–57. https://doi.org/10.1016/j.egypro.2013.08.007.

Jimenez, P.A., González-Rouco, J.F., García-Bustamante, E., Navarro, J., Montávez, J.P., de Arellano, J.V.G., de Duhia, J. and Muñoz-Roldan, A. (2010) Surface wind regionalization over complex terrain: evaluation and analysis of a high-resolution WRF simulation. *Journal of Applied Meteorology and Climatology*, 49, 262–287. https://doi.org/10.1175/2009JAMC2175.1.

Jiménez, P.A., González-Rouco, J.F., Montávez, J.P., Garcıa-Bustamante, E. and Navarro, J. (2008) Climatology of wind patterns in the northeast of the Iberian Peninsula. *International Journal of Climate*, 29, 501–525. https://doi.org/10.1002/joc.1705.

Katsafados, P., Papadopoulos, A., Mavromatidis, E. & Gikas, N. (2011). Quantitative verification statistics of WRF predictions over the mediterranean region. Paper presented at: 12th Annual WRF Users' Event, June 20–24, 2011, Boulder, CO. Available at: http://galaxy.hua.gr/meteoclima/images/stories/model/12WRF2011.extabs.pdf. [Accessed 15th July 2021].

Komusanac, I., Brindley, G., Fraile, D. and Ramirez, L. (2021) *Wind energy in Europe 2020 statistics and the outlook for 2021–2025*. WindEurope.

Landelius, T., Dahlgren, P., Gollvik, S., Jansson, A. and Olsson, E. (2016) A high-resolution regional reanalysis for Europe. Part 2: 2D analysis of surface temperature, precipitation and wind. *Quarterly Journal of the Royal Meteorological Society*, 142, 2132–2142. https://doi.org/10.1002/qj.2813.

Larosa, F. and Mysiak, J. (2019) Mapping the landscape of climate services. *Environmental Research Letters*, 14, 093006. https://doi.org/10.1088/1748-9326/ab304d.

Lim, Y.-K. (2015) The East Atlantic/West Russia (EA/WR) teleconnection in the North Atlantic: climate impact and relation to Rossby wave propagation. *Climate Dynamics*, 44, 3211–3222. https://doi.org/10.1007/s00382-014-2381-4.

Lledó, L., Cionni, I., Torralba, V., Bretonnière, P.-A. and Samsó, M. (2020) Seasonal prediction of Euro-Atlantic teleconnections from multiple systems. *Environmental Research Letters*, 15, 074009. https://doi.org/10.1088/1748-9326/ab87d2.

Lledó, L. and Doblas-Reyes, F. (2020) Predicting daily mean wind speed in Europe weeks ahead from MJO status. *Monthly Weather Review*, 148, 3413–3426. https://doi.org/10.1175/MWR-D-19-0328.1.

Lledó, L., Torralba, V., Soret, A., Ramon, J. and Doblas-Reyes, F.J. (2019) Seasonal forecasts of wind power generation. *Renewable Energy*, 143, 91–100. https://doi.org/10.1016/j.renene.2019.04.135.

Martín, M.L., Valero, F., Morata, A., Luna, M.Y., Pascual, A. and Santos-Muñoz, D. (2011a) Springtime coupled modes of regional wind in the Iberian Peninsula and large-scale variability patterns. *International Journal of Climate*, 31, 880–895. https://doi.org/10.1002/joc.2127.

Martín, M.L., Valero, F., Pascual, A., Morata, A. and Luna, M.Y. (2011b) Springtime connections between the large-scale sea-level pressure field and gust wind speed over Iberia and the Balearics. *Natural Hazards and Earth System Sciences*, 11, 191–203. https://doi.org/10.5194/nhess-11-191-2011.

Montávez, J.P., Lorente-Plazas, R., Jerez, S., Jiménez-Guerrero, P., García-Valero, J.A. and Jiménez, P.A. (2014) Climatología del viento sobre la Península Ibérica: Observaciones y modelos. *Aemet*, 1, 675–685.

Monteiro Correia, J. (2015) *Impacto dos Principais Modos de Variabilidade Climática na Potência Eólica em Portugal*. PhD dissertation.

NCAR. (2020) *Weather Research Forecasting model*. National Center of Atmospheric Research. Available at: https://www.mmm.ucar.edu/weather-research-and-forecasting-model [Accessed 5th September 2020].

Neelin, J.D., Battisti, D.S., Hirst, A.C., Jin, F.-F., Wakata, Y., Yamagata, T. and Zebiak, S.E. (1998) ENSO theory. *Journal of Geophysical Research: Oceans*, 103, 14261–14290. https://doi.org/10.1029/97JC03424.

Peña, J.C., Aran, M., Cunillera, J. and Amaro, J. (2011) Atmospheric circulation patterns associated with strong wind events in Catalonia. *Natural Hazards and Earth System Sciences*, 11, 145–155. https://doi.org/10.5194/nhess-11-145-2011.

Ramon, J., Lledó, L., Bretonnière, P.-A., Samsó, M. and Doblas-Reyes, F.J. (2021) A perfect prognosis downscaling methodology for seasonal prediction of local-scale wind speeds. *Environmental Research Letters*, 16, 054010. https://doi.org/10.1088/1748-9326/abe491.

Ravestein, P., Van der Schrier, G., Haarsma, R., Scheele, R. and Van den Broek, M. (2018) Vulnerability of European intermittent renewable energy supply to climate change and climate variability. *Renewable and Sustainable Energy Reviews*, 97, 497–508. https://doi.org/10.1016/j.rser.2018.08.057.

Rife, D.L., Vanvyve, E., Pinto, J.O., Monaghan, A.J. and Davis, C.A. (2013) Selecting representative days for more efficient dynamical climate downscaling: application to wind energy. *Bulletin of the American Meteorological Society*, 52, 47–63. https://doi.org/10.1175/JAMC-D-12-016.1.

S2S4E Project. (2020) S2S4E Proj. Available at: https://s2s4e.eu/ [Accessed 10th September 2020].

Salcedo-Sanz, S., Pérez-Bellido, A.M., Ortiz-García, E.G., Portilla-Figueras, A., Prieto, L. and Correoso, F. (2009) Accurate short-term wind speed prediction by exploiting diversity in input data using banks of artificial neural networks. *Neurocomputing*, 72, 1336–1341. https://doi.org/10.1016/j.neucom.2008.09.010

Santos, J.A., Rochinha, C., Liberato, M.L.R., Reyers, M. and Pinto, J.G. (2015) Projected changes in wind energy potentials over Iberia. *Renewable Energy*, 75, 68–80. https://doi.org/10.1016/j.renene.2014.09.026.

Santos-Alamillos, F.J., Pozo-Vázquez, D., Ruiz-Arias, J.A., Lara-Fanego, V. and Tovar-Pescador, J. (2014) A methodology for evaluating the spatial variability of wind energy resources: application to assess the potential contribution of wind energy to baseload power. *Renewable Energy*, 69, 147–156.

Scaife, A., Arribas, A., Blockley, E., Brookshaw, A., Clark, R., Dunstone, N., Eade, R., Fereday, D., Folland, C., Gordon, M., Hermanson, L., Knight, J., Lea, D., MacLachlan, C., Maidens, A., Martin, M., Peterson, K., Smith, D., Vellinga, M. and Williams, A. (2014) Skilful long range prediction of European and North American winters. *Geophysical Research Letters*, 41, 2514–2519. https://doi.org/10.1002/2014GL059637.

Schildt, H. (2014) Java 8. 1st ed. Madrid: Anaya Multimedia.

Scoccimarro, E., Gualdi, S., Sanna, A., Bucchignani, E. and Montesarchio, M. (2011) Extreme events in high resolution cmcc regional and global climate models. CMCC Research Paper No. 110, Available at SSRN: https://ssrn.com/abstract=1960499 or http://dx.doi.org/10.2139/ssrn.1960499

SECLI-FIRM (2020) The added value of seasonal climate forecasting for integrated risk management. Available at: http://www.secli-firm.eu/. [Accessed 21st July 2021].

Soret, A., Torralba, V., Cortesi, N., Christel Jiménez, I., Palma, L., Manrique-Suñén, A., Lledo, L., González-Reviriego, N. and Doblas-Reyes, F. (2019) Sub-seasonal to seasonal climate predictions for wind energy forecasting. *Journal of Physics Conference Series*, 1222, 012009. https://doi.org/10.1088/1742-6596/1222/1/012009.

Sturm, B. and Sunyaev, A. (2017) *If you want your research done right, do you have to do it all yourself? Developing design principles for systematic literature search systems*. Karlsruher: Karlsruher Institut für Technologie, pp. 138–146.

Swiatek, B. and Dutka, M. (2015) Wind power prediction for onshore wind farms using neural networks. *RE&PQJ*, 333–338.

The C3S Energy Operational Service. (2020) Operational service for energy sector. Available at: https://climate.copernicus.eu/operational-service-energy-sector [Accessed 11th September 2020].

Torralba, V., Gonzalez-Reviriego, N., Cortesi, N., Manrique-Suñén, A., Lledó, L., Marcos, R., Soret, A. and Doblas-Reyes, F. J. (2021) Challenges in the selection of atmospheric circulation patterns for the wind energy sector. *International Journal of Climatology*, 41, 1525–1541. https://doi.org/10.1002/joc.6881.

United Nations (2015) Paris Agreement. Available at: https://unfccc.int/sites/default/files/english_paris_agreement.pdf. [Accessed 5th May 2021].

US National Library of Medicine National Institutes of Health. (2020) https://pubmed.ncbi.nlm.nih.gov/ [Accessed 21st July 2021].

Van der Wiel, K., Bloomfield, H.C., Lee, R.W., Stoop, L.P., Blackport, R., Screen, J.A. and Selten, F.M. (2019) The influence of weather regimes on European renewable energy production and demand. *Environmental Research Letters*, 14, 094010. https://doi.org/10.1088/1748-9326/ab38d3.

Vautard, R. (1990) Multiple weather regimes over the North Atlantic: analysis of precursors and successors. *Monthly Weather Review*, 118, 2056–2081. https://doi.org/10.1175/1520-0493(1990)118<2056:MWROTN>2.0.CO;2.

Walz, M.A., Befort, D.J., Otto Kirchner-Bossi, N., Ulbrich, U., and Leckebusch, G.C. (2018). Modelling serial clustering and interannual variability of European winter windstorms based on large-scale drivers. *Int J Clim*. 38, 3044–3057. https://doi.org/10.1002/joc.5481

Wallace, J.M. and Gutzler, D.S. (1981) Teleconnections in the geopotential height field during the Northern Hemisphere winter. *Monthly Weather Review*, 109, 784–812. https://doi.org/10.1175/1520-0493(1981)109<0784:TITGHF>2.0.CO;2.

Wen-Yeau, C. (2014) A literature review of wind forecasting methods. *Journal of Energy Engineering*, 2, 161–168. https://doi.org/10.4236/jpee.2014.24023.

Wind Business Association. (2020) Canary map. Available at: https://www.aeeolica.org/sobre-la-eolica/la-eolica-espana/mapa-de-parques-eolicos/canarias [Accessed 11th September 2020].

Zhang, C. (2005) Madden–Julian oscillation. *Reviews of Geophysics*, 43, RG2003. https://doi.org/10.1029/2004RG000158.

Zubiate, L., McDermott, F., Sweeney, C. and O'Malley, M. (2017) Spatial variability in winter NAO–wind speed relationships in western Europe linked to concomitant states of the East Atlantic and Scandinavian patterns. *Quarterly Journal of the Royal Meteorological Society*, 143, 552–562. https://doi.org/10.1002/qj.2943.

Zhang, Y., Wang, J. and Wang, X. (2014) Review on probabilistic forecasting of wind power generation. *Renew Sust Energ Rev*, 255–270. https://doi.org/10.1016/j.rser.2014.01.033

How to cite this article: Bayo-Besteiro, S., García-Rodríguez, M., Labandeira, X., & Añel, J. A. (2022). Seasonal and subseasonal wind power characterization and forecasting for the Iberian Peninsula and the Canary Islands: A systematic review. *International Journal of Climatology*, *42*(5), 2601–2613. https://doi.org/10.1002/joc.7359