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ELECTRICITY PRICE FORECASTING: A SYSTEMATIC LITERATURE REVIEW INFORMED BY TEXT MINING

REVISÃO DE PREÇOS DE ELETRICIDADE: UMA REVISÃO SISTEMÁTICA DA LITERATURA COM AUXÍLIO DE MINERAÇÃO DE TEXTO

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Resumo: Desenvolver modelos preditivos é uma tarefa complexa. Especificamente no que diz respeito aos preços da eletricidade, prever com precisão valores futuros permite a minimização de riscos de planejamento. Este fato torna-se ainda mais relevante no atual cenário geopolítico, representado pela guerra entre a Rússia e a Ucrânia. Diante do exposto, este artigo apresenta uma revisão sistemática da literatura sobre modelos de previsão de preços de eletricidade. Utilizou-se uma metodologia consolidada para levantamento da literatura acadêmica de maior relevância para a temática (n=554). Após essa busca: (i) construiu-se uma matriz de atributos das publicações e (ii) apresentou-se uma análise descritiva com base em dados bibliográficos e relações em rede. O período amostral compreende os anos de 1991 a 2019, com taxa de crescimento anual igual a 23,13% e taxa de publicação anual de 19 artigos. Apesar do aumento do número de estudos sobre previsão de preços de energia elétrica, verificou-se o predomínio de artigos produzidos em poucos países. Este fato reforça a necessidade do fomento de projetos de pesquisa e desenvolvimento relacionados com o mercado energético. Também se constatou que as redes de colaboração em pesquisa ainda são fracas, evidenciando a necessidade de novas parcerias entre países e instituições de pesquisa. Assim, estimular a segurança energética global, bem como incentivar a cooperação e a transferência de tecnologia entre os países torna-se relevante.

Palavras-chave: Previsão do preço da eletricidade; Mercado de comercialização de curto prazo; Revisão sistemática; Bibliometrix.

Abstract: *Developing forecasting models is a difficult task. Particularly concerning electricity prices, accurately predicting their forthcoming values makes it possible to minimize planning risks. This fact becomes even more relevant in the current geopolitical scenario, represented by the war between Russia and Ukraine. Given the above, this paper presents a systematic review of the literature on electricity price forecasting (EPF) models. It presents a methodology that does a robust search of the literature, obtaining the most relevant papers (n = 554) that addressed this theme. Following that search, we: (i) constructed an attribute matrix of the publications, and (ii) presented a descriptive analysis based on bibliographic data, and network relationships. The sample period comprises the years 1991 to 2019, with an annual growth rate equal to 23.13% and an annual publication rate of 19 papers. Despite the increase in the number of studies on electricity price forecasting, the predominance of papers is produced in only a few countries. This fact reinforces the need to encourage research and development projects related to the energy market. It was also found that research collaboration networks are still weak, highlighting the need for new partnerships between countries, and research institutions. Thus, stimulating global energy security, as well as encouraging cooperation and technology transfer between countries, becomes relevant.*

Keywords*: Electricity price forecasting; Day-ahead market; Systematic Review; Bibliometrix.*

1 INTRODUÇÃO

Commodity prices, in general, exhibit stochastic behavior, meaning that future prices are uncertain and difficult to predict (GOMES, 2015). The renewable energy market is no different. Due to this complexity, understanding the dynamics of future energy prices in both the short- and long-term markets is of academic, business, and social relevance (PRIMC & SLABE-ERKER, 2020). This fact becomes even more relevant in the current scenario of global energy insecurity, derived from factors such as the war between Russia and Ukraine (STEFFEN & PATT, 2022) and the repeated interventions of the Organization of the Petroleum Exporting Countries (OPEC) in oil prices over the last few decades (ZUHAIRA & MOHAMMED, 2022).

Successful electricity price forecasting models are based on different techniques such as: (i) classic time series procedures like the autoregressive moving average, autoregressive integrated moving average, generalized

autoregressive conditional heteroscedastic, among others (LIU & SHI, 2013; MIŠNIĆ et al., 2022); (ii) pre-processing techniques like spectrum analysis, wavelets, and Fourier analysis (MIRANIAN, ABDOLLAHZADE & HASSANI, 2013; IWABUCHI et al., 2022); and, (iii) machine learning approaches like neural networks, fuzzy systems, and support vector machines (BUI et al., 2016). Additionally, an alternative class of hybrid models (ZHANG, TAN & WEI, 2020) aims to combine machine learning (YANG et al., 2022) representations with different methods. Instances of these methods are focused time-delay neural networks (CHEN et al., 2019), neural networks with fuzzy inputs (LIU et al., 2015), finite-impulse response neural networks (PIR, SHAH & ASGER, 2017), local feedback dynamic fuzzy neural networks (NAGARAJA et al., 2016), type recurrent fuzzy networks (JAIN et al., 2014; LI, WOO & COX, 2021), and neuro-fuzzy inference systems (MORENO & DOS SANTOS COELHO, 2018), among others.

Due to the economic relevance of the energy market, and the growing interest in renewable sources, the recent development of predictive techniques has attracted the attention of the electricity community (SOEIRO e DIAS, 2020). This is important because it allows analysis of the behavioral pattern of the prices, as well as comprehension of the evolution of the predictive models used. Thus, an electricity price forecasting community has emerged worldwide. To investigate how expert collaboration could be enhanced, it is essential to answer some questions, namely:

i. what are the leading countries, authors, and theoretical approaches related to electricity price forecasting?

ii. what are the gaps in the literature that should be explored, given what has been published so far?

Some papers have begun to address this issue (WERON, 2004; ANTONOPOULOS et al., 2020). The present study approaches the problem using text mining tools such as the Bag-of-words model for language processing and attributes matrices. Benefits include simplifying the representation of substantial textual information. This method has been used in recent literature reviews on innovation (VAN RAAN, 2017), medicine (NAFADE et al., 2018), physics (VAN ECK & WALTMAN, 2017), among others. Based on this framework, we conducted a robust systematic review focusing on the main statistical methods used to predict electricity prices. We also evaluated how the leading agents in this community articulate among themselves.

The present study contributes to the electricity price forecasting literature. The first contribution is methodological, presenting a method for selecting the core publications in the area. It is innovative in that we selected papers from different scientific bases and developed an automatic way to remove duplicates and establish a unified metadata base. Hence, it is possible to establish the flow of knowledge. The second contribution is identifying the most prominent authors, countries, and publications through objective criteria, highlighting the leading research groups.

Finally, our main findings may assist researchers in better understanding the main forecasting techniques and the most important upcoming research topics, arising from this issue. In practical terms, this research will serve as a guide for those interested in the subject, including researchers, policymakers, companies, and other interested parties, showing the leading publications in the area.

The present paper is structured in four sections, as follows. Section 2 explains the methodology and scope of the systematic review. Section 3 presents the papers considered for this review and discusses their main features. Section 4 presents the main findings of the present study, and potential pathways for future studies to explore models, for predicting electricity prices.

2. THEORETICAL BACKGROUND

Energy planning policies foment the interest of regulatory agencies, local

governments, and the business sector. However, reconciling the interests of all the agents involved is not a simple task (Bhattacharyya, 2019) since, for the management to be fulfilled, it is necessary to achieve simultaneous success in: energy supply, attracting investments, the fiscal balance of the government, and tariff modicity (RAO, 2004). Additionally, investing in renewable energies in the present portends reducing the use of fossil fuels in the future, thus generating a positive externality for society (TJØRRING and GAUSSET, 2015). Therefore, the promotion of energy policies favors regional development and, consequently, an improved standard of living for individuals (XU et al., 2019).

Due to the complexity of this issue, and the number of variables involved, public policies for energy trading occupy a prominent place in the energy industry since such policies should provide security in the investment environment (PABLO-ROMERO GIL-DELGADO et al., 2017). Thus, a safe marketing regime is one that accurately signals the price of electricity to agents, allowing them adequately to remunerate the efficiency, reliability, and flexibility of the energy generating sources (WAN et al., 2016).

In this context, the Brazilian government defined the attributions of the Electric Energy Trading Chamber (CCEE) with Decree No. 5,177/2004 (BRASIL, 2004a). One of the CCEE's main responsibilities is to account for the amount of electricity sold in the National Interconnected System (SIN), as well as to promote settlement for the operational values of the purchase and sale of electricity in the Short-Term Market (MCP) (ANEEL, 2013). The same Decree also establishes that the valuation of the amounts settled in the MCP be used for the Settlement Price of Differences (PLD). This price is calculated weekly by the CCEE, considering sub-regional energy markets and load levels to be marketed (EBERT and SPERANDIO, 2018).

The basis for calculating the PLD is the Marginal Operating Cost (CMO), derived from the mathematical methods (Newave and Decomp) used by the National Electric System Operator (ONS) to define the system operation schedule. It should be noted that this arrangement is delimited by a minimum price and a maximum price, established annually by the National Electric Energy Agency (ANEEL) (ANEEL, 2013).

Despite its relevance to the free energy market, the Brazilian PLD is undergoing reformulations. Accordingly, the Ministry of Mines and Energy (MME) has developed a plan for the modernization of the electrical system with Ordinance No.300/2019 (BRASIL, 2019b). The proposals include improvements to the existing computational models for the operation of the national electricity system and adoption of a new method (based on hourly prices) for pricing electricity in the Brazilian spot market. The goal is to bring the price of energy closer to that of the National Electric System (CAPELETTI, 2019; MARCHETTI & REGO, 2022).

The purpose of these procedure is to stimulate energy pricing in a context of demand response programs (JORDEHI, 2019; KALAVANI et al., 2019); i.e., to assign value to energy according to the moment of production, with higher prices at times of higher demand or lower generation, for example. This should lead to efficiency gains for the electrical system, in the long term. At the same time, the changes in the PLD will bring the Brazilian trading system closer to international systems that already adopt hourly prices. These systems include: (i) The Nordic Electicity Market - Nord Pool (HAUGOM et al., 2020); (ii) The Italian Electricity Market - Mercati Energetici Manager (GME) (ILEA et al., 2017); and (iii) The Iberic Electricity Market – Iberian Electricity Market (MIBEL) (PASTOR et al., 2018), among others.

3. MATERIALS AND METHODS

This section presents the methodology, data sources, and data analyses.

3.1 Population, sample, and data collection

An extensive survey of publications, indexed in both the Web of Science (WoS) and the Scopus databases, was conducted. Papers related to electricity price forecasting were

evaluated. Table 1 shows the list of descriptors used in this research. This research utilized boolean operators. It was used as conjunctions to combine or exclude keywords in a search: “AND” and “OR”. We selected journal publications because they had already gone through a peer-reviewed process.

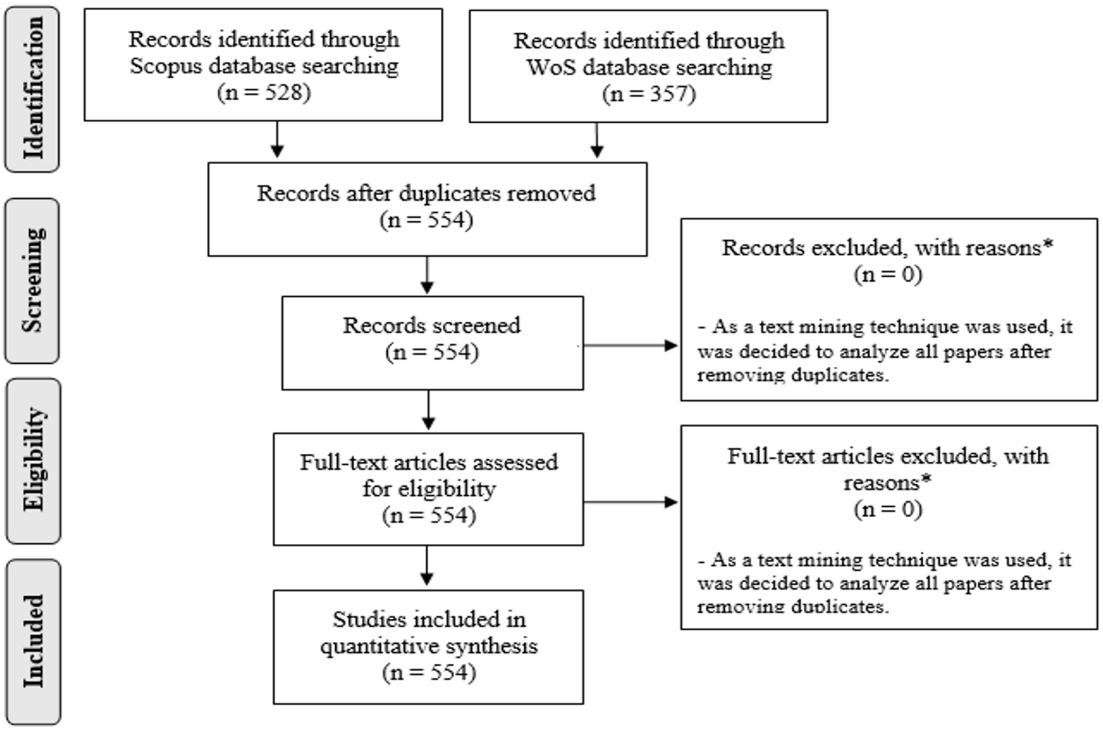
Table 1 - List of descriptors used in the present study

Database	Descriptors
Web of Science	((TS=((("forecasting electricity" OR "predicting electricity") AND ("electricity spot" OR "electricity day-ahead" OR "electricity price")) OR (("price forecasting" OR "price prediction" OR "forecasting price" OR "predicting price" OR "forecasting spikes" OR "forecasting VAR") AND ("electricity spot price" OR "electricity price" OR "electricity market" OR "day-ahead market" OR "power market"))))).
Scopus	((TITLE-ABS-KEY((("forecasting electricity" OR "predicting electricity") AND ("electricity spot" OR "electricity day-ahead" OR "electricity price")) OR (("price forecasting" OR "price prediction" OR "forecasting price" OR "predicting price" OR "forecasting spikes" OR "forecasting VAR") AND ("electricity spot price" OR "electricity price" OR "electricity market" OR "day-ahead market" OR "power market"))))) AND (LIMIT-TO (DOCTYPE,"ar")))

Source: Elaborated by the author

It is noteworthy that WoS and Scopus are the academic citation databases most used to define a study (WERON, 2014). Data extraction from Scopus and WoS (2020-08-30) considered the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement (MOHER et al., 2009) (Figure 1).

Figure 1 - Flowchart outlining the protocol adopted in this systematic review based on MOHER et al. (2009).



Source: Elaborated by the author

Following the merging of the Scopus (n = 528) and Web of Science (n = 357) metadata, the duplicates (n = 331) were removed. This resulted in a population encompassing all publications in English between 1991 and 2019 (n = 554) for the present study. The choice of the research scenario is justified as follows: the first scientific paper on this subject was published in 1991; and 2019 is the year of the most recent publication having complete information available. To filter bibliographic records, we searched for papers that included some of the descriptors presented in Table 2.1 in their titles, abstracts or keywords.

3.2 Data treatment and analysis

After compiling the data, we created a list of publications according to the following attributes: authors and affiliations, paper titles, abstracts, keywords, and the complete references for the analyzed registers. We divided the investigation into sub-stages: first, a descriptive analysis of a bibliographic data frame.

In this sub-stage, we analyzed the annual publication of predictive methods used for electricity price forecasting in the most relevant sources (journals), as well as the most productive countries based on corresponding authors. We also described seminal papers according to the total number of citations, and the most relevant sources utilized in each of them.

Next, we presented the scientific publications on electricity price forecasting as network matrices. These networks displayed meaningful properties of the underlying research, and the influence of bibliometric units, such as scholars, and journals (WALTMAN & VAN ECK, 2012; ARIA & CUCCURULLO, 2017).

3.3 Software and Hardware

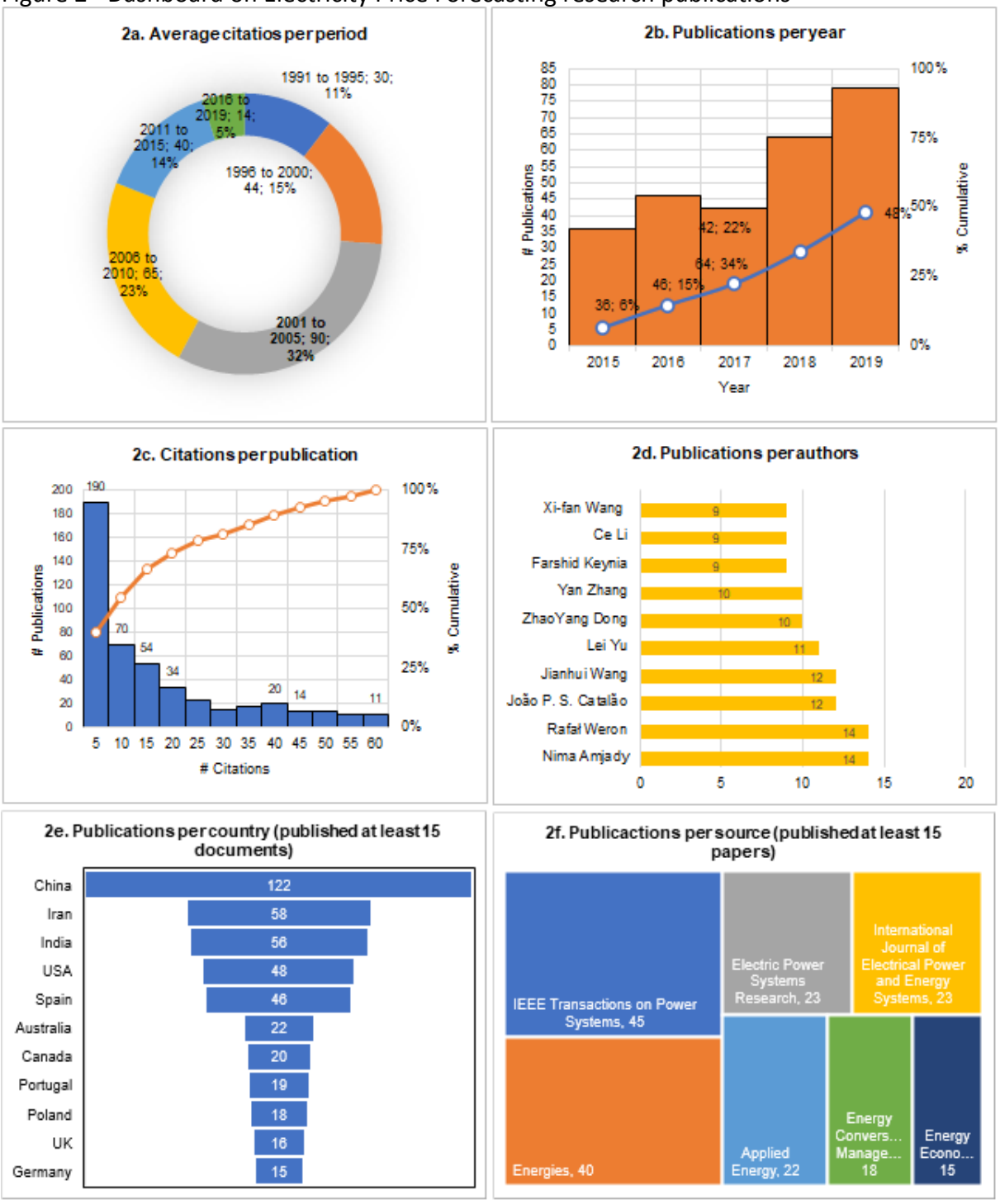
The systematic review of the literature presented in the present study was developed using both the R® (v.3.5.2) software and the "Bibliometrix R-package" proposed by Aria and Cuccurullo (2017), available at http://www.bibliometrix.org. This package utilizes a machine learning framework with data reduction techniques for dealing with substantial textual information, classified here as a classic "Bag of words" problem. To construct the temporal evolution of keywords, and network relationships, we used the free bibliometric software, VOSviewer, proposed by van Eck and Waltman (2010), available at http://www.vosviewer.com/. Hardware specifications of the system used to perform the procedures are CPU Intel Core i5-7200U, 2.70 GHz, 16 GB RAM installed, and the Windows 10 operating system.

4. RESULTS AND DISCUSSION

The papers used for the present study were published between 1991 and 2019. It is noteworthy that the 554 publications analyzed were written by 1115 different authors and published in 206 journals. The publications analyzed comprised 15099 bibliographic references. It was also observed that the 554 publications of the present study used 1416 distinct keywords.

Figure 2a shows that approximately 32% of the bibliographic citations were from 2001 to 2005, indicating that this was the period during which the main work in this area was carried out. Figure 2b shows an exponential growth in the number of papers published on EPF, indicating its academic relevance. Figure 2c shows a concentration of papers having a maximum of 5 citations. Figure 2d shows empirical evidence of Lotka's Law, which describes the frequency of publication by authors in any given field (LOTKA, 1926). The importance of professors Nima Amjady and Rafal Weron is highlighted, each with 14 papers on EPF. With 122 publications (22%), China was the country with the greatest number of papers (Figure 2e). With 45 papers (8%), IEEE Transactions on Power Systems (impact factor equal to 6.62 in 2019) was the most productive source (Figure 2f).

Figure 2 - Dashboard on Electricity Price Forecasting research publications



Source: Elaborated by the author

The publication with the highest number of citations was Mohsenian-Rad & Leon-Garcia (2010). The most recent work was Gellert et al. (2019) (Table 2).

Table 2 - Highlights of Electricity Price Forecasting publications

	Reference	Citations	Title	Contribution
Pioneers	Constantopoulos, Schweppe & Larson (1991)	90	ESTIA: A real-time consumer control scheme for space conditioning usage under spot electricity pricing	Utilizes a decision modeling approach developed for prescribing consumer response to varying electricity price. The case of space conditioning usage is analyzed in detail and a real-time control scheme is proposed.
Most cited	Mohsenian-Rad & Leon-Garcia, (2010)	1288	Optimal residential load control with price prediction in real-time electricity pricing environments	Proposes an optimal and automatic residential energy consumption scheduling framework which attempts to achieve a trade-off between minimizing the electricity payment and minimizing the waiting time for the operation of each appliance in household, in the presence of a real-time pricing tariff combined with inclining block rates.
Most Recent	Gellert et al., (2019)	11	A study on forecasting electricity production and consumption in smart cities and factories	A method for forecasting energy demand and production is proposed. Predictions contribute to balancing and smoothing the electricity intake from the power grid. Experimental evaluation is performed on data recorded in a real energy-management system.

Source: Elaborated by the author

Following the descriptive analyses of these publications, the investigation of the keywords used was undertaken. Table 3 (next page) shows the number of times that each of the 50 main keywords was used. As expected, the most used keywords were derivations of the expression electricity price forecasting. Regarding the predictive models used, the expression artificial neural networks (and its derivations) was present in at least 76 papers in the sample.

In addition, models based on the wavelet transform were cited in at least 25 different documents. This is supported by the fact that many energy trading markets operate on hourly frequency basis; therefore, the EPF forecasts have time series with many observations (ZHANG, LI & LI, 2018; CHANG, ZHANG & CHEN, 2019). Thus, with a lower number of occurrences, there is a greater diversity of techniques used, with emphasis on the classic models of time series, such as those of the Arima class (BANDYOPADHAYAY, ROY & GHOSH, 2013).

Also, as Table 3 shows, several methodologies were used, such as those based on: support vector machine (YUAN, 2013; MA et al., 2018; ZAHID et al., 2019), probabilistic forecasting (UNIEJEWSKI, MARCJASZ & WERON, 2019), fuzzy logic (POUSINHO, MENDES & CATALÃO, 2012), particle swarm optimization (RANI & VICTOIRE, 2019), lasso (STEINHERT & ZIEL, 2019), and hybrid models (DE MARCOS, BELLO & RENESES, 2019), among others. Thus, it is highlighted that EPF is a research segment that uses different forecasting methods, and the development of research to investigate new models is relevant.

Table 3 - Most relevant words – Author's keywords

Rank	Terms	Frequency	Rank	Terms	Frequency
1	electricity price forecasting	112	26	market clearing price	9
2	price forecasting	86	27	short-term forecasting	9
3	electricity market	67	28	deregulation	8
4	forecasting	59	29	electricity price forecast	8
5	electricity price	33	30	prediction intervals	8
6	artificial neural networks	28	31	ann	7
7	neural networks	28	32	artificial intelligence	7
8	electricity markets	26	33	bidding strategy	7
9	neural network	26	34	electricity price prediction	7
10	wavelet transform	25	35	genetic algorithm	7
11	electricity prices	21	36	price spikes	7
12	artificial neural network	20	37	smart grid	7
13	price forecast	19	38	correlation analysis	6
14	time series analysis	15	39	demand response	6
15	day-ahead market	13	40	differential evolution	6
16	power market	13	41	electricity	6
17	support vector machine	13	42	forecast combination	6
18	arima	12	43	hybrid model	6
19	feature selection	12	44	lasso	6
20	probabilistic forecasting	12	45	load forecasting	6
21	particle swarm optimization	11	46	locational marginal price	6
22	data mining	10	47	particle swarm optimization (pso)	6
23	fuzzy logic	10	48	power markets	6
24	time series	10	49	prediction	6
25	electricity spot price	9	50	price prediction	6

Source: Elaborated by the author

The results of Table 3 can be visualized in Figure 3 which shows the wordcloud for the main keywords used. Since the number of occurrences of keywords varies widely for the sample analyzed, the square root of the number of occurrences was taken to improve the visualization of Figure 3. Thus, the wordcloud considered the 100 words with the highest number of occurrences in the sample studies.

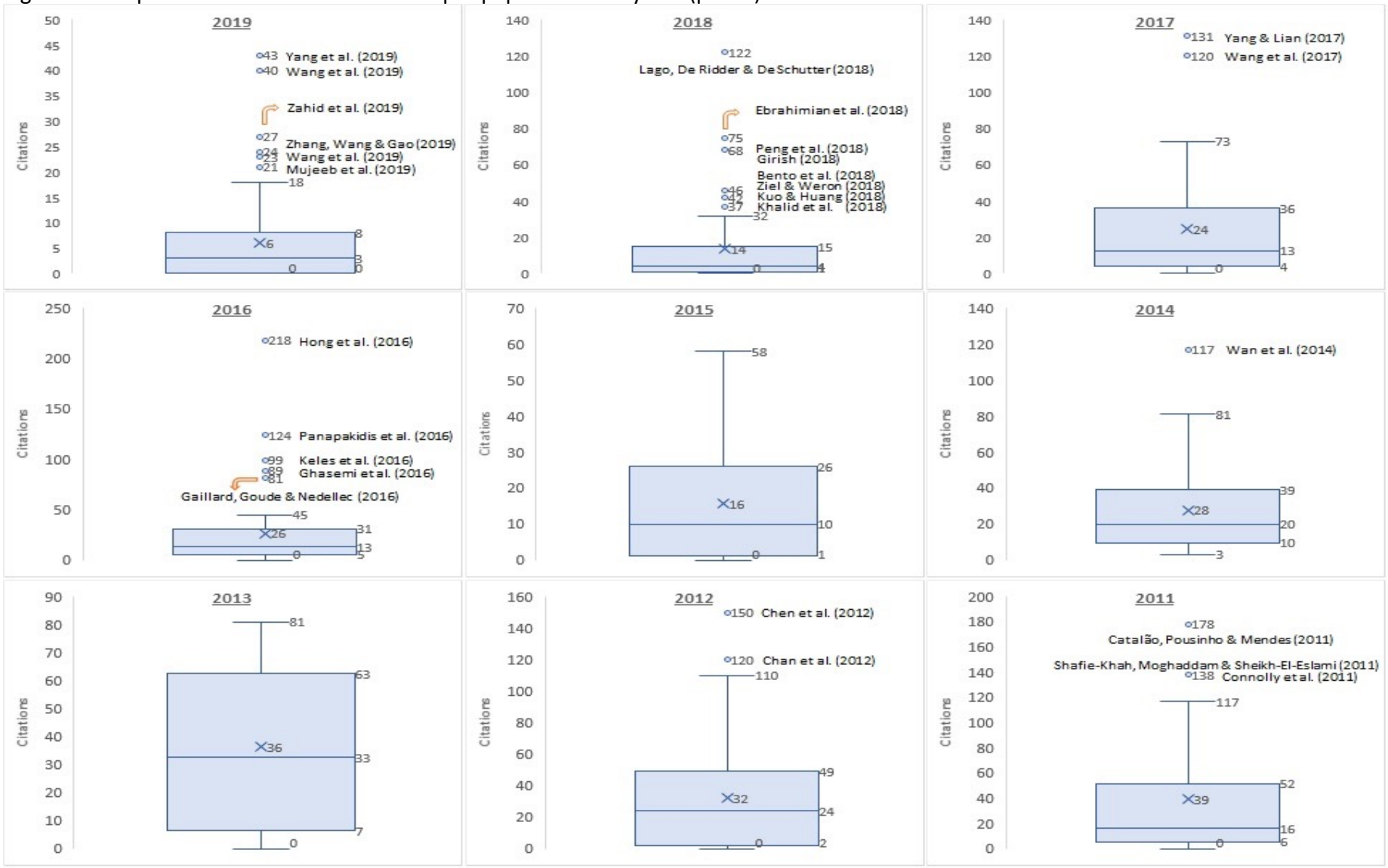
Figure 3 - Wordcloud containing the top 100 keywords used in the sample

Source: Elaborated by the author Figure 3 shows additional details of predictive models

The relevance of models based on spot prices, such as the day-ahead-market, is highlighted. These models use a wide range of techniques, among which the following stand out: ann (WINDLER, BUSSE, & RIECK, 2019), armax (ZHANG et al., 2019), big data (WANG et al., 2019), bootstrap (TAHMASEBIFAR, SHEIKH-EL-ESLAMI & KHEIROLLAHI, 2017), calibration window (HUBICKA, MARCJASZ & WERON, 2018), classification (SHRIVASTAVA, PANIGRAHI & LIM, 2016), clustering analysis (JIN et al., 2015), correlation analysis (PENG, LIU & XIANG, 2013), data mining (GHAYEKHLOO et al., 2019), garch (ZHANG et al., 2019), and genetic algorithm (ALAMANIOTIS et al., 2015), among others.

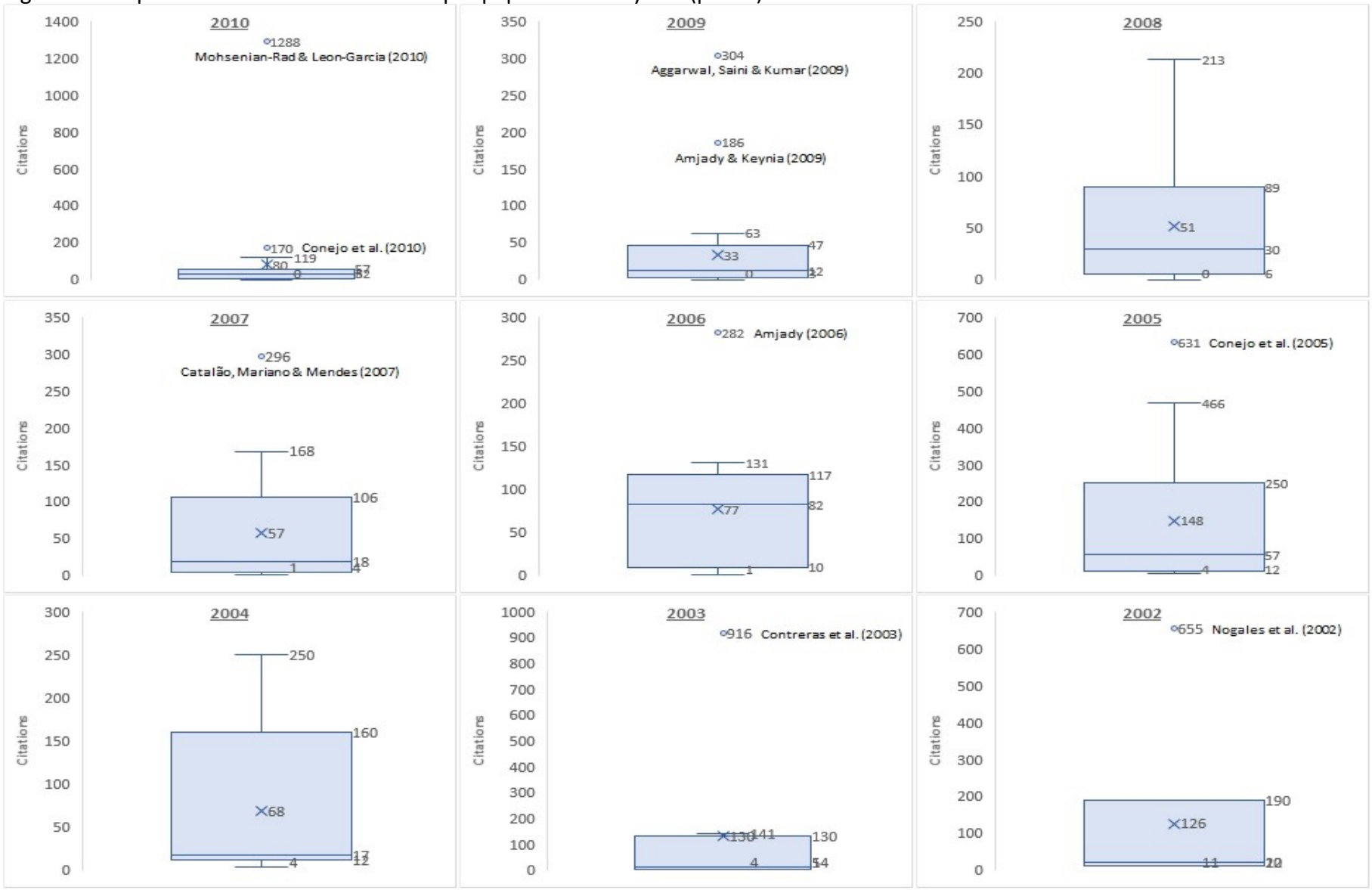
Figures 4 and 5 (next pages) show the evolution of research published over the years, based on the number of citations for each paper. Although the sample analyzed dates from 1991, it is only after 2002 that it is possible to build a boxplot. Publications located beyond the upper limit of the interquartile distance are highlighted. Due to their academic impact, they can be considered references in EPF.

Figure 4 - Boxplot of the number of citations per paper over the years (part a)



Source: Elaborated by the author

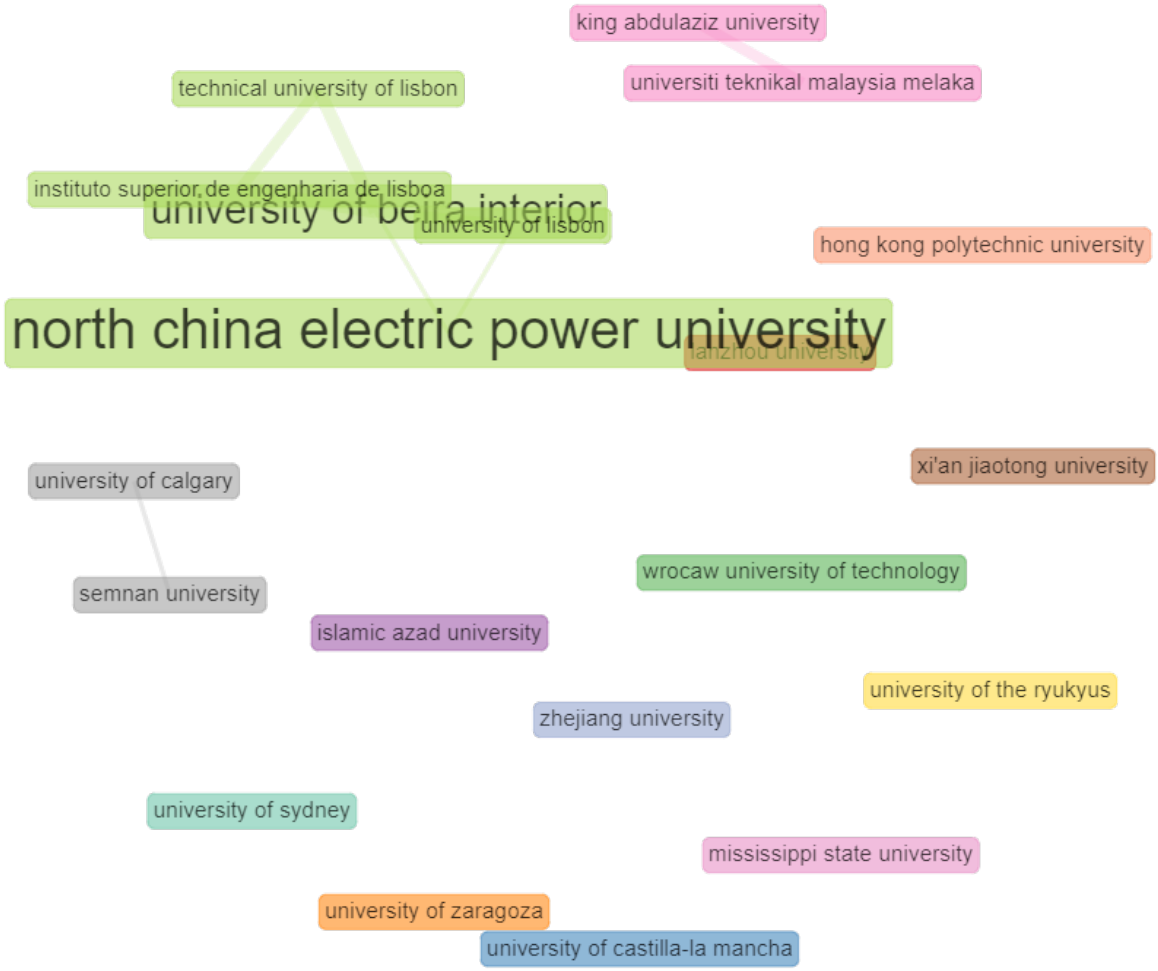
Figure 5 - Boxplot of the number of citations per paper over the years (part b)



Source: Elaborated by the author

Equally as important as the descriptive analyses of publications on EPF, are the investigations by the existing EPF collaboration networks. Figure 6 shows the research relationships between the main research institutions that have published on the topic. This network was designed based on information from each of the published papers and the respective teaching and research institutions of the co-authors. The font size for each institution varies, depending on the number of papers published by the institution. The lines that connect the institutions are a visual representation of the strength of the relationship between two institutions, where thicker lines denote stronger relationships. The network shows the top 20 organizations that published on EPF.

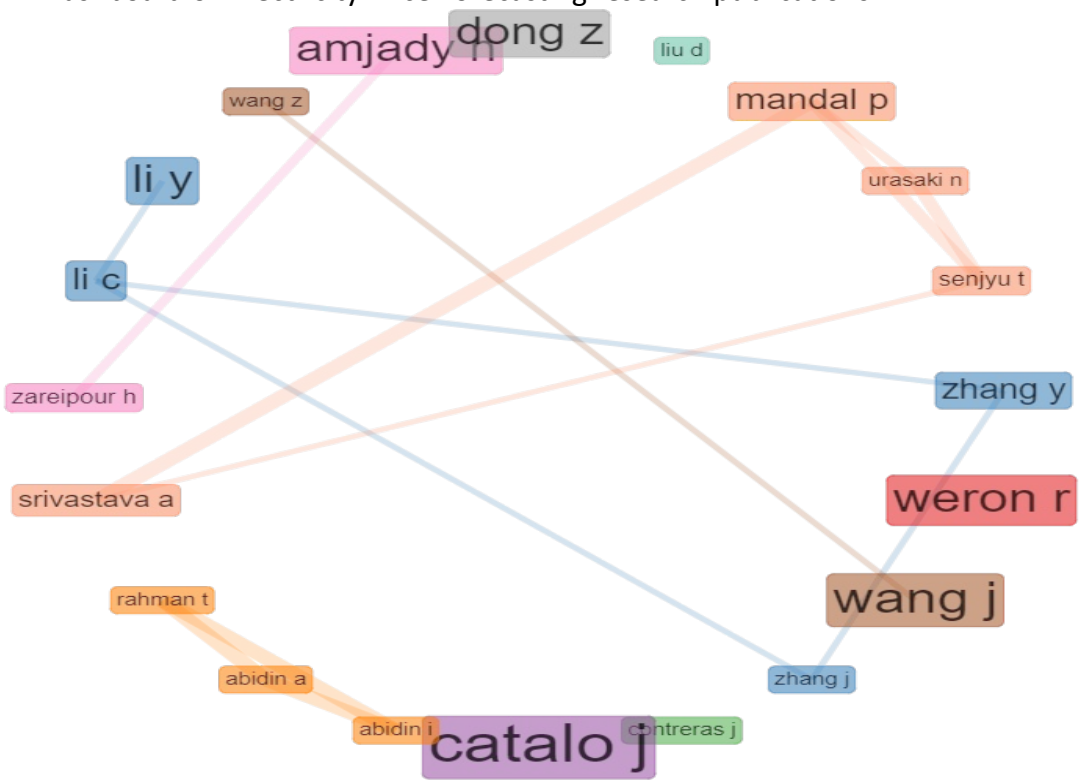
Figure 6 - Dashboard on Electricity Price Forecasting research publications.



Source: Elaborated by the author

As shown in Figure 6, the institutions are separated by color, according to the proximity of their relationships. However, most of the papers on EPF are published in the single country publication format since, as this is a strategic and local issue, collaborations between institutions are still incipient. The main cluster, green, is formed by four Portuguese educational institutions (Technical University of Lisbon; Instituto Superior de Engenharia de Lisboa; University of Veira Interior and University of Lisbon) and one Chinese institution (North Chine Electric Power University). Complementary to Figure 6, Figure 7 (next page) presents a similar analysis. However, it focuses on the partnership networks between the main authors.

Figure 7 - Dashboard on Electricity Price Forecasting research publications



Source: Elaborated by the author

It is reinforced that the degree of collaboration between authors is limited. In most cases, it is restricted to collaboration among authors of the same nation.

5. CONCLUSIONS

Forecasting electricity prices attracts the attention of different agents, since it is a central issue for good planning in the energy production chain. Due to its importance, the growth rate of publications on EPF, in the main journals around the world, is approximately 23% per year. The present study investigated 554 publications on this topic, published between 1991 and 2019, that were indexed simultaneously in the Scopus and Web of Science databases. The present paper used the PRISMA research protocol, which provides a high degree of reliability in the face of the analyses carried out. In addition, data science procedures, such as text mining, were used to describe the main attributes of the bibliographic information collected.

It is noteworthy that the present paper empirically verified the validity of some bibliometric laws, namely, Lotka's Law and Bradford's Law. That is, it provides evidence of a predominance of a few authors (Nima Amjady, Rafal Weron) who publish more, as well as a small set of journals (IEEE Transactions on Power Systems, Energies) that focus scientific production, on the topic. It was found that the years from 2001 to 2005 form the period during which the greatest volume of citations was concentrated.

The present paper also analyzed the main keywords and quantitative methods used in studies on EPF. It was found that, despite the great recurrence of studies based on artificial neural networks, and wavelet transform, there is also a wide range of research being developed based on classic statistical approaches, regression models, hybrid methods, and recent machine learning procedures, for example.

Finally, despite the increasing number of recent studies, the predominance of papers is

still being produced in only a few countries. This inequality highlights both the importance of international cooperation to close the gap, and the need for more connected research clusters. Future development of predictive models depends heavily on the collection, and availability of reliable databases, which is a notable research obstacle in developing countries.

REFERENCES

ALAMANIOTIS, Miltiadis et al. Genetic optimal regression of relevance vector machines for electricity pricing signal forecasting in smart grids. **IEEE transactions on smart grid**, v. 6, n. 6, p. 2997-3005, 2015.

ANEEL. AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA – ANEEL. **Normative Resolution no. 583/2013**. Establishes the procedures and conditions for obtaining and maintaining the situation operational and definition of installed power and net of generating enterprise electricity, 2013.

ANTONOPOULOS, Ioannis et al. Artificial intelligence and machine learning approaches to energy demand-side response: A systematic review. **Renewable and Sustainable Energy Reviews**, v. 130, p. 109899, 2020.

ARIA, Massimo; CUCCURULLO, Corrado. bibliometrix: An R-tool for comprehensive science mapping analysis. **Journal of informetrics**, v. 11, n. 4, p. 959-975, 2017.

BANDYOPADHAYAY, Amitava; ROY, Soumya; GHOSH, Dipojjwal. Forecasting day-ahead price of electricity–a dynamic regression approach. **International Journal of Business Excellence**, v. 6, n. 5, p. 584-604, 2013.

BHATTACHARYYA, Subhes C. Markets for Electricity Supply. In: **Energy Economics**. Springer, London, 2019. p. 699-733.

BRASIL. Presidency of the Republic. **Decree No. 5177/2004**. Regulates articles 4th and 5th of Law No. 10,848, of March 15, 2004, and provides for the organization, attributions and functioning of the Electric Energy Commercialization Chamber - CCEE.

BRASIL. Ministry of Mines and Energy/Office of the Minister. **Ordinance No 300/2019**. Approves, under the terms of this Ordinance, the improvements proposed by the Methodology Working Group of the Standing Committee for Analysis of Methodologies and Computational Programs in the Electricity Sector, 2019.

BUI, Dieu Tien et al. Spatial prediction models for shallow landslide hazards: a comparative assessment of the efficacy of support vector machines, artificial neural networks, kernel logistic regression, and logistic model tree. **Landslides**, v. 13, n. 2, p. 361-378, 2016.

CAPELETTI, Marcelo. **Análise da implementação do preço de liquidação das diferenças (PLD) horário no Brasil e a relação com variáveis de entrada do modelo de cálculo no horizonte de curto prazo**. Course Completion Paper presented to the Electrical Engineering Course, University Federal of Santa Maria – UFSM. Rio Grande do Sul, Santa Maria, 2019.

CHANG, Zihan; ZHANG, Yang; CHEN, Wenbo. Electricity price prediction based on hybrid model of adam optimized LSTM neural network and wavelet transform. **Energy**, v. 187, p. 115804, 2019.

CHEN, Yanhua et al. A novel combined model based on echo state network for multi-step ahead wind speed forecasting: A case study of NREL. **Energy conversion and management**, v. 179, p. 13-29, 2019.

CONSTANTOPOULOS, Panos; SCHWEPPE, Fred C.; LARSON, Richard C. ESTIA: A real-time consumer control scheme for space conditioning usage under spot electricity pricing. **Computers & operations research**, v. 18, n. 8, p. 751-765, 1991.

DE MARCOS, Rodrigo A.; BELLO, Antonio; RENESES, Javier. Short-term electricity price forecasting with a composite fundamental-econometric hybrid methodology. **Energies**, v. 12, n. 6, p. 1067, 2019.

EBERT, P. S.; SPERANDIO, Mauricio. Influence of Integration of Wind Power in Planning the Operation of a Hydrothermal System Using Dynamic Systems. **IEEE Latin America Transactions**, v. 16, n. 5, p. 1432-1438, 2018.

GELLERT, Arpad et al. A study on forecasting electricity production and consumption in smart cities and factories. **International Journal of Information Management**, v. 49, p. 546-556, 2019.

GHAYEKHLOO, M. et al. A combination approach based on a novel data clustering method and Bayesian recurrent neural network for day-ahead price forecasting of electricity markets. **Electric Power Systems Research**, v. 168, p. 184-199, 2019.

GOMES, Renan Veloso. **Modelo de opções reais para avaliar a estratégia de produção em uma indústria eletrointensiva face ao preço da energia elétrica**. Dissertação de Mestrado, Universidade Federal de Minas Gerais, Belo Horizonte, Brasil 2015.

HAUGOM, Erik; MOLNÁR, Peter; TYSDAHL, Magne. Determinants of the forward premium in the Nord pool electricity market. **Energies**, v. 13, n. 5, p. 1111, 2020.

HUBICKA, Katarzyna; MARCJASZ, Grzegorz; WERON, Rafał. A note on averaging day-ahead electricity price forecasts across calibration windows. **IEEE Transactions on Sustainable Energy**, v. 10, n. 1, p. 321-323, 2018.

ILEA, Valentin et al. Impact of the price coupling of regions project on the day-ahead electricity market in Italy. In: **2017 IEEE Manchester PowerTech**. IEEE, 2017. p. 1-6.

IWABUCHI, Koki et al. Flexible electricity price forecasting by switching mother wavelets based on wavelet transform and Long Short-Term Memory. **Energy and AI**, v. 10, p. 100192, 2022.

JAIN, Lakhmi C. et al. A review of online learning in supervised neural networks. **Neural computing and applications**, v. 25, n. 3, p. 491-509, 2014.

JIN, Cheng Hao et al. Short-term electricity load and price forecasting based on clustering and next symbol prediction. **IEEJ Transactions on Electrical and Electronic Engineering**, v. 10, n. 2, p. 175-180, 2015.

JORDEHI, A. Rezaee. Optimisation of demand response in electric power systems, a review. **Renewable and sustainable energy reviews**, v. 103, p. 308-319, 2019.

KALAVANI, Farshad; MOHAMMADI-IVATLOO, Behnam; ZARE, Kazem. Optimal stochastic scheduling of cryogenic energy storage with wind power in the presence of a demand response program. **Renewable energy**, v. 130, p. 268-280, 2019.

LI, Raymond; WOO, Chi-Keung; COX, Kevin. How price-responsive is residential retail electricity demand in the US?. **Energy**, v. 232, p. 120921, 2021.

LIU, Heping; SHI, Jing. Applying ARMA–GARCH approaches to forecasting short-term electricity prices. **Energy Economics**, v. 37, p. 152-166, 2013.

LIU, Hui et al. Wind speed forecasting approach using secondary decomposition algorithm and Elman neural networks. **Applied Energy**, v. 157, p. 183-194, 2015.

LOTKA, Alfred J. The frequency distribution of scientific productivity. **Journal of the Washington academy of sciences**, v. 16, n. 12, p. 317-323, 1926.

MA, Ziming et al. Month ahead average daily electricity price profile forecasting based on a hybrid nonlinear regression and SVM model: an ERCOT case study. **Journal of Modern Power Systems and Clean Energy**, v. 6, n. 2, p. 281-291, 2018.

MARCHETTI, Isabella; REGO, Erik Eduardo. The impact of hourly pricing for renewable generation projects in Brazil. **Renewable Energy**, v. 189, p. 601-617, 2022.

MIRANIAN, Arash; ABDOLLAHZADE, Majid; HASSANI, Hossein. Day-ahead electricity price analysis and forecasting by singular spectrum analysis. **IET Generation, Transmission & Distribution**, v. 7, n. 4, p. 337-346, 2013.

MIŠNIĆ, Nikola et al. The Economic Viability of PV Power Plant Based on a Neural Network Model of Electricity Prices Forecast: A Case of a Developing Market. **Energies**, v. 15, n. 17, p. 6219, 2022.

MOHER, David et al. Reprint—preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. **Physical therapy**, v. 89, n. 9, p. 873-880, 2009.

MOHSENIAN-RAD, Amir-Hamed; LEON-GARCIA, Alberto. Optimal residential load control with price prediction in real-time electricity pricing environments. **IEEE transactions on Smart Grid**, v. 1, n. 2, p. 120-133, 2010.

MORENO, Sinvaldo Rodrigues; DOS SANTOS COELHO, Leandro. Wind speed forecasting approach based on singular spectrum analysis and adaptive neuro fuzzy inference system. **Renewable energy**, v. 126, p. 736-754, 2018.

NAFADE, Vaidehi et al. A bibliometric analysis of tuberculosis research, 2007–2016. **PloS one**, v. 13, n. 6, p. e0199706, 2018.

NAGARAJA, Y. et al. A survey on wind energy, load and price forecasting:(Forecasting methods). In: **2016 International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT)**. IEEE, 2016. p. 783-788.

PABLO-ROMERO GIL-DELGADO, María del Populo; POZO BARAJAS, Rafael del; YÑÍGUEZ OVANDO, Rocío. Global changes in residential energy consumption. **Energy Policy, 101, 342-352.**, 2017.

PASTOR, Ricardo et al. Market-based bidding strategy for variable renewable generation in the MIBEL. In: **2018 15th International Conference on the European Energy Market (EEM)**. IEEE, 2018. p. 1-5.

PENG, Chunhua; LIU, Gang; XIANG, Longyang. Short-term electricity price forecasting using relief-correlation analysis based on feature selection and differential evolution support vector machine. **Diangong Jishu Xuebao(Transactions of China Electrotechnical Society)**, v. 28, n. 1, p. 277-284, 2013.

PIR, M. Yasin; SHAH, Firdous Ahmad; ASGER, Mohammed. Comparative study of different wavelet based neural network models for IIP growth forecasting using different yield spreads. **International Journal of Electrical Electronics & Computer Science Engineering**, v. 4, n. 6, p. 5-13, 2017.

PRIMC, Kaja; SLABE-ERKER, Renata. Social policy or energy policy? Time to reconsider energy poverty policies. **Energy for Sustainable Development**, v. 55, p. 32-36, 2020.

POUSINHO, Hugo Miguel Inácio; MENDES, V. M. F.; CATALÃO, João Paulo da Silva. Short-term electricity prices forecasting in a competitive market by a hybrid PSO–ANFIS approach. **International Journal of Electrical Power & Energy Systems**, v. 39, n. 1, p. 29-35, 2012.

RANI, R. Hannah Jessie; VICTOIRE, T. Aruldoss Albert. A hybrid Elman recurrent neural network, group search optimization, and refined VMD-based framework for multi-step ahead electricity price forecasting. **Soft Computing**, v. 23, n. 18, p. 8413-8434, 2019.

RAO, Surendra Laxminarayan. **Governing power: A new institution of governance, the experience with independent regulation of electricity**. The Energy and Resources Institute (TERI), 2004.

SHRIVASTAVA, Nitin Anand; PANIGRAHI, Bijaya Ketan; LIM, Meng-Hiot. Electricity price classification using extreme learning machines. **Neural Computing and Applications**, v. 27, n. 1, p. 9-18, 2016.

SOEIRO, Susana; DIAS, Marta Ferreira. Renewable energy community and the European energy market: main motivations. **Heliyon**, v. 6, n. 7, p. e04511, 2020.

STEFFEN, Bjarne; PATT, Anthony. A historical turning point? Early evidence on how the Russia-Ukraine war changes public support for clean energy policies. **Energy Research & Social Science**, v. 91, p. 102758, 2022.

STEINERT, Rick; ZIEL, Florian. Short-to mid-term day-ahead electricity price forecasting using futures. **The Energy Journal**, v. 40, n. 1, 2019.

TAHMASEBIFAR, Reza; SHEIKH-EL-ESLAMI, Mohammad Kazem; KHEIROLLAHI, Reza. Point and interval forecasting of real-time and day-ahead electricity prices by a novel hybrid approach. **IET Generation, Transmission & Distribution**, v. 11, n. 9, p. 2173-2183, 2017.

TJØRRING, Lise; GAUSSET, Quentin. Energy renovation models in private households in Denmark. **Community governance and citizen-driven initiatives in climate change mitigation**, p. 89-106, 2015.

UNIEJEWSKI, Bartosz; MARCJASZ, Grzegorz; WERON, Rafał. On the importance of the long-term seasonal component in day-ahead electricity price forecasting: Part II—Probabilistic forecasting. **Energy Economics**, v. 79, p. 171-182, 2019.

VAN ECK, Nees Jan; WALTMAN, Ludo. Software survey: VOSviewer, a computer program for

bibliometric mapping. **scientometrics**, v. 84, n. 2, p. 523-538, 2010.

VAN ECK, Nees Jan; WALTMAN, Ludo. Citation-based clustering of publications using CitNetExplorer and VOSviewer. **Scientometrics**, v. 111, n. 2, p. 1053-1070, 2017.

VAN RAAN, Anthony FJ. Patent Citation Analysis and Its Value in Research Evaluation: A Review and A New Approach to Map Technology-Relevant Research. **Journal of Data and Information Science**, v. 2, n. 1, p. 13-50, 2017.

WALTMAN, Ludo; VAN ECK, Nees Jan. A new methodology for constructing a publication-level classification system of science. **Journal of the American Society for Information Science and Technology**, v. 63, n. 12, p. 2378-2392, 2012.

WAN, Chunlei et al. Flexible thermoelectric foil for wearable energy harvesting. **Nano Energy**, v. 30, p. 840-845, 2016.

WANG, Kun et al. Robust big data analytics for electricity price forecasting in the smart grid. **IEEE Transactions on Big Data**, v. 5, n. 1, p. 34-45, 2017.

WERON, Rafał. Electricity price forecasting: A review of the state-of-the-art with a look into the future. **International journal of forecasting**, v. 30, n. 4, p. 1030-1081, 2014.

WINDLER, Torben; BUSSE, Jan; RIECK, Julia. One month-ahead electricity price forecasting in the context of production planning. **Journal of Cleaner Production**, v. 238, p. 117910, 2019.

XU, Fei et al. Electricity production enhancement in a constructed wetland-microbial fuel cell system for treating saline wastewater. **Bioresource technology**, v. 288, p. 121462, 2019.

YANG, Wendong et al. A novel machine learning-based electricity price forecasting model based on optimal model selection strategy. **Energy**, v. 238, p. 121989, 2022.

YUAN, Xiaoming. Overview of problems in large-scale wind integrations. **Journal of Modern Power Systems and Clean Energy**, v. 1, n. 1, p. 22-25, 2013.

ZAHID, Maheen et al. Electricity price and load forecasting using enhanced convolutional neural network and enhanced support vector regression in smart grids. **Electronics**, v. 8, n. 2, p. 122, 2019.

ZHANG, Yang; LI, Ce; LI, Lian. Wavelet transform and Kernel-based extreme learning machine for electricity price forecasting. **Energy Systems**, v. 9, n. 1, p. 113-134, 2018.

ZHANG, Jin-Liang et al. Forecasting day-ahead electricity prices using a new integrated model. **International Journal of Electrical Power & Energy Systems**, v. 105, p. 541-548, 2019.

ZHANG, Jinliang; TAN, Zhongfu; WEI, Yiming. An adaptive hybrid model for short term electricity price forecasting. **Applied Energy**, v. 258, p. 114087, 2020.

ZUHAIRA, Zaid; LI, Jizu; MOHAMMED, Hayder Dhahir. The future of the shale industry in light of the fluctuations in global oil prices. **Energy & Environment**, p. 0958305X221129223, 2022.