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Review

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Electricity Markets in the Context of Distributed Energy Resources and Demand Response Programs: Main Developments and Challenges Based on a Systematic Literature Review

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Abstract: Distributed energy resources have been increasingly integrated into electrical grids. Consequently, electricity markets are expected to undergo changes and become more complex. However, while there are many scientific publications on the topic, a broader discussion is still necessary. Therefore, a systematic literature review on electricity markets in the context of distributed energy resources integration was conducted in this paper to present in-depth discussions on the topic, along with shedding light on current perspectives, the most relevant sources, authors, papers, countries, metrics, and indexes. The software R and its open-source tool Bibliometrix were used to perform the systematic literature review based on the widely recognized databases Web of Science and Scopus, which led to a total of 1685 articles after removing duplicates. The results demonstrate that demand response, renewable energy, uncertainty, optimization, and smart grid are the most-used keywords. By assessing highly impactful articles on the theme, emphasis on energy storage systems becomes clear compared to distributed generation and electric vehicles. However, electric vehicles draw attention in terms of citations. Furthermore, multi-level stochastic programming is the most-applied methodology among highly impactful articles. Due to the relevance of the demand response keyword, this paper also conducts a specific review on the topic aligned with electricity markets and distributed energy resources (296 articles). The results demonstrate that virtually all high-impact publications on the topic address day-ahead or real-time pricing. Based on the literature found, this paper presents a discussion on the main challenges and future perspectives related to the field. The complexity of electrical power systems and electricity markets is increasing substantially according to what this study found. Distributed generation development is already advanced, while energy storage systems and electric vehicles are limited in many countries. Peer-to-peer electricity trading and virtual power plant are newer concepts that are currently incipient, and DR programs showcase an intermediate stage of evolution. A particular lack of research on social issues is verified, and also a lack of all-encompassing studies that address multiple interconnected topics, which should be better addressed in the future. The in-depth assessment carried out in this paper is expected to be of high value to researchers and policy-makers and facilitate future research on the topic.

Keywords: demand side management; distributed energy system; distributed generation; electric vehicles; smart markets; energy storage systems; comprehensive literature review

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1. Introduction

1.1. Motivation

Energy storage systems (ESSs) have been gaining momentum to foster the large-scale commercialization of electric vehicles (EVs) and the implementation of smart grids [1]. Batteries are highly promising among storage technologies due to recent technological and economic breakthroughs and their applicability in mobile devices. Lithium-ion batteries are regarded as the leading chemistry in terms of potential due to several advantages (e.g., relatively high lifespan, energy density, and efficiency). They are expected to further develop due to increasing maturity and economies of scale, enabling emerging applications (e.g., utility-scale battery energy storage systems/BESSs). Hu et al. [1] estimate that Li-ion batteries have approximately five times more lifespan, three times more energy density, and 10% more efficiency than their lead–acid batteries counterparts; however, these values might vary. Nevertheless, the high cost of Li-ion is still a significant bottleneck in some applications [2]. At the same time, other battery chemistries are also important, such as redox flow batteries (RFBs), and contribute concurrently to the deployment of BESSs and to support the electrical grid [3]. Additionally, non-electrochemical ESSs, such as pumped hydro storage systems, are also essential for promoting energy storage applications. For instance, Onu et al. obtained a cost of electricity of only 0.13 USD/kWh for an off-grid isolated community in Africa [4]. In this context, energy storage has been extensively studied by the research community [5–7] and is characterized as a topic of remarkable interest.

Extensive deployment of distributed generation (DG) is already a reality in several regions (e.g., Australia [8], California [9], and Germany [10]) due to its decreasing cost and the implementation of incentive policies, such as net metering and a feed-in tariff (FIT), to boost the installed capacity in the early stages [11]. Estimations claim that DG will present a compound annual growth rate of more than 10% in the short-term [12]. Photovoltaic (PV) generation stands out among DG sources due to its high modularity that allows small-scale investments, thus increasing the market potential for DG systems. According to Anaya et al. [13], PV DG corresponds to roughly half of the overall DG demand. DG can bring several benefits to the electrical grid and society, such as energy loss reduction [14], reliability enhancement [15], reduction in environmental impacts [16], and investment deferral [17], along with socioeconomic welfare increases. Consequently, electrical systems with unidirectional power flow are in the process of changing. For instance, Costa et al. [18] estimated that DG would lead to socioeconomic welfare gains of around USD2.5 billion in Brazil if the net metering scheme were to be maintained.

Although the cost of EVs is still high and their commercialization is limited (especially in emerging countries), they are regarded as a future replacement for internal combustion engine vehicles due to their ongoing breakthroughs and environmental friendliness [19]. Bauer et al. [20] estimate that EVs can represent only 22% of the lifetime emissions of an internal combustion engine vehicle if renewable electricity is used to charge the EVs. However, large-scale deployment of EVs poses substantial challenges to the electrical system since their charge must be properly scheduled to avoid grid overload, power quality issues, or extensive increases in operational costs [21]. For instance, Jenn et al. [22] estimate that approximately 20% of Californian circuits will require an upgrade if 6 million EVs are adopted. At the same time, EVs can operate in vehicle-to-grid (V2G) mode and inject electricity into the grid in periods of high demand if they are not being used; thus, they can potentially provide services to the system. Due to the inherent challenges related to the transition to an EV-based fleet, this topic has also been extensively studied by the research community (e.g., optimal charge and discharge schemes [23–26]). In Mohamed et al. [27], optimal management of EVs was able to reduce voltage fluctuations by 50%, harmonic distortion by 40%, and current by 64%.

ESSs, DG, and EVs are characterized as distributed energy resources (DERs). In addition to the impact that DERs have on the grid, they also substantially transform electricity markets [28]. For instance, DERs require the development and implementation of advanced business models for ancillary service applications [29] and introduce the concept of

peer-to-peer (P2P) electricity trading [30]. DERs could encourage the usage of blockchain technology to facilitate transactions and improve security [31]. Furthermore, DERs influence the formation of electricity tariffs in regulated and deregulated markets [32,33].

Demand response (DR) programs are associated with deliberate modifications to consumers' behaviors regarding energy usage to achieve specific outcomes. More specifically, they are implemented to balance supply and demand by encouraging electricity consumption in periods of low demand while discouraging electricity consumption in periods of high demand. For instance, Roscoe et al. [34] estimated that DR programs could reduce UK peak demand by 8–11 GW. DR programs are usually economically based, as incentives are typically implemented through dynamic electricity pricing schemes or other forms of economic incentives [35,36]. The enhanced balance between supply and demand is essential since it leads to improved grid efficiency and investment deferral [37]. Therefore, DR programs are among the most important topics in the context of modern power systems and smart grids.

Power systems are evolving substantially. DERs are being increasingly integrated into the grid, and market designs are changing through the implementation of advanced DR programs (e.g., real-time pricing—RTP). At the same time, there is a trend toward the deregulation of the power sector, with more independent market players being introduced (e.g., DER aggregators and charging station companies) and more means of commercialization (e.g., P2P electricity trading through blockchain technology). These market players typically have conflicting interests. Additionally, countries are transitioning to renewable-based electricity matrices, which are subject to intermittence issues. While such an all-encompassing and intricate power system and electricity market transformation takes time, it will inherently occur at some point (in fact, changes are already occurring worldwide). Future power systems and electricity markets bring several opportunities for improvement but also substantial challenges that require thorough research.

Given this background, this paper conducts a systematic literature review (SLR) on electricity markets in the context of DERs and DR programs to carry out a complete review of the articles and present in-depth discussions on the topic, along with shedding light on essential information such as current perspectives, most relevant sources, authors, papers, countries, metrics, and indexes. Moreover, the research seeks to identify essential challenges and potential directions for future research, thereby contributing to the development of the theme.

1.2. Preliminary Literature Review and Contributions

To ensure novelty and originality, the following descriptors were applied to the Web of Science (WoS) and Scopus (SC) databases: ((“systematic literature review” OR “comprehensive review”) AND “electricity market” AND (“distributed energy resources” OR “distributed generation” OR “energy storage” OR “electric vehicles”)). The topic category was selected, i.e., the descriptors must be present in the title, abstract, or keywords. A total of 18 and 22 documents were found in WoS and SC, respectively. Although these review documents were found, where one or more addressed themes are inserted in this paper's scope, none of them focus on a global analysis of electricity markets in the context of increasing DER integration, as described in a sample shown in Table 1. In contrast, this paper initially focuses on a general review of studies related to electricity markets aligned with DERs based on big data processing and then conducts a more specific assessment of DR issues aligned with electricity markets and DERs. DR issues are analyzed more closely due to their relevance to the topic (this will become evident in Section 3.1.5). Therefore, this paper provides a novel contribution and is of high value to the research community by supporting meaningful insights into how the theme evolved, what the trends are, and how to address the main challenges.

Table 1. Sample of review articles preliminarily found in the WoS and SC databases.

Author	Article/Reference	Business Models	DR	ESS	EV	Expansion Planning	P2P	VPP	Proposed in This Paper
Lu et al.	[38]	✓							
Botelho et al.	[39]	✓							
Padmanabhan et al.	[40]		✓	✓					
Alshahrani et al.	[41]				✓				
Patil et al.	[42]				✓				
Sadeghi et al.	[43]					✓			
Dranka et al.	[44]					✓			
Hemmati et al.	[45]					✓			
Hemmati et al.	[46]					✓			
Sousa et al.	[30]						✓		
Khorasany et al.	[47]						✓		
Zhou et al.	[48]						✓		
Bjarghov et al.	[49]						✓		
Wörner et al.	[50]						✓		
Zhang et al.	[51]							✓	
Podder et al.	[52]							✓	
This paper			✓						✓

It is worth clarifying that the aim of this preliminary search was only to show the gap in review papers addressed to electricity markets in the context of DERs and DR programs. However, a sample of the most impactful papers was assessed in this section.

Lu et al. [38] assess fundamental concepts, classifications, and available resources of aggregators. The authors demonstrate the importance of insights into loads, prices, and generation in aggregators' business models. Moreover, the authors present challenges faced by resource aggregators, such as the influence of DG on the load's estimation, rebound effect (shifted peak) modeling, diversifying DR programs, and cyber-attack.

Botelho et al. [39] address business models associated with DG, focusing on enablers and barriers. The authors conclude that, depending on the region, regulatory issues are obstacles to implementing innovative business models. Furthermore, the paper infers that there must be improvements in conservative policies, administrative issues, market barriers, infrastructure, and information so that business models can be properly implemented and developed. Moreover, the authors divide innovative business models into five groups: (1) aggregators business models, which are associated with the concept of VPP, (2) DR business models, which aim to shift electricity consumption to increase the system's efficiency, (3) P2P trading platforms, (4) energy-as-a-service business models, in which the prosumer can explore selling a full range of electricity-related services, and (5) collective services business models, where collective self-consumption can be achieved. These business models are expected to be key in future electrical systems if barriers are properly dealt with.

In another paper, Pad-manabhan et al. [40] approach DR and ESS participation in North American electricity markets. The authors separate the modalities of DR based on their mode of procurement, participation period and operational domain (energy, ancillary services, etc.), and the type of DR programs. The participation of ESS in ancillary services is also thoroughly assessed. Among the presented challenges, the following stand out: declining participation of DR in energy services due to less attractive monetary gain and determining the bid/offer structure to appropriately offer the available DR capacity. In order to overcome such challenges, novel frameworks are required, along with mathematical models for DR participation in electricity markets.

Alshahrani et al. [41] approach EV applications and challenges, including the effects of EV integration on grids. It is demonstrated that the slow pace of grid upgrading and the associated costs impair the large-scale integration of EVs. However, the authors highlight

some of the techniques that can be applied to mitigate the detrimental impacts of EV integration. Patil et al. [42] present a similar work emphasis to Alshahrani et al. [41]; however, the authors focus more on economic incentives that can be given to distinct market players in the context of EV integration. Moreover, the potential to benefit multiple market players (e.g., aggregators and end-users) from optimal EV charging by applying multi-objective optimization is discussed.

Sadeghi et al. [43] address generation expansion planning issues, providing insights on directions for future research. For instance, the authors argue that smart grid implementation must be accounted for in long-term expansion planning models. Moreover, several planning issues are thoroughly assessed, such as the liberalization of the electricity industry, climate change and environmental issues, current developments in technologies, modern regulatory policies, and emerging techniques associated with optimization.

Dranka et al. [44] address co-optimization approaches for operational and planning problems. The authors argue that such approaches present benefits; however, increasing complexities and trade-offs of the energy sector require improvements in the models. Hemmati et al. [45] focus on transmission expansion planning. The authors demonstrate that methodologies on the topic should consider different aspects, such as uncertainty, market concepts, congestion management, reactive power planning, and DG. However, a commonly applied methodology is not available, as researchers address the problem from distinct perspectives. Furthermore, some points of concern are raised, such as the influence of DG on expansion planning, which has not been properly studied. Hemmati et al. [46] present a similar work emphasis.

Sousa et al. [30] review P2P electricity trading, mentioning that future research should assess the possibility of switching from the wholesale and retail markets to the P2P markets and vice versa. This is particularly important since P2P markets are not a substitute for other markets but rather a complement. Among P2P market designs, the hybrid P2P market design (peers negotiating electricity with community managers who manage trading activities) proved to be the most suitable for scalability. That being said, hybrid P2P is challenging to implement in practice. A similar work emphasis is verified in [47–50]. In turn, Zhang et al. [51] and Podder et al. [52] categorize VPP and assess its feasibility and applicability in modern power systems. The coordination between resources provided by VPP is expected to improve the operation of power systems; however, its implementation is challenging due to uncertainties. The concept of VPP is separated into internal and external aspects. Internal aspects are related to variable integration methods applied by the VPP entity, whereas external aspects are formulated as a competitive participator in the electricity market aimed at profit maximization.

By assessing the articles indicated in Table 1, it is concluded that electric power systems and electricity markets are at a turning point, as their complexity is increasing substantially. The state of development of DG is already advanced in general [8–10]. Authors are focusing on their potential effects on the grid and market and on developing improved business models [38,39]. On the other hand, the diffusion of ESSs and EVs is relatively limited compared to DG; however, a broad diffusion will inherently occur at some point. For this reason, they are also frequently studied, even in futuristic applications [32,40–42]. P2P electricity trading and VPP are newer concepts that are currently incipient; however, they show great potential in the future. In turn, DR programs showcase an intermediate stage of evolution, as they are successfully implemented in developed countries in general, but there is a lack of satisfactory and advanced programs in underdeveloped countries [53] (e.g., low adherence to DR programs in Brazil).

Note that this preliminary sample has only review papers, and the analysis of such articles demonstrates that they are more specific than this paper, as authors typically assess only one topic related to electricity markets. In turn, the general review of electricity markets conducted here is expected to shed light on multiple issues (e.g., ESSs, DG, EVs, DR, etc.).

1.3. Paper Structure

Section 2 describes the methodology applied in this paper and the questions that will be answered. Section 3 is dedicated to presenting the results and analyses. In Section 3.1, a general review of electricity markets in the context of increasing DER integration is conducted. It is divided as follows: main information (Section 3.1.1), scientific production and citations over time (Section 3.1.2), article sources (Section 3.1.3), authors and articles (Section 3.1.4), and countries and keywords (Section 3.1.5). In Section 3.2, a higher emphasis is given to DR issues, focusing on the articles and the most-addressed dynamic pricing schemes. In Section 3.3, a comparison between DG, ESSs, and EVs is carried out in four topics: main authors, most-cited articles, state-of-the-art articles, and DR issues. Such a comparison is based on the focus employed for each technology on the four topics. Section 3.4 is dedicated to presenting a set of challenges on the topic and recommendations for future work. Finally, Section 4 presents the conclusions of the research.

2. Methodology

In this paper, a systematic literature review (SLR) is applied. SLRs are far superior to conventional literature reviews since [54] (i) the latter present no clear guidelines and methodology, (ii) the latter is subject to a biased assessment, (iii) the former ensures research reproducibility, and (iv) the former allows the processing of big data, thereby increasing the robustness of the analysis. SLRs are defined by one or more research questions (RQs) that are to be answered from the assessment of research published in scientific databases. SLRs differ from conventional literature reviews since, in conventional reviews, the published research selected for analysis does not follow a very well-defined pattern, which leads to the problems mentioned above in this paragraph. There are several scientific databases worldwide; however, the two most important in the energy field are WoS and SC, as presented by De Doile et al. [55] in recent research on wind, solar PV, and ESSs. Even searching in two or more databases, the SLR allows the replicability of results, making the paper an important source for other researchers in the same field.

The following RQs are addressed in this paper:

RQ 1: what are the main features of the electricity markets literature in the context of increasing DER integration?

RQ 2: what are the dynamic pricing schemes in electricity markets in the context of DR and increasing DER integration?

RQ 3: what are the most relevant articles addressing electricity markets in the context of DR issues and increasing DER integration?

The WoS and SC databases were selected since they are the most relevant sources for the physical sciences [55]. DR issues are analyzed together with DERs in RQs 2 and 3 since DERs are critical elements in the context of DR program implementation [38]. To properly answer the RQs, the following descriptors were applied:

Descriptor 1: (“electricity market” AND (“distributed energy resources” OR “distributed generation” OR “energy storage” OR “electric vehicles”));

Descriptor 2: (“electricity market” AND “demand response” AND (“distributed energy resources” OR “distributed generation” OR “energy storage” OR “electric vehicles”)).

It is essential to clarify that the original and main purpose of the research is a comprehensive literature review related to electricity markets in the context of increasing DER integration since DERs are being increasingly integrated, and this process transforms electricity markets substantially. However, as it was verified that DR programs are essential in the same context, by assessing the most relevant keywords in terms of frequency, we also opted to assess publications about DR programs. Therefore, the research was conducted as follows:

We applied Descriptor 1 to assess papers related to electricity markets in the context of increasing DER integration; then, we verified that DR programs are essential in the same context; finally, we came up with Descriptor 2 so that the themes DER and DR programs could be assessed together, thereby leading to more all-encompassing research.

It is noteworthy that among DER technologies, the importance of DG, ESS, and EVs stands out, and sometimes authors do not identify these technologies as DER, making their inclusion necessary in descriptors to find respective publications.

The topic category was selected for both Descriptors 1 and 2. Only peer-reviewed articles published in journals were considered due to their strict reference formats, which facilitate the calculation of the metrics and indexes. For simplicity, the articles obtained from Descriptors 1 and 2 are called Samples 1 and 2. Sample 1 consisted of 1685 articles, while Sample 2 consisted of 296 articles after removing duplicated articles. It is worth mentioning that Sample 2 is contained in Sample 1, as only one new keyword was added to Descriptor 1. However, it was necessary to assess work related to DER and DR separately from the ones related only to DER. The metadata of the samples are made available in a repository to foster research on the topic [56]. It is important to mention that the research was conducted in January 2022.

The metadata obtained from the samples were processed by R software and its open-source tool Bibliometrix, programmed and designed by Aria et al. [57]. This tool is key, since it automatically calculates several important metrics and indexes and organizes information. Moreover, it is widely recognized, as it has been used in dozens of publications [58].

3. Results and Analyses

Firstly, a quantitative analysis of the two samples was made to show the state-of-the-art of the researched theme. In this section, researchers can find the number of published articles, main authors and their research focus, who the main producers are, etc. The quantitative analysis can be used, among other purposes, to (i) assist other researchers in selecting journals for submitting papers, (ii) spot experts on the topic (the papers published by such experts are expected to be highly valuable), (iii) identify in which countries the theme is more developed and in which countries the theme is incipient, and (iv) identify related research based on the most-used keywords.

3.1. Sample 1

3.1.1. Main Information

To provide an overview of Sample 1, its main information is described in Table 2.

Table 2. Main information from sample 1. Source: own study using data from Bibliometrix.

Description	Results
Timespan	1990:2022
Sources	288
Articles	1685
Average years from publication [a]	4.83
Average citations per document	26.16
Average citations per year per document	3.699

[a] Average time that it takes for an article to stop being cited.

3.1.2. Scientific Production and Citations over Time

There is an increasing number of publications (annual growth rate of 25.21%), as illustrated in Figure 1, highlighting that the research community's interest in the topic has been expanding. The first article was published in 1990, focusing on research and development (R&D) programs in the context of ESSs and peak and off-peak electricity markets [59]. However, more than 99% of the articles were published after 2000, since the large-scale deployment of DERs.

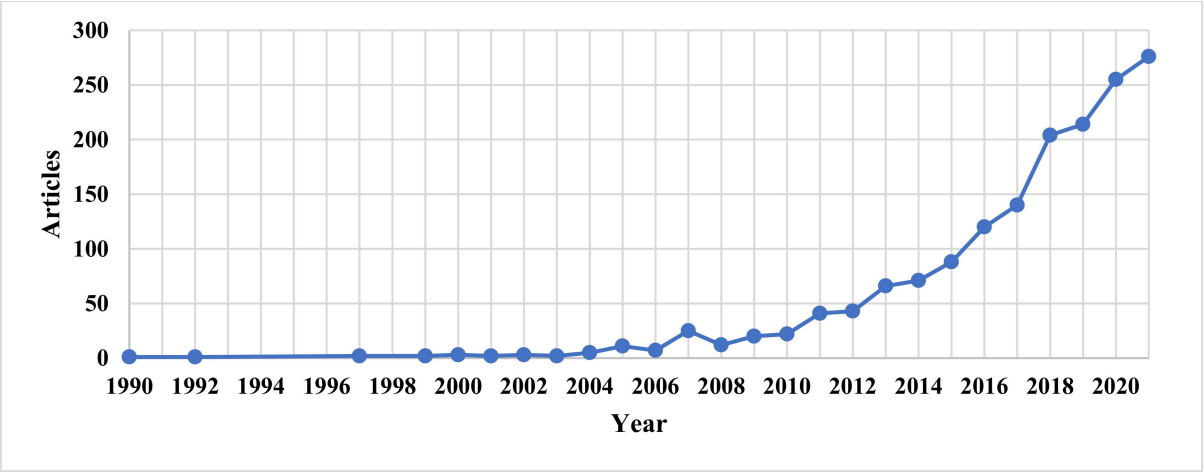

Figure 1. Annual scientific production. Source: own study using data from Bibliometrix.

The average number of article citations per year is illustrated in Figure 2. It is calculated based on Equation (1) and is important to verify critical years and trends. An anomaly (high peak) can be verified in 2001. As verified in Figure 1, only two articles were published in 2001. Ackermann et al. [60], one of the two articles published in 2001, is the reason for such an anomaly, since it presents 1802 total citations (the Sample 1 most-cited article) and approximately 86 total citations per year. Ackermann et al. focus on defining DG, which was a new concept in 2001. The following definition was proposed "electric power generation within distribution networks or on the customer side of the network" [60]. In the last decade, the average number of citations has fluctuated around 5, indicating stability. The decrease in 2021 is expected since there has not been enough time for the articles to be cited.

$$Average\ citations\ per\ year = \frac{Total\ number\ of\ citations}{Total\ number\ of\ articles \cdot Time} \quad (1)$$

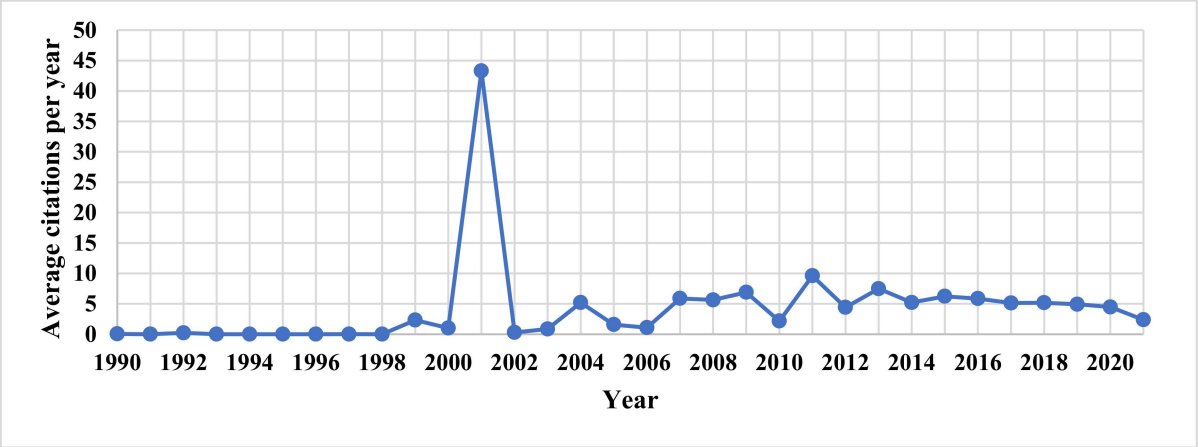

Figure 2. Average article citations per year. Source: own study using data from Bibliometrix.

3.1.3. Article Sources

The main article sources (journals) are illustrated in Figure 3 based on four indicators: (a) number of articles, (b) total citations, (c) h-index (a researcher has index h if h of his/her N_P papers have at least h citations each, and the other (N_P − h) papers have no more than h citations each), and (d) g-index (given a set of articles ranked in decreasing order of the number of citations that they received, the g-index is the unique largest number such that the top g articles received together at least g^2 citations). Both the h-index and g-index have

the purpose of measuring productivity. The h-index is a more conventional approach [61], whereas the g-index is a more modern approach that considers the citation count of very highly cited articles [62]. As demonstrated in Figure 3, Applied Energy, IEEE Transactions on Power Systems, IEEE Transactions on Smart Grid, and Energy are leading journals on the topic (taking into account the four indicators).

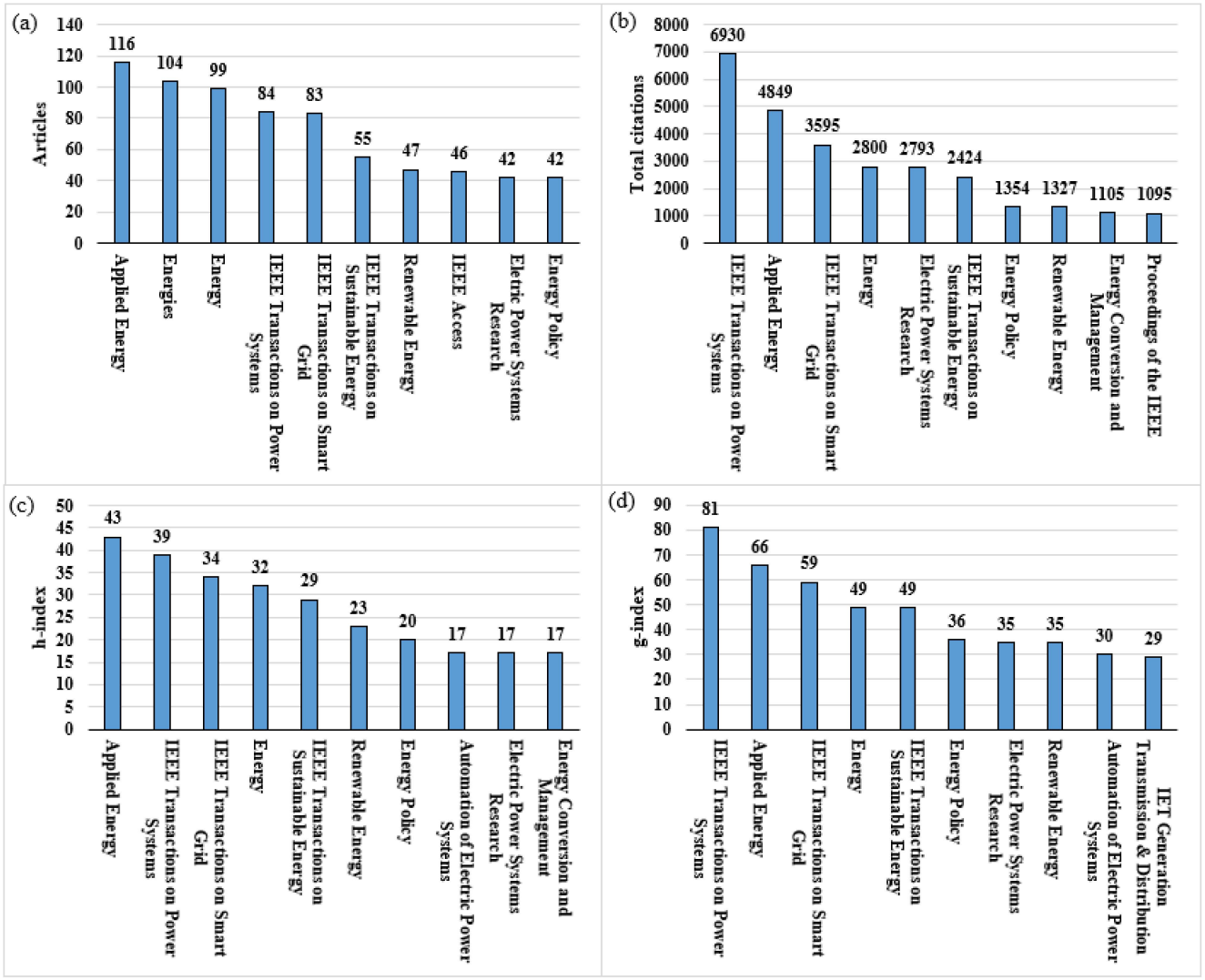

Figure 3. Main article sources by (**a**) the number of published articles, (**b**) total citations, (**c**) h index, and (**d**) g index. Source: own study using data from Bibliometrix.

The ten journals mentioned in Figure 3a are responsible for 43% of the articles, which is a significant number but also demonstrates that there are many other journals on the topic. It was verified that the 20% of journals with the highest number of publications (58 journals) are responsible for 80% of publications; thus, they provide a reasonable view of the sample that presents a total of 288 journals. It is also important to mention that 54% of journals published only one article, highlighting that such publications are occasional rather than the journals' focus. The ten journals mentioned in Figure 3b are responsible for 64% of the total citations, indicating a concentration of citations among the main journals.

An indication that there are a limited number of reviews on the topic is that the journal Renewable and Sustainable Energy Reviews (RSER), which is known for publishing high-impact review articles, presents only ten articles within Sample 1, ranking 30th on the list of the most productive journals. The oldest articles from RSER date from 2019, highlighting that the subject is current and has been gaining momentum. Moreno et al. [63]

is the most-cited article from RSER, with 23 citations. The authors analyze the impact of virtual power plant (VPP) technology composition on wholesale electricity prices in Europe. Diaz et al. [64] is the second-most cited, with 17 citations. The authors assess the importance of time resolution, operational flexibility, and risk aversion in quantifying the value of energy storage in long-term energy planning studies. Brown et al. [65] is the third, with 14 citations. The authors focus on modeling the benefits of PV generation in the USA (including environmental and health benefits). Therefore, the most-cited articles from RSER within Sample 1 are not review articles. However, four articles of RSER are, in fact, review articles, namely Botelho et al. [39], which, as previously discussed, address business models associated with DG. Ramos et al. [66] also focus on business models associated with DG, evaluating risks and opportunities. Furthermore, the authors propose four business models for small consumers. Martin et al. [67] review energy storage policy and regulatory options for Australia, concluding that development policies are required to advance future domestic ESSs. Rancilio et al. [68] address ancillary services of DERs in European electricity markets, focusing on the differences of each country. In conclusion, Botelho et al. [39] and Ramos et al. [66] focus specifically on business models, Martin et al. [67] focus specifically on regulatory aspects, and Rancilio et al. [68] focus specifically on ancillary services. Such a conclusion complies with the assessment conducted in Section 1.1, i.e., there is a research gap in general SLRs of electricity markets in the context of DERs, highlighting the novelty/contributions of this paper. This becomes apparent by evaluating the descriptors applied in Botelho et al. [39], i.e., "prosumer"—"business model"—"regulation"—"market design"—"technologies"—"renewable energy integration"—"distributed energy sources"—"barriers"—"enablers". As verified, more specific descriptors were applied, leading to a much smaller sample (160 references).

3.1.4. Authors and Articles

The ten main authors on the topic in terms of scientific production are exhibited in Table 3. They published between 17 and 23 articles, and their h-index and g-index ranged from 8 to 13 and 13 to 19, respectively. Regarding total citations, they ranged from 307 to 762. The three most-cited articles of each of the main authors are described in Table A1 in Appendix A. The methods and most significant results of some articles are presented in Table A6.

Table 3. Main authors. Source: own study using data from Bibliometrix.

Author	Articles	Articles Fractionalized [a]	Total Citations [b]	h-Index [b]	g-Index [b]
Wang, X.	23	5.65	315	10	17
Shafie-Khah, M.	22	5.00	651	12	19
Vale, Z.	21	4.74	384	10	18
Wang, Y.	19	3.80	349	9	16
Catalao, J.	18	3.89	500	10	16
Zhang, Y.	18	3.48	307	8	15
Dong, Z.	17	3.47	762	13	16
Liu, W.	17	3.44	319	10	17
Mohammadi-Ivatloo, B.	17	3.55	329	8	13
Siano, P.	17	4.10	633	11	16

[a] Assumes an equal contribution by all coauthors in the calculation. [b] Considers only articles within the sample.

Among impactful research, stand out: Dong, Z. et al. [2] propose a new battery operation strategy for better utilization of ESSs and mitigation of operational risks related to price volatility. Concerning the methodology, the authors apply a series of forecast toolboxes, including OptiLoad, OptiWind, and OptiSolar, and formulate the objective function as the distribution company's profit from energy transactions, system planning,

and operation cost savings. Results demonstrated that although lead–acid batteries are cheaper, they present significant drawbacks that limit their risk mitigation potential, such as low charge power and high weight. Yet, profits/benefits of around 10% were achieved by the authors. Li-ion batteries are expected to be more promising in the future. However, their high cost is currently a bottleneck in such an application.

Dong, Z. et al. [69] propose a new optimal EV route model to minimize the total costs. The methodology is based on a learnable partheno-genetic algorithm and aims to minimize the total distribution costs of the EV route while satisfying the constraints of battery capacity, charging time, EV demands, and the effects of vehicle loading on the vehicle's electricity consumption. By applying the model, a profit factor of 1.67 was obtained by the charging station. The authors conclude that the number and location of charging stations can impact the EVs' route and cost significantly. Moreover, EV charging also impacts the operation level of the power system.

Siano, P. et al. [70] propose a stochastic mixed-integer linear programming problem for the participation of a DER aggregator in the day-ahead market in the presence of demand flexibility. The authors verify that the proper interactions between local energy systems are essential to increase the aggregator's profits. Such interactions can take advantage of the synergies between DERs. An expected aggregator's profit of 2342.66 EUR/day was achieved, even considering the few electricity consumers (17 consumers of distinct classes), which is quite impressive.

Therefore, high variability of topics is verified among impactful research, as Dong, Z. et al. [2] approach risk mitigation, Dong, Z. et al. [69] address EV routing, and Siano, P. et al. [70] study a DER aggregator entity. This draws attention to the several applications and problems that must be assessed and solved concerning electricity markets and DER integration.

Table A1 demonstrates that the most-cited articles of Shafie-Khah, M. and Catalao, J. are the same, thus implying collaboration between them.

A strong focus of the main authors on DR issues and optimization methods is demonstrated in Table A1, even though they were not directly assumed in Descriptors 1 (first search). This can be further emphasized by the three-field plot (Sankey diagram), as illustrated in Figure 4. The left column was set as the countries, the middle column as the authors, and the right column as the keywords. The size of the rectangles relates to the frequency. It can be verified that the main authors mention China, Portugal, Iran, the USA, and Spain frequently. Regarding keywords (excluding keywords included in Descriptors 1), demand response, uncertainty, renewable energy, smart grid, and optimization are the most used by the main authors.

In the case of Sample 1, it was verified that the majority of the most-cited articles are not included in Table A1. Therefore, in Table A2, the twenty most-cited articles from Sample 1 are described (duplicates concerning Table A1 are disregarded). Among impactful research, some are highlighted:

Lopes, J. et al. [71] propose a framework for integrating EVs into electric power systems. The methodology is based on a logical algorithm that conducts power flow simulations for varying EV penetrations to verify its impact on the grid. It is demonstrated in the case study that the grid can withstand 10% EV penetration without changes. The authors assess not only the technical implications of EV integration, but also market aspects. Moreover, they argue that large-scale diffusion of EVs should not occur instantly. Instead, EVs should be adopted first by commercial transportation service providers (e.g., taxis) and be gradually extended to the general public. This strategy increases the adaptation time of the system operator and enables potential improvements in market design and system operation.

Qian, K. et al. [72] propose a methodology for modeling and analyzing the load demand in a distribution system due to EV battery charging. The authors assume the charging cost as the objective function to be minimized. The model takes into account the risk associated with the starting time of batteries, charging, and the initial state of charge. Such risks are inherent to real-world EV applications. The authors demonstrated that a fleet composed of 10% of EVs is enough to increase the peak power demand by 17.9%. This

draws attention to the high power demand that EV charging represents. Such demand increase has substantial implications in electricity markets (electricity price increase) and must be thoroughly evaluated in practice.

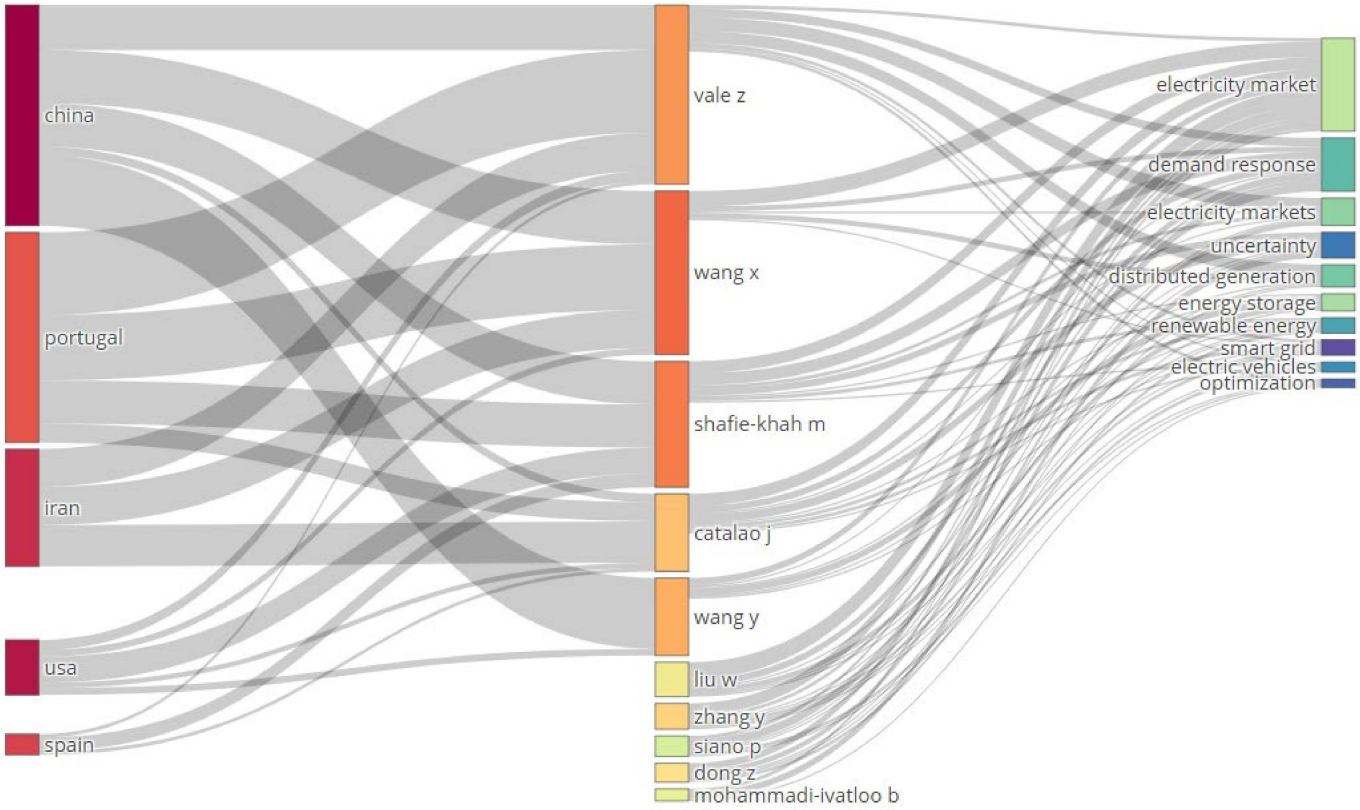

Figure 4. Three-field plot (countries/authors/keywords). Source: own study, elaborated by Bibliometrix.

Tomic, J. et al. [73] analyze the potential of EVs to provide power for electricity markets in V2G applications. The model is developed based on newly introduced equations for the value of V2G regulation, revenue, cost, and electrical power capacity for V2G. The authors study existing USA electricity markets and conclude that V2G applications can be profitable for the company that owns the fleet when certain conditions are met (low value of regulation). Annual profits of up to 260,000 USD were obtained for a particular company.

While the studies conducted by Lopes, J. et al. [71], Qian, K. et al. [72], and Tomic, J. et al. [73] differ significantly in work emphasis, they assess applications and problems concerning EVs. It was verified that articles that address EVs tend to be highly cited (this will be discussed more thoroughly in Section 3.3) due to their importance in decreasing the market penetration of internal combustion engine vehicles. Moreover, the effects of EVs on the electricity market, grid, and environment are intricate, requiring the development of robust models.

Naturally, older articles are more likely to have more citations, i.e., newer articles are unlikely to be included in Table A2. Therefore, it is important to verify the most-cited state-of-the-art articles on the topic. The ten most-cited articles from 2020 onward are described in Table A3 (duplicates are disregarded). As verified, in addition to DR issues, P2P electricity trading and the blockchain are very current topics.

Three out of ten articles focus on P2P electricity trading (Khorasany, M. et al. [74], Tushar, W. et al. [75], and Zhang, Z. et al. [76]), whereas two focus on blockchain aspects (Van Leeuwen, G. et al. [77] and Dehghani, M. et al. [78]).

Khorasany, M. et al. [74] focus on developing a P2P model to maximize the market players' socioeconomic welfare, whereas the proposed model by Zhang, Z. et al. [76] focuses

on risk aspects related to P2P trading, such as PV generation forecasting. The proposed model allows for around 55% of PV forecast error to be balanced locally.

In turn, Tushar, W. et al. [75] conduct a review on P2P electricity trading, analyzing advances and emerging challenges. Currently, the implementation of P2P is limited to trial schemes in developed countries [79]; thus, P2P is expected to remain in the spotlight for a long period.

Botelho et al. [39] highlight the importance of P2P electricity trading in the future by stating that the regulatory timeline for prosumers follows the order: FIT, net metering, self-consumption, and P2P negotiation. It is emphasized that P2P electricity trading and the blockchain are interconnected topics, i.e., blockchains are possible solutions for satisfactorily implementing P2P electricity trading [80].

The most-cited article of Table A3 (Gillingham, K. et al. [81]) addresses the COVID-19 pandemic, which is obviously a topic of recent interest [82,83].

3.1.5. Countries and Keywords

Figure 5 illustrates the corresponding authors' countries, where SCP stands for simple country publication and MCP stands for multiple country publication. As verified, China has the highest number of corresponding authors (291) and the highest collaboration with other countries (due to the higher MCP). The ten countries mentioned in Figure 5 account for 71% of the corresponding authors, highlighting the imbalance between countries. Figure 6 describes the total citations per country. As observed, the USA is the leading country in total citations (5729). The ten countries mentioned in Figure 6 account for 73% of the total citations.

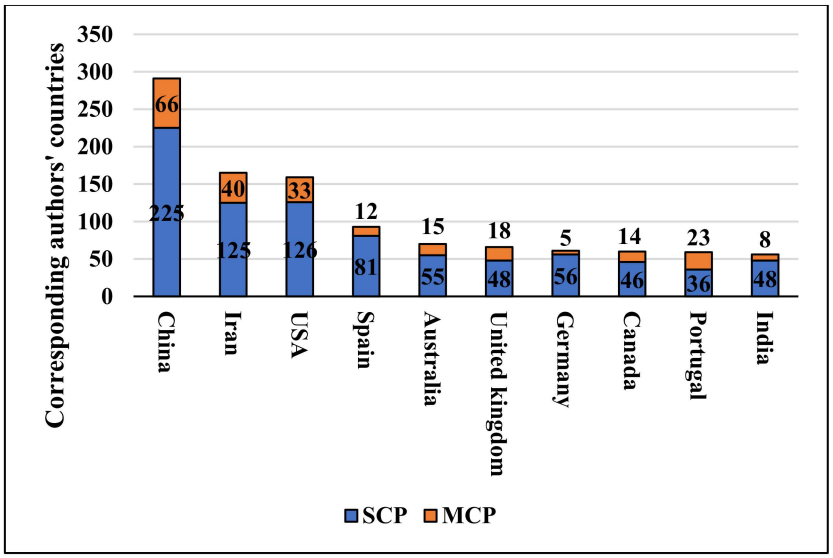

Figure 5. Corresponding authors' countries. Source: own study using data from Bibliometrix.

A worldwide overview of scientific production is illustrated in Figure 7, where NP regards no publications and $Q_{1,\ldots,4}$ regards the quartiles. There are 64 countries with publications included in Sample 1. Q_1 regards countries with one article, Q_2 countries with 2–6 articles, Q_3 countries with 7–18 articles, and Q_4 countries with 19–291 articles. The relevance of Africa is restricted, with only one (Morocco) and three countries (Tunisia, Egypt, and South Africa) in Q_1 and Q_2, respectively. The relevance of South America is decent but not particularly high, as there are four (Uruguay, Argentina, Peru, and Ecuador), one (Chile), and two countries (Brazil and Colombia) in Q_1, Q_2, and Q_3, respectively (not accounting for French Guinea, since it is a French territory). Europe, Asia, North America, and Oceania present nine, four, two, and one countries in Q_4, respectively. Therefore, it is evident that Europe is an essential continent for the development of the theme. The relationship

between scientific production and socioeconomic development becomes evident when assessing Figure 7.

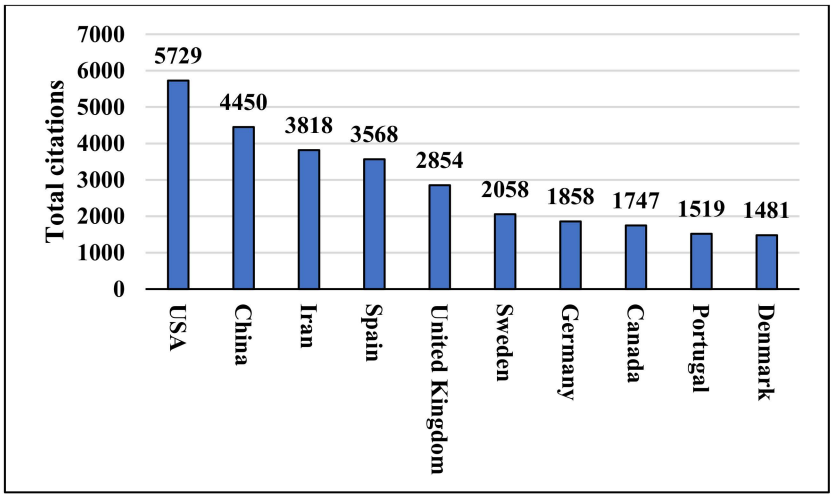

Figure 6. Total citations per country. Source: own study using data from Bibliometrix.

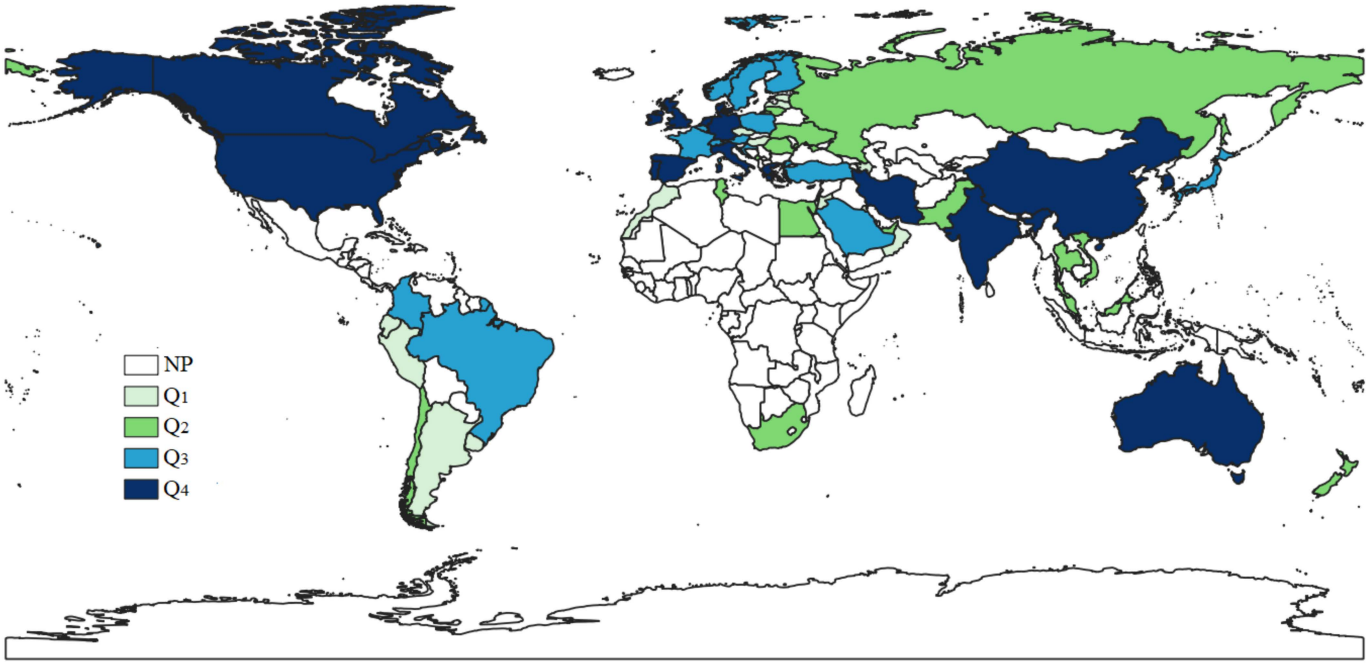

Figure 7. Worldwide overview on scientific production. Source: own study using data from Bibliometrix.

The most relevant keywords in terms of frequency are described in Figure 8 (equivalent keywords, such as electricity market and electricity markets, are combined in Figure 8). Demand response, renewable energy, uncertainty, optimization, and smart grid appear in both Figures 4 and 8, indicating that both the overall research community and the main authors use relatively similar keywords. Among the strings used in Descriptors 1, a higher emphasis on energy storage is demonstrated in Figure 8, with 277 appearances compared to electric vehicles (142), distributed generation (125), and distributed energy resources (69). The relevance of demand response is highlighted as it presents more appearances than one of the strings (distributed energy resources). Among energy storage technologies, batteries lead, with 29 appearances, compared to thermal energy storage with 23 appearances. Surprisingly, wind power showcased substantially higher research interest among renewable sources, with 87 appearances, compared to solar energy with only 16.

However, this might be related to the distributed generation keyword encompassing solar PV generation. Among the methods, stochastic programming leads with 58 appearances. The relevance of stochastic programming becomes evident when assessing the high-impact publications described in this paper, as [70,72,84–92] apply stochastic programming (mostly multi-level optimization, where an objective function is assumed in each optimization stage) to assess advanced or even futuristic applications of DERs and DR programs. This is because of the robustness of such methodology, which allows the solution of complex problems. In contrast, AI/Evolutionary algorithms are verified in [2,69,93,94]. Even though P2P and the blockchain are relatively new concepts, they appear 18 and 7 times, respectively. Lastly, attention is drawn to the concept of VPP, with 56 appearances. VPP aggregates independent energy resources for efficient system operation by employing software-based technology [95]. While the VPP presents great potential, its implementation is challenging and currently limited to developed countries, justifying the high research interest.

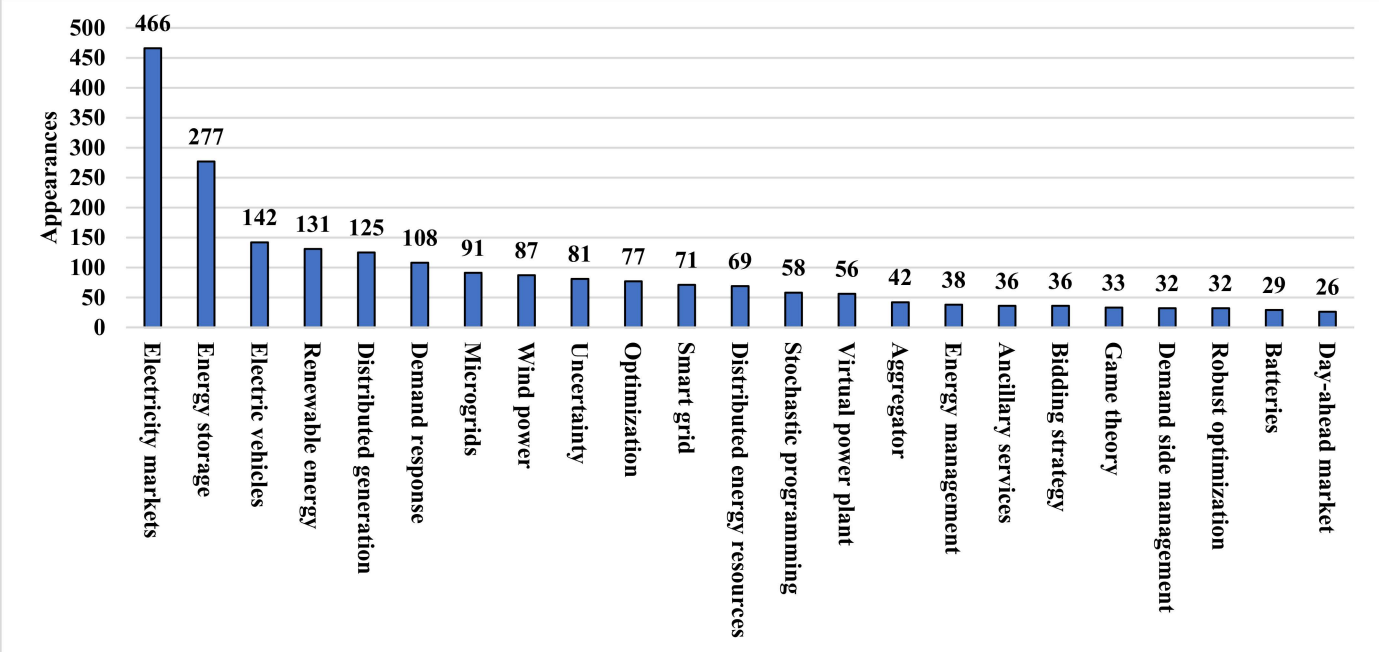

Figure 8. Most relevant keywords in terms of frequency. Source: own study using data from Bibliometrix.

It is important to note that while the keywords frequency assessment is of utmost importance to check for trends, authors might assess a topic without necessarily adding it to the keywords.

3.2. Sample 2

In this section, DR issues are analyzed more closely due to their relevance in the context of electricity markets and DERs. Sample 2 presents 296 articles, and the first publication date is 2007. The average citations per document of Sample 2 (24.55) is almost the same as Sample 1. Overall, in numerical terms, Samples 1 and 2 are similar (normalized indexes concerning the number of publications), as presented in Table A5 in Appendix A.

The twenty most-cited articles from Sample 2 are described in Table A4 (duplicates were removed). For superior insights, a column informing the pricing scheme applied in the context of DR is introduced (outlined by posterior research of the articles). As verified, day-ahead pricing (DAP) and RTP are widely assessed among high-impact publications.

Kardakos, E. et al. [96] address the optimal bidding strategy problem of a commercial VPP comprised of DERs in the context of DAP. The authors develop a multi-level optimization model and conclude that it allows the VPP to decide the desired risk prior to conducting the optimal bidding strategy.

Marzband, M. et al. [97] develop an energy management system to optimally operate and schedule microgrids in the context of DAP. The authors seek to meet customers' requirements with minimum cost. Cost reductions of around 15% were achieved.

Kardakos, E. et al. [96] and Marzband, M. et al. [97] demonstrate that, in general, the models of the articles described in Table A4 are robust but might assess different problems.

Both DAP and RTP present significant volatility and complexity, especially in the context of increasing DER integration, justifying the high research interest in such schemes. While several countries already deploy DAP- and RTP-based markets (e.g., the USA [35], Japan [98], Italy [99], and the UK [100]), the examples are typically restricted to developed countries (this is corroborated in Table A4), where market deregulation is advanced. In contrast, Table A4 demonstrates that time-of-use (TOU) pricing is analyzed in only one publication (Shojaabadi, S. et al. [101]). In the TOU scheme, the day is separated into blocks with distinct prices, which are established in advance of use [102,103]. Moreover, the prices established for each block are typically maintained for long periods (e.g., months). Therefore, the volatility and complexity of TOU are relatively low. Examples of TOU-based markets are more common in emerging and underdeveloped countries (e.g., Brazil [53], Senegal, and Uganda [104]). However, the potential of TOU schemes to generate substantial DR is confined compared to more advanced schemes. Hence, lower research interest in TOU pricing among high-impact publications is expected.

The most-cited article from Sample 2 (Walawalkar, R. et al. [35]) addresses a range of DR programs that have been implemented in the USA. Some programs are not necessarily related to the electricity tariff, such as emergency DR programs, where participants are paid for responding during system emergencies (participants might be compensated based on a fixed amount per MWh). While this is true, the majority of articles in Table A4 assess DR programs in the context of dynamic electricity pricing (as previously mentioned, mainly DAP and RTP).

There is a natural tendency to transition to more advanced schemes. For instance, Ramos et al. [66] emphasize that Brazil recently implemented a trial DR program [105] to target the reduction in consumption by previously qualified consumers as an alternative to dispatching thermal plants (similar to an interruptible load DR program), thus ensuring enhanced reliability and lower tariffs for final consumers. While only qualified consumers are currently eligible to participate in the program, the idea is to increase participation over time once it becomes more mature.

3.3. Comparison between Distributed Generation, Energy Storage Systems, and Electric Vehicles

In this section, a comparison among DG, ESSs, and EVs is carried out on four topics: (1) main authors (Table A1); (2) most-cited articles (Table A2); (3) state-of-the-art articles (Table A3); and (4) DR issues (Table A4). The idea is not to indicate that one technology is superior to others, but such comparison leads to valuable conclusions and is beneficial for readers that intend to use the results shown in Tables A1–A4 in their research. Figure 9 illustrates the comparison in terms of scientific production. It is emphasized that when an article focuses on two technologies (e.g., DG and ESSs), both are quantified in Figures 9–11. As verified, DG, ESSs, and EVs are the technologies of focus in 27, 35, and 18 articles, respectively. ESSs are highly researched by the main authors (12 articles) and in the context of DR issues (12 articles). Although less emphasis is given to EVs, seven of the most-cited articles focus on them. In Figure 10, the comparison in terms of total citations is illustrated. As observed, DG, ESSs, and EVs present 5241, 4346, and 4506 total citations, respectively. Hence, ESSs are not as cited. The high number of citations concerning DG is largely driven by Ackermann, T. et al. [60] as it presents 1802 total citations. EVs are highly cited even though only 18 articles focus on them. Figure 10 also demonstrates that EVs are the most cited in Table A2. Finally, the comparison in terms of average citations per article is illustrated in Figure 11. Logically, EVs gain relevance in the results shown in Figure 11 due to fewer articles. If the average number of citations is calculated in a combined way for Tables A1–A4, it results in 194.1, 124.2, and 250.3 for DG, ESSs, and EVs, respectively.

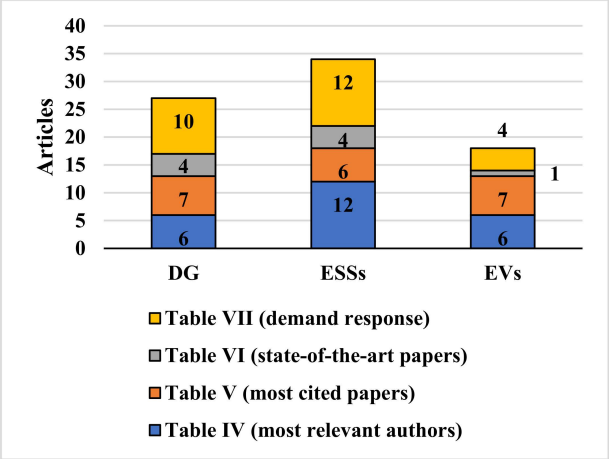

Figure 9. Comparison among the emphasis on distributed generation, energy storage systems, and electric vehicles in terms of published articles. Source: own study using data from Bibliometrix.

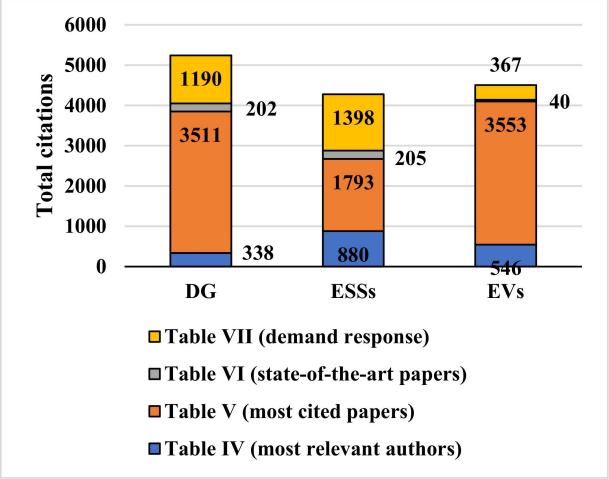

Figure 10. Comparison among the emphasis on distributed generation, energy storage systems, and electric vehicles in terms of total citations. Source: own study using data from Bibliometrix.

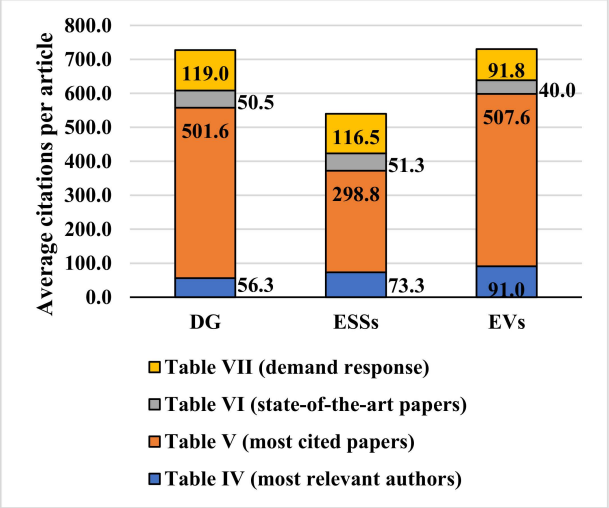

Figure 11. Comparison among the emphasis on distributed generation, energy storage systems, and electric vehicles in terms of average citations per article. Source: own study using data from Bibliometrix.

Three research questions, whose answers were presented throughout this article and are summarized below, were chosen to support the literature review:

RQ 1: what are the main features of the electricity markets literature in the context of increasing DER integration? Articles on the topic have been published since the 1990s; however, scientific production gained momentum after the 2000s. Since then, the production has increased substantially, indicating an expansion of research interest. The average number of citations has fluctuated around 5, indicating stability. Applied Energy, IEEE Transactions on Power Systems, IEEE Transactions on Smart Grid, and Energy are leading journals on the topic, but there are several other important journals. The main authors and their notable research were described in Tables 3 and A1, respectively, whereas the most overall cited articles were described in Table A2. The assessment demonstrated a high emphasis on robust optimization methodologies, particularly multi-level stochastic programming. However, a high variability of topics is verified (stochastic programming can be applied to solve numerous problems). In turn, by assessing more current research (2020 onwards), an emphasis on P2P electricity trading and the blockchain is clear (see Table A3). China, Iran, and USA proved to be the countries with the highest scientific production in the theme. On the other hand, the theme is underdeveloped in South America and Africa. Several keywords proved to be essential in the context of electricity markets and DERs, in special demand response. ESSs draw attention in terms of scientific production, whereas EVs in terms of citations.

RQ 2: what are the dynamic pricing schemes in electricity markets in the context of DR and increasing DER integration? There is a range of DR programs that have been implemented in developed countries (e.g., USA [35]), and some of them are not necessarily related to the electricity tariff, such as emergency DR programs, where participants are paid for responding during system emergencies. However, the research demonstrated that virtually all high-impact publications on the topic address DAP or RTP.

RQ 3: what are the most relevant articles addressing electricity markets in the context of DR issues and increasing DER integration? The most relevant articles were described in Table A4, including valuable additional information, such as the country and region that the articles focus on, the technologies (DG, ESSs, or EVs), the pricing schemes, and the work emphases. Moreover, Section 3.2 assessed such articles and the pricing schemes more closely.

3.4. Challenges and Recommendations for Future Research

Based on the SLR conducted, this section points out the challenges and essential opportunities for future work. The focus is on electricity markets in the context of DERs and DR issues; however, as there are no proper means of completely separating such themes, technical and environmental factors are also addressed.

Virtual Power Plant: Although several publications address VPP, opportunities for further research were verified. For instance, the grid topology and power delivery substantially impact the VPP's potential of conducting an optimal decision-making process [96,106]. In fact, grid and VPP interests are often conflicting [107]. In future research, it is essential not only to analyze the impact of grid topology, but also to propose practical solutions for cases where the topology jeopardizes the operation of the VPP. Furthermore, several types of VPPs form distinct coalitions (e.g., large-scale VPPs, micro VPPs) and might apply distinct bidding strategies [108]. A commonly used approach is to assume a uniform bidding strategy for each VPP when simulating electricity markets; however, in reality, strategies are likely to vary over time, and combinations of strategies are also anticipated. Therefore, it is essential to assess this issue in future research. Moreover, when multiple VPPs exist in an electricity market, efforts are required to model the entrance of a candidate to a particular VPP instead of another. Finally, it is important to guarantee fairness for all participants, taking into account individual characteristics. Table 4 describes important issues concerning VPP.

Table 4. Problems, suggestions, and impacts of VPP. Source: own study.

Problem to Be Solved	Suggested Analysis and/or Tool	Impact to Measure
Transmission and/or distribution grid constraint	Grid optimization; design of experiments; ANN	Constraint reductions; demand reduction at peak time
Inadequate market models	Macro and micro economic	Utilities profit
Inappropriate assignation models	Economic strategies; auction theories; regulatory aspects	Participation and discount in auctions

Demand Response and Dynamic Pricing: There is a difficulty in accurately modeling human behavior in the context of dynamic pricing due to individual characteristics and uncertainty of responses [93]. Such difficulty might harm not only the effectiveness of dynamic pricing schemes in increasing socioeconomic welfare, but also impair grid operation. Therefore, it is important to focus on the accurate modeling of human behavior in future research (e.g., artificial neural network/ANN approaches capable of capturing complex individual characteristics). The complexity of the theme is highlighted in Ziras et al. [109], which prove that DERs modify consumer behavior and preferences. Moreover, publications typically address cost functions and probability distributions as known [110]; however, there might be errors when estimating the electricity cost, which should be accounted for. Additionally, emerging technologies in the context of DR (e.g., ZigBee-enabled DR systems and in-home energy use displays) and their effects on human behavior should be analyzed in future research [35]. Finally, whereas day-ahead and real-time are undoubtedly essential, the SLR demonstrated a gap in how to efficiently transition to such schemes. Analyzing this issue can surely benefit emerging countries that present deferred electricity markets. Utility functions are important tools for modeling human behavior, as they aim to model the quality of life added by electricity consumption. Costa et al. [111] generalize conventional quadratic utility functions to represent the cross-elasticities' effects in day-ahead pricing electricity markets. In future work, it is important to combine the model proposed by Costa et al. with ANN approaches and include DERs in the modeling. This is particularly true since most state-of-the-art models take into account the cost or profit as objective functions and disregard the quality of life added by electricity consumption. Import issues regarding DR and dynamic pricing are described in Table 5.

Table 5. Problems, suggestions, and impacts of demand response and dynamic pricing. Source: own study.

Problem to Be Solved	Suggested Analysis and/or Tool	Impact to Measure
Human behavior modeling	Field research; ANN; multivariate statistics	Skills to reduce energy demand
Price schemes	Field research; pilot projects; ANN; multivariate statistics; optimized tariff model	Demand reductions; energy bill variations

Electric Vehicles: As previously mentioned, publications concerning optimal charging and discharging strategies for EVs are relatively common [23–26]. Likewise, some publications address optimal routing [69]. However, simultaneously addressing both issues is a complex task that should be assessed in future research. Moreover, instabilities in electricity markets and grids due to a high share of EVs should also be analyzed concurrently [112]. It is also critical to apply rigorous forecasting techniques (e.g., hybrid autoregressive integrated moving average/ARIMA and ANN models) to predict prices and driving patterns when running optimization algorithms to increase the studies' veracity and applicability [113]. Lastly, further research should take into account faithful and dynamic user restrictions based on advanced communication schemes. Table 6 describes important queries concerning EVs.

Table 6. Problems, suggestions, and impacts of EVs. Source: own study.

Problem to Be Solved	Suggested Analysis and/or Tool	Impact to Measure
Charging, discharging, and optimal routing	Common studies; holistic approaches; ANN	Demand; energy prices
EV into the energy market	Economic; holistic approach; forecasting techniques; ARIMA	Demand; energy prices
Faithful and dynamic user restrictions	Real-world data	Effects of real data

Distributed generation: This study demonstrated a high effort in solving optimal distributed generation placement (ODGP) problems [114]. However, ODGP studies should simultaneously consider uncertainties (e.g., through stochastic programming), grid management (e.g., islanding), and expansion planning (thereby enabling long-term assessments [115]. The same can be inferred for other DERs, i.e., a more integrated evaluation is needed. This becomes clear when assessing Singh et al. [116], as it reviews DG planning based on minimization of power loss, oscillations, and maximization of power system's loadability, stability, reliability, security, power transfer capacity, operation's flexibility, etc. However, studies usually consider only one or a few of the mentioned topics [117]. Simultaneously optimizing all these issues based on a multi-objective optimization approach is still a daunting challenge. Furthermore, it is evident that evaluating technical factors by themselves is not enough, as the economics of DG and its impact on the electricity market are of utmost importance. For instance, future work should evaluate the potential influence of the system's stability, reliability, and security on the electricity market. Issues regarding DG are further described in Table 7.

Table 7. Problems, suggestions, and impacts of DG. Source: own study.

Problem to Be Solved	Suggested Analysis and/or Tool	Impact to Measure
Lack of integrated studies for all DG sources	Long term planning; power flow; dynamic studies; supervision and control schemes	Energy production and demand; losses
System operation	Multi-objective optimization	Outages reduction
Influence of the system behavior in the energy market	Economic; ANN; multivariate statistics	Energy prices

Energy Storage Systems: A high emphasis on ESSs studies was demonstrated by this SLR; however, there is difficulty in enabling some technologies to ensure greater diversification. For instance, among high-impact publications addressed in this paper, Wang et al. [118], Liu et al. [119], and Mohammadi-Ivatloo et al. [120] address power-to-gas technology; however, Liu et al. [119] state that such technology is "generally economically inefficient based on the present levels of transforming efficiency, cost, and capacity". This is a problem that is likely to delay the development of electricity markets. Diversification of storage technologies is essential, for example, to enable multiple ancillary services based on advanced business model schemes, as each technology has specific advantages and disadvantages. In this context, hybrid ESSs can be a valuable solution to improve the economics and applicability of ESSs in electricity markets in the future by combining the advantages of multiple technologies [1] and must be well investigated in future works. Moreover, the development of advanced management systems (e.g., battery management systems) is of utmost importance to promote the wide diffusion of ESSs and further enhance electricity markets. Advanced battery management systems must be able to acquire data, estimate the state of charge, control charge and discharge specifications, manage thermal conditions, and guarantee safety, thereby making energy storage much more attractive and economical. Management systems can also integrate market signals for improved decision-making based on predefined user specifications. Such an all-encompassing concept is very

promising in the context of smart grids and smart market development. Table 8 outlines queries concerning ESSs.

Table 8. Problems, suggestions, and impacts of ESSs. Source: own study.

Problem to Be Solved	Suggested Analysis and/or Tool	Impact to Measure
Economic viability	Economic; holistic approaches	Return of investments
Absence of ancillary services markets	Economic; holistic approaches	Service costs
Robust management systems	Dynamic simulations	Safety; lifetime prolongation; efficiency

Peer-to-peer electricity trading: As previously mentioned, P2P electricity trading is a relatively new concept that showcases substantial potential in the context of electricity market development. There are three main designs of P2P markets [30]: full P2P market (only peers negotiating electricity), community-based market (presents a community manager who manages trading activities), and hybrid P2P market (combination of the previous designs). Although mathematical formulations already exist for the three designs, the main challenge is not necessarily related to the mathematical formulation but how to implement them in practice, since P2P electricity trading should not eliminate conventional electricity markets. It is necessary to develop means of both existing in harmony, ensuring fairness for all market players, including low-income consumers who are not able to participate in P2P electricity trading markets. This consideration gains relevance since this study demonstrated a gap in methodologies and frameworks that focus on decreasing social inequality and guaranteeing the interests of low-income consumers. Among P2P market designs, the full P2P market presents a high level of anarchy, which might be challenging to implement adequately. Further issues regarding P2P markets are specified in Table 9.

Table 9. Problems, suggestions, and impacts of P2P markets. Source: own study.

Problem to Be Solved	Suggested Analysis and/or Tool	Impact to Measure
P2P market	Economic; regulatory	Prosumers profit; ease of transactions; security; privacy; socioeconomic welfare
Social inclusion	Economic; consumer behaviors	Energy access; socioeconomic welfare
Dynamic markets	Economic; regulatory	Utilities profit; costs; socioeconomic welfare; security; privacy; energy price stability

Blockchain: The blockchain is also a relatively new concept that presents numerous applications in the electrical sector, such as [121]: decentralized data storage and control in power grids, P2P electricity trading, EVs (selecting suitable charging places), and carbon credit. The usage of blockchain technology in such applications ensures anonymity, transparency, democracy, and security. However, there are several challenges related to the broad implementation of blockchain technology in the electrical sector, such as privacy (e.g., electricity consumption records may be leaked), the sheer volume of data in large-scale electricity markets, and governmental interventions and legal issues. Musleh et al. [122] also draw attention to slower transactions due to the various operations involved. Therefore, it is important to address and mitigate such problems in the future to promote the broad usage of blockchain technology in the electrical sector. Blockchain aspects are further assessed in Table 10.

Table 10. Problems, suggestions, and impacts of blockchain. Source: own study.

Problem to Be Solved	Suggested Analysis and/or Tool	Impact to Measure
How to introduce blockchain in the electricity market	Economic; regulatory; legal aspects	Ease of transactions, security; privacy

Market design, regulation, and business models: These are essential factors to promote the conscious and efficient deployment of DERs [1], and there are several publications dedicated to assessing and developing new schemes [123]; however, empirical assessments are usually conducted, and the effectiveness of schemes is typically restricted to specific regions [66]. The problem is not directly related to the specificity of schemes, but which to adopt in each region, since there is often more than one candidate option, and the choice becomes typically empirical. Furthermore, the combination of schemes can also enhance the deployment of DERs and electricity markets, highlighting the complexity of the topic. Moreover, schemes should be addressed as changeable. For instance, Brazil will shortly modify the net metering policy since the installed capacity has reached significant levels [124]. Similar procedures (reduction in incentives as the installed capacity grows) have taken place in other countries (e.g., reduction in FIT in Germany [125]). Therefore, publications should not only propose a current market design, regulation, and business model but also assess how it can evolve. Lastly, business models should include and promote as many ancillary services as possible, which is achievable only if the remuneration is diversified and fair. Costa et al. [18] combine three models/techniques (Bass diffusion model—forecasting model of DG integration, optimized tariff model—socioeconomic regulated electricity market model, and life cycle assessment—environmental impact analysis technique) to holistically evaluate the impact of changes in the DG regulation over time, i.e., to assess socioeconomic and environmental impacts of changing the regulation. Table 11 describes queries concerning market design, regulation, and business models.

Table 11. Problems, suggestions, and impacts of market, regulation, and business models. Source: own study.

Problem to Be Solved	Suggested Analysis and/or Tool	Impact to Measure
Obsolescence of market models	Economic; regulatory; multi-objective optimization; ANN	Production; demand; costs; energy prices
Obsolescence of business models	Economic; regulatory; multi-objective optimization; ANN	Production; demand; costs; energy prices
Obsolescence of regulatory frameworks	Economic; regulatory; multi-objective optimization; ANN	Production; demand; costs; energy prices

Environmental factors in the context of electricity markets and DERs: Although some high-impact DER publications take into account environmental factors [115], the conducted SLR demonstrated that they are significantly more unusual than publications that address technical and economic issues. Furthermore, environmental factors are typically analyzed independently. Additionally, the majority of publications only address global warming [115,126], even though there are several environmental impact categories (e.g., metal depletion, human toxicity, environmental toxicity, etc.). Hence, it is important to address all environmental impact categories jointly with technical and economic factors (electricity market) in future works. For instance, it is important to evaluate if and how environmental toxicity can influence the market, since there are already market mechanisms for the global warming environmental impact category (e.g., carbon credit), thereby contributing to a more environmentally friendly electricity sector. Market mechanisms can be implemented with the support of blockchain technology [121]. Moreover, interest in circular economy-based systems has been increasing [122], and it is also important to integrate such concepts into electricity markets through advanced market mechanisms that promote the circular use of DERs. This is particularly important since the adequate disposal of DERs is a general concern [122]. Table 12 discusses issues of environmental factors.

Table 12. Problems, suggestions, and impacts of environmental aspects. Source: own study.

Problem to Be Solved	Suggested Analysis and/or Tool	Impact to Measure
Lack of holistic environmental approaches	Economic; circular economy; life cycle assessment	Environmental impacts; economic effects of carbon credits and similar mechanisms

The described challenges above and recommendations for future work highlight the interconnection between the topics; hence, for the development of electricity markets, integrated studies that take into account multiple knowledge areas are needed. Every time, a holistic approach considering the environment and especially the human being, social inclusion, and energy poverty reduction should be assumed.

While the information and perspectives provided in this paper are of substantial importance, systematic literature reviews addressing other descriptors (e.g., ancillary services, among others) are certainly valuable in future research and will contribute concurrently to the development of electricity markets.

Due to the large sample size and several issues assessed in this paper (e.g., VPP, blockchain, P2P markets, etc.), in future research, we recommend a more in-depth analysis of models, methodologies, and numerical results, along with the assessment of the state and development of energy market systems depending on the state and development of smart grid technology or smart power systems and the state and development of distributed energy resources, as well as demand response.

The in-depth assessment of the preliminary sample of articles presented in the introduction section of this paper is also recommended.

4. Conclusions

The increasing integration of distributed energy resources into modern power systems, also known as smart grids or grid edge, is a worldwide trend. In this context, challenges emerge regarding how to structure and operate electricity markets properly and ensure that distributed energy resources are being exploited to their full potential. Given the importance of the theme of electricity markets in the context of increasing distributed energy resources integration and demand response programs, a systematic literature review on the topic was conducted using the Web of Science and Scopus databases.

Essential information and perspectives were provided, along with in-depth discussions. The research demonstrated that the state of integration of distributed generation is already progressed in general. Authors are approaching their potential effects on the grid and market (how to decrease detriments while increasing benefits) and on developing enhanced business models. On the other hand, the diffusion of energy storage systems and electric vehicles is relatively restricted compared to distributed generation; however, given that their wide diffusion will occur at some point, they are also frequently studied, even in futuristic conditions. Peer-to-peer electricity trading and virtual power plant are currently incipient in terms of real-world applications; however, they show notable potential in the future. Lastly, demand response programs present an intermediate stage of evolution, as they are successfully implemented in developed countries in general, but there is a lack of satisfactory and advanced programs in developing countries.

It was also demonstrated that the research community's interest in the theme has been expanding due to the growing number of publications, most addressing energy storage systems; however, distributed generation and electric vehicles are also substantially studied. Furthermore, an emphasis on day-ahead and real-time demand response schemes is notable. Additionally, state-of-the-art articles often address peer-to-peer electricity trading and blockchain issues, which are very current and critical topics. Lastly, among high-impact publications, multi-level stochastic programming is the most-applied method for electricity market optimization, although evolutionary algorithms are also extensively used.

An essential finding of the research is the lack of all-encompassing studies that address multiple interconnected topics (e.g., concurrently assessing market design/regulation and environmental factors). Although conducting such studies is inherently challenging, it is of the utmost importance to further develop electricity markets and the electrical sector in general. The robustness and intricacy of the applied models among impactful research, especially multi-level stochastic programming, highlights the monumental challenges behind this, as the resources must be assessed from a system perspective and not only from an owner or prosumer perspective.

It remains a daunting task to maximize the potential of distributed energy resources in electricity markets from a holistic approach, i.e., considering economic, environmental, technical, social, and political aspects, while satisfying the interests of all market players and integrating advanced and beneficial demand response programs. Moreover, the evident lack of social studies is especially worrisome. None of the high-impact publications described in this paper particularly focus on social aspects. While advanced market optimization models are essential (frequent among high-impact publications), a higher emphasis on social aspects is required to mitigate social inequality (mainly in emerging and underdeveloped regions). It might be urgent to focus on problems of current electricity markets and not only on problems of advanced and futuristic smart electricity markets.

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Data Availability Statement: The metadata of the samples are made available in a repository to foster research on the topic [57].

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Appendix A

Tables A1–A4 detail important information concerning the main authors' most-cited articles from Sample 1, most-cited articles from Sample 1, most-cited state-of-the-art articles from Sample 1, and most-cited articles from Sample 2, respectively. The country or region that the study focuses on (different from affiliation), the technology of focus, and the work emphasis are not provided by the Bibliometrix tool since they are not characterized as metadata; thus, they were outlined by posterior research of the articles. Whenever "no information" is assigned, it means that the authors were not very clear or that we did not have access to the full text. Some of the titles can give a proper idea of the work emphasis, but this is not always the case. In column "work emphasis", beyond the paper's emphasis, a qualitative analysis was performed, showing the purpose, methodology, tools, and some results of the papers.

Table A1. Main authors' most-cited articles from Sample 1. Source: own study using data from Bibliometrix.

Author	First Author?	Article/ Reference	Year	Country/ Region [a]	Technology of Focus	Title	Journal	Total Citations	Work Emphasis
Wang, X. et al.	No	[127]	2009	China	No information	Smart Grid from the Perspective of Demand Response	Automation of Electric Power Systems	100	Assess the collaboration between smart grid and DR
Wang, X. et al.	No	[106]	2017	No information	DERs in general	Bidding Strategy Analysis of Virtual Power Plant Considering Demand Response and Uncertainty of Renewable Energy	IET Generation Transmission & Distribution	39	Propose a bidding strategy optimization model considering DR and the uncertainty of renewable energy for VPP
Wang, X. et al.	No	[107]	2018	China	DERs in general	Stackelberg Game-Based Coordinated Dispatch of Virtual Power Plant Considering Electric Vehicle Management	Automation of Electric Power Systems	28	Use of a VPP as an electricity retailer to participate in the coordinated optimization model of the management of EV charging
Shafie-Khah, M. and Catalao, J. et al.	Yes	[84]	2016	Spain	EVs	Optimal Behavior of Electric Vehicle Parking Lots as Demand Response Aggregation Agents	IEEE Transactions on Smart Grid	130	Develop a model to derive optimal strategies of parking lots, as responsive demands, in both price-based and incentive-based demand response programs
Shafie-Khah, M. and Catalao, J. et al.	Yes	[85]	2015	Spain	EVs	A Stochastic Multilayer Agent-Based Model to Study Electricity Market Participants Behavior	IEEE Transactions on Power Systems	79	Propose a stochastic multilayer agent-based model, where the first layer concerns the wholesale market players, including renewable power producers, and the second layer concerns responsive customers, including plug-in electric vehicle owners and consumers who participate in DR programs
Shafie-Khah, M. and Catalao, J. et al.	No	[86]	2020	No information	ESSs	Coordinated Wind-Thermal-Energy Storage Offering Strategy in Energy and Spinning Reserve Markets Using a Multi-stage Model	Applied Energy	70	Develop a three-stage stochastic multi-objective offering framework based on mixed-integer programming formulation for a wind-thermal-energy storage generation company in the energy and spinning reserve markets

Table A1. *Cont.*

Author	First Author?	Article/ Reference	Year	Country/ Region [a]	Technology of Focus	Title	Journal	Total Citations	Work Emphasis
Vale, Z. et al.	No	[128]	2012	Spain	DG	Multilevel Negotiation in Smart Grids for VPP Management of Distributed Resources	IEEE Intelligent Systems	67	Provide an overview of multilevel negotiation mechanism for operating smart grids and negotiating in electricity markets considering the advantages of virtual power player management
Vale, Z. et al.	No	[87]	2015	Texas (USA)	DG and ESSs	Incentive-Based Demand Response Programs Designed by Asset-Light Retail Electricity Providers for the Day-Ahead Market	Energy	60	Propose a model to suggest how a retail electricity provider with light physical assets can survive in a competitive retail market
Vale, Z. et al.	No	[108]	2011	Spain	DG	A New Approach for Multiagent Coalition Formation and Management in the Scope of Electricity Markets	Energy	55	Present a new methodology for the creation and management of coalitions in electricity markets
Wang, Y. et al.	No	[129]	2017	USA	ESSs	Scalable Planning for Energy Storage in Energy and Reserve Markets	IEEE Transactions on Power Systems	55	Use of a bilevel formulation to optimize the location and size of ESSs, which perform energy arbitrage and provide regulation services
Wang, Y. et al.	Yes	[130]	2017	Test system	ESSs	Lookahead Bidding Strategy for Energy Storage	IEEE Transactions on Sustainable Energy	51	Propose a look-ahead technique to optimize a merchant energy storage operator's bidding strategy considering both the day-ahead and the following day
Wang, Y. et al.	Yes	[118]	2015	No information	ESSs	Enabling Large-Scale Energy Storage and Renewable Energy Grid Connectivity a Power-to-Gas Approach	Proceedings of the Chinese Society of Electrical Engineering	51	Discuss the basic concept of the power-to-gas in the energy internet vision and proposes a framework of virtual energy storage for future electricity and gas network
Zhang, Y. et al.	No	[93]	2016	California (USA)	No information	Dynamic Pricing and Energy Consumption Scheduling with Reinforcement Learning	IEEE Transactions on Smart Grid	99	Develop reinforcement learning algorithms that allow service providers and electricity customers to learn their strategy without a priori information about the microgrid

Table A1. *Cont.*

Author	First Author?	Article/ Reference	Year	Country/ Region [a]	Technology of Focus	Title	Journal	Total Citations	Work Emphasis
Zhang, Y. et al.	No	[38]	2020	Multiple regions	DG and ESSs	Fundamentals and Business Model for Resource Aggregator of Demand Response in Electricity Markets	Energy	59	Review resource aggregators' roles in electricity markets, as well as their difference from other market entities, and analyzes the business model for resource aggregators
Zhang, Y. et al.	No	[131]	2011	Test system	DG	An Electricity Market Model with Distributed Generation and Interruptible Load Under Incomplete Information	Proceedings of the Chinese Society of Electrical Engineering	23	Assess the market equilibrium in the context of interruptible loads and distributed generation
Dong, Z. et al.	No	[2]	2014	USA	ESSs	Optimal Allocation of Energy Storage System for Risk Mitigation of Discos with High Renewable Penetrations	IEEE Transactions on Power Systems	241	Propose a new battery operation strategy for better utilization of ESSs and mitigation of operational risks related to price volatility
Dong, Z. et al.	No	[69]	2015	Test system	EVs	Electric Vehicle Route Optimization Considering Time-of-Use Electricity Price by Learnable Partheno-Genetic Algorithm	IEEE Transactions on Smart Grid	135	Propose a new optimal EV route model under the time-of-use pricing modality to minimize the total costs
Dong, Z. et al.	No	[110]	2017	USA	EVs	C-VaR Constrained Optimal Bidding of Electric Vehicle Aggregators in Day-Ahead and Real-Time Markets	IEEE Transactions on Industrial Informatics	57	Propose an optimization model to determine the day-ahead inflexible bidding and real-time flexible bidding under market uncertainties to minimize the conditional expectation of electricity purchase
Liu, W. et al.	Yes	[119]	2016	No information	ESSs	Cost Characteristics and Economic Analysis of Power-to-Gas Technology	Automation of Electric Power Systems	53	Discuss the possible application of power-to-gas technology in multi-energy systems and analyzes its costs and benefits
Liu, W. et al.	No	[132]	2018	Texas (USA)	ESSs	Provision of Flexible Ramping Product by Battery Energy Storage in Day-Ahead Energy and Reserve Markets	IET Generation Transmission & Distribution	40	Propose an optimization model for a battery energy storage aggregator to optimally provide flexible ramping products in day-ahead energy and reserve markets, aiming to maximize its monetary benefits

Table A1. *Cont.*

Author	First Author?	Article/ Reference	Year	Country/ Region [a]	Technology of Focus	Title	Journal	Total Citations	Work Emphasis
Liu, W. et al.	No	[133]	2018	Australia	DERs in general	Electricity Scheduling Strategy for Home Energy Management System with Renewable Energy and Battery Storage: a Case Study	IET Renewable Power Generation	35	Develop a home energy management system model with renewable energy, storage devices, and plug-in electric vehicles to minimize the electricity purchase and maximize the renewable energy utilization
Mohammadi-Ivatloo, B. et al.	No	[134]	2017	Alberta (Canada)	ESSs	Risk-Constrained Bidding and Offering Strategy for a Merchant Compressed Air Energy Storage Plant	IEEE Transactions on Power Systems	93	Propose an information gap decision theory-based risk-constrained bidding/offering strategy for a merchant CAES plant that participates in the day-ahead energy markets considering price forecasting errors
Mohammadi-Ivatloo, B. et al.	No	[88]	2017	No information	EVs	Stochastic Scheduling of Aggregators of Plug-in Electric Vehicles for Participation in Energy and Ancillary Service Markets	Energy	87	Analyze the optimal scheduling problem of plug-in electric vehicle aggregators in electricity markets considering the uncertainties of market prices, availability of vehicles, and status of being called by the independent system operator in the reserve market
Mohammadi-Ivatloo, B. et al.	No	[120]	2020	Test system	ESSs	Integrated Energy HUB System based on Power-to-Gas and Compressed Air Energy Storage Technologies in the Presence of Multiple Shiftable Loads	IET Generation Transmission & Distribution	33	Propose a stochastic model to determine the optimal day-ahead scheduling of the energy hub system with the coordinated operating of power-to-gas storage and tri-state CAES system
Siano, P. et al.	No	[135]	2011	Test system	DERs in general	Combined Operations of Renewable Energy Systems and Responsive Demand in a Smart Grid	IEEE Transactions on Sustainable Energy	216	Propose an energy management system behaving as an aggregator of DERs and aiming at optimizing the smart grid operation

Table A1. *Cont.*

Author	First Author?	Article/ Reference	Year	Country/ Region [a]	Technology of Focus	Title	Journal	Total Citations	Work Emphasis
Siano, P. et al.	No	[70]	2019	Turin (Italy)	DG and ESSs	Optimal Bidding Strategy for a DER Aggregator in the Day-Ahead Market in the Presence of Demand Flexibility	IEEE Transactions on Industrial Electronics	74	Propose an optimization model for the participation of a DER aggregator in the day-ahead market in the presence of demand flexibility.
Siano, P. et al.	No	[89]	2016	Iberian Peninsula	EVs	Optimal Trading of Plug-in Electric Vehicle Aggregation Agents in a Market Environment for Sustainability	Applied Energy	58	Propose a multi-stage stochastic model of a plug-in electric vehicle aggregator to participate in day-ahead and intraday electricity markets

[a] Country/region that the study focuses on (e.g., country/region where the case study is applied to or country/region where data are taken for the case study).

Table A2. Most-cited articles from Sample 1. Source: own study using data from Bibliometrix.

Author	Article/ Reference	Year	Country/Region	Technology of Focus	Title	Journal	Total Citations	Work Emphasis
Ackermann, T. et al.	[60]	2001	Multiple regions	DG	Distributed Generation: a Definition	Electric Power Systems Research	1802	Provide a general definition for distributed power generation in competitive electricity markets
Lopes, J. et al.	[71]	2011	Test system	EVs	Integration of Electric Vehicles in the Electric Power System	Proceedings of the IEEE	976	Present a conceptual framework to integrate electric vehicles into electric power systems covering grid technical operation and the electricity market environment
Qian, K. et al.	[72]	2010	UK	EVs	Modeling of Load Demand Due to EV Battery Charging in Distribution Systems	IEEE Transactions on Power Systems	859	Present a methodology for modeling and analyzing the load demand in a distribution system due to EV battery charging
Tomic, J. et al.	[73]	2007	USA	EVs	Using Fleets of Electric-Drive Vehicles for Grid Support	Journal of Power Sources	604	Evaluate the economic potential of utility-owned fleets of EVs to provide power for a specific electricity market
Georgilakis, P. et al.	[114]	2013	Multiple regions	DG	Optimal Distributed Generation Placement in Power Distribution Networks: Models, Methods, and Future Research	IEEE Transactions on Power Systems	491	Present an overview of the state-of-the-art models and methods applied to optimize the location/sizing of DG systems, analyzing and classifying current and future research trends in this field

Table A2. *Cont.*

Author	Article/ Reference	Year	Country/Region	Technology of Focus	Title	Journal	Total Citations	Work Emphasis
Rotering, N. et al.	[112]	2010	California (USA)	EVs	Optimal Charge Control of Plug-In Hybrid Electric Vehicles in Deregulated Electricity Markets	IEEE Transactions on Power Systems	489	Propose two algorithms to avoid grid overload in the context of increasing integration of plug-in hybrid electric vehicles (PHEVs)
Garcia-Gonzalez, J. et al.	[90]	2008	Spain	ESSs	Stochastic Joint Optimization of Wind Generation and Pumped-Storage Units in an Electricity Market	IEEE Transactions on Power Systems	421	Assess the combined optimization of a wind farm and a pumped-storage facility from the point of view of a generation company in a market environment
Ruiz, N. et al.	[136]	2009	Spain	DERs in general	A Direct Load Control Model for Virtual Power Plant Management	IEEE Transactions on Power Systems	370	Develop an optimization algorithm to manage a VPP composed of a large number of customers with thermostatically controlled appliances
Nikkhajoei, H. et al.	[137]	2009	USA	DG and ESSs	Distributed Generation Interface to the CERTS Microgrid	IEEE Transactions on Power Delivery	336	Analyze the ESS and the power electronic interface included in microsources of the Consortium for Electric Reliability Technology Solutions microgrid, which was established in 1999
Lund, H. et al.	[138]	2009	Nordic region	ESSs	The Role of Compressed Air Energy Storage (CAES) in Future Sustainable Energy Systems	Energy Conversion and Management	329	Assess the value of integrating CAES into future sustainable energy systems with higher shares of fluctuating renewable energy sources
El-khattam, W. et al.	[139]	2004	Test system	DG	Optimal Investment Planning for Distributed Generation in a Competitive Electricity Market	IEEE Transactions on Power Systems	302	Propose a new heuristic approach for GD capacity investment planning from the perspective of distribution companies
Walawalkar, R. et al.	[140]	2007	New York (USA)	ESSs	Economics of Electric Energy Storage for Energy Arbitrage and Regulation in New York	Energy Policy	265	Investigate the economics of two emerging electric energy storage technologies: sodium-sulfur batteries and flywheel energy storage systems in New York state's electricity market
Vagropoulos, S. et al.	[91]	2013	Test system	EVs	Optimal Bidding Strategy for Electric Vehicle Aggregators in Electricity Markets	IEEE Transactions on Power Systems	244	Assess the optimal bidding strategy of an EV aggregator participating in day-ahead energy and regulation markets using stochastic programming

Table A2. *Cont.*

Author	Article/ Reference	Year	Country/Region	Technology of Focus	Title	Journal	Total Citations	Work Emphasis
Parvania, M. et al.	[141]	2013	USA	DG and ESSs	Optimal Demand Response Aggregation in Wholesale Electricity Markets	IEEE Transactions on Smart Grid	222	Propose a model where DR aggregators offer customers various contracts for load curtailment, load shifting, utilization of onsite generation, and energy storage systems as possible strategies for hourly load reductions
Bradbury, K. et al.	[142]	2014	USA	ESSs	Economic Viability of Energy Storage Systems based on Price Arbitrage Potential in Real-Time U.S. Electricity Markets	Applied Energy	220	Use linear optimization to find the ESS power and energy capacities that maximize the internal rate of return when used to arbitrage 2008 electricity prices
Kristoffersen, T. et al.	[113]	2011	Nordic region	EVs	Optimal Charging of Electric Drive Vehicles in a Market Environment	Applied Energy	202	Present a framework for optimizing charging and discharging of electric vehicles, given the driving patterns of the fleet and the variations in market prices of electricity
Wang, Q. et al.	[143]	2015	Multiple regions	DERs in general	Review of Real-Time Electricity Markets for Integrating Distributed Energy Resources and Demand Response	Applied Energy	197	Review advanced typical real-time electricity markets, focusing on their market architectures and incentive policies for integrating DER and DR programs
Morstyn, T. et al.	[144]	2019	Test system	DERs in general	Bilateral Contract Networks for Peer-to-Peer Energy Trading	IEEE Transactions on Smart Grid	190	Propose bilateral contract networks as a new scalable market design for peer-to-peer energy trading
Hemmati, R. et al.	[46]	2013	Multiple regions	DG	Comprehensive Review of Generation and Transmission Expansion Planning	IET Generation Transmission & Distribution	179	Present a review of expansion planning problems from different aspects and views such as modeling, solving methods, reliability, distributed generation, electricity market, uncertainties, line congestion, reactive power planning, and demand-side management
Graff Zivin, J. et al.	[115]	2014	USA	DG and EVs	Spatial and Temporal Heterogeneity of Marginal Emissions: Implications for Electric Cars and other Electricity-Shifting Policies	Journal of Economic Behavior & Organization	179	Develop a methodology for estimating marginal emissions of electricity demand that vary by location and time of day across the United States

Table A3. Most-cited state-of-the-art articles from Sample 1. Source: own study using data from Bibliometrix.

Author	Article/ Reference	Year	Country/Region	Technology of Focus	Title	Journal	Total Citations	Work Emphasis
Gillingham, K. et al.	[81]	2020	USA	DERs in general	The Short-run and Long-run Effects of COVID-19 on Energy and the Environment	Joule	87	Evaluate how the short-run effects of COVID-19 in reducing air pollutants emissions can be outweighed by the long-run effects in slowing clean energy innovation
Khorasany, M. et al.	[74]	2020	Test system	DG and ESSs	A Decentralized Bilateral Energy Trading System for Peer-to-Peer Electricity Markets	IEEE Transactions on Industrial Electronics	76	Propose a decentralized P2P energy trading scheme for electricity markets with high penetration of DERs
Van Leeuwen, G. et al.	[77]	2020	Amsterdam (Netherlands)	DERs in general	An Integrated Blockchain-Based Energy Management Platform with Bilateral Trading for Microgrid Communities	Applied Energy	68	Propose an integrated blockchain-based energy management platform that optimizes energy flows in a microgrid whilst implementing a bilateral trading mechanism
Mohamed, M. et al.	[92]	2020	Test system	ESSs	An Effective Stochastic Framework for Smart Coordinated Operation of Wind Park and Energy Storage Unit	Applied Energy	51	Propose a methodology to assess the operation of a wind park-energy storage system in a day-ahead electricity market considering the system's technical constraints
Dehghani, M. et al.	[78]	2021	Test system	DG	Blockchain-Based Securing of Data Exchange in a Power Transmission System Considering Congestion Management and Social Welfare	Sustainability	48	Assess cyber-attacks in the context of blockchain and DG
Jafari, A. et al.	[94]	2020	Test system	DG and ESSs	A Fair Electricity Market Strategy for Energy Management and Reliability Enhancement of Islanded Multi-Microgrids	Applied Energy	41	Propose an electricity market strategy for the optimal operation of multi-microgrids
Tushar, W. et al.	[75]	2021	Multiple regions	DERs in general	Peer-to-Peer Energy Systems for Connected Communities: a Review of Recent Advances and Emerging Challenges	Applied Energy	40	Provide a comprehensive review of existing research in the peer-to-peer energy system
Szinai, J. et al.	[145]	2020	California (EUA)	EVs	Reduced Grid Operating Costs and Renewable Energy Curtailment with Electric Vehicle Charge Management	Energy Policy	40	Properly represent electricity markets and PEV charging together

Table A3. *Cont.*

Author	Article/ Reference	Year	Country/Region	Technology of Focus	Title	Journal	Total Citations	Work Emphasis
Zhang, Z. et al.	[76]	2020	Test system	DERs in general	A Novel Peer-to-Peer Local Electricity Market for Joint Trading of Energy and Uncertainty	IEEE Transactions on Smart Grid	39	Propose a P2P local electricity market model incorporating both energy trading and uncertainty trading simultaneously
Das, S. et al.	[146]	2020	Kolkata (India)	DG and ESSs	Day-Ahead Optimal Bidding Strategy of Microgrid with Demand Response Program Considering Uncertainties and Outages of Renewable Energy Resources	Energy	37	Propose an optimal bidding strategy considering the uncertainty of renewable energy resources and DR programs based on their outage probabilities

Table A4. Most-cited articles from Sample 2. Source: own study using data from Bibliometrix.

Author	Article/ Reference	Year	Country/Region	Technology of Focus	Pricing Scheme	Title	Journal	Total Citations	Work Emphasis
Walawalkar, R. et al.	[35]	2010	USA	DG and ESSs	Several schemes	Evolution and Current Status of Demand Response (DR) in Electricity Markets: Insights from PJM and NYISO	Energy	174	Review the evolution of the DR programs in PJM and NYISO markets and analyze current opportunities
Kardakos, E. et al.	[96]	2016	Greece	DG and ESSs	DAP	Optimal Offering Strategy of a Virtual Power Plant: A Stochastic Bi-Level Approach	IEEE Transactions on Smart Grid	169	Assess the optimal bidding strategy problem of a commercial VPP comprised of DERs and electricity consumers who participate in the day-ahead market
Marzband, M. et al.	[97]	2013	Test system	DG and ESSs	DAP	Experimental Validation of a Real-Time Energy Management System for Microgrids in Islanded Mode Using a Local Day-Ahead Electricity Market and MINLP	Energy Conversion and Management	153	Propose an energy management system algorithm based on mixed-integer nonlinear programming for microgrids in islanding mode

Table A4. *Cont.*

Author	Article/ Reference	Year	Country/Region	Technology of Focus	Pricing Scheme	Title	Journal	Total Citations	Work Emphasis
Jin, C. et al.	[147]	2013	New York (EUA)	ESSs and EVs	DAP and RTP	Optimizing Electric Vehicle Charging With Energy Storage in the Electricity Market	IEEE Transactions on Smart Grid	152	Assess the scheduling of EV charging with energy storage from an electricity market perspective with joint consideration for the aggregator energy trading in the day-ahead and real-time markets
Marzband, M. et al.	[148]	2014	Test system	DG and ESSs	DAP	Experimental Validation of a Real-Time Energy Management System Using Multi-Period Gravitational Search Algorithm for Microgrids in Islanded Mode	Applied Energy	149	Propose a method to optimize the performance of microgrids, including different types of DG units, with particular attention to the technical constraints
Mathieu, J. et al.	[149]	2015	California (EUA)	ESSs	RTP	Arbitraging Intraday Wholesale Energy Market Prices With Aggregations of Thermostatic Loads	IEEE Transactions on Power Systems	127	Investigate the potential for aggregations of residential thermostatically controlled loads to arbitrage intraday wholesale electricity market prices via non-disruptive load control
Valero, S. et al.	[150]	2007	No information	DG	DAP and RTP	Methods for Customer and Demand Response Policies Selection in New Electricity Markets	IET Generation, Transmission & Distribution	116	Demonstrate the capability of self-organizing maps to classify customers and their response potential
Ahmad, A. et al.	[151]	2017	Pakistan	DG and ESSs	DAP	An Optimized Home Energy Management System with Integrated Renewable Energy and Storage Resources	Energies	104	Propose an optimized home energy management system that facilitates the integration of renewable energy sources and ESSs and incorporates the residential sector into demand-side management activities
Wu, H. et al.	[152]	2015	Test system	No information	DAP	Demand Response Exchange in the Stochastic Day-Ahead Scheduling With Variable Renewable Generation	IEEE Transactions on Sustainable Energy	102	Propose a pool-based DR exchange model in which economic DR is traded among participants as an alternative for managing the variability of renewable energy sources

Table A4. *Cont.*

Author	Article/ Reference	Year	Country/Region	Technology of Focus	Pricing Scheme	Title	Journal	Total Citations	Work Emphasis
Sezgen, O. et al.	[153]	2007	New York (USA)	DG	Several schemes	Option Value of Electricity Demand Response	Energy	97	Demonstrate that financial engineering methodologies originally developed for pricing equity and commodity derivatives can be used to estimate the value of DR technologies
Nunna, H. et al.	[154]	2017	Test system	DERs in general	DAP	Multiagent-based transactive energy framework for distribution systems with smart microgrids	IEEE Transactions on Industrial Informatics	96	Propose an agent-based transactive energy management framework with a comprehensive energy management system as a solution to address the aggregated complexity induced by microgrids in distribution systems
Ciwei, G. et al.	[155]	2013	China	DG and ESSs	No information	Methodology and Operation Mechanism of Demand Response Resources Integration Based on Load Aggregator	Automation of Electric Power Systems	87	Provide an overview of the definition and function of load aggregator from the perspective of integrating demand response resources
Finn, P. et al.	[156]	2012	Ireland	EVs	DAP	Demand side management of electric car charging: Benefits for consumer and grid	Energy	76	Examine how optimizing the charging cycles of an electric car using demand-side management could be used to achieve financial savings, increased demand on renewable energy, reduced demand on thermal generation plants, and reduced peak load demand
Wang, Z. et al.	[157]	2017	Test system	EVs	RTP	Optimal Residential Demand Response for Multiple Heterogeneous Homes With Real-Time Price Prediction in a Multi-agent Framework	IEEE Transactions on Smart Grid	76	Present a multi-agent system to evaluate optimal residential DR implementation in a distribution grid

Table A4. *Cont.*

Author	Article/ Reference	Year	Country/Region	Technology of Focus	Pricing Scheme	Title	Journal	Total Citations	Work Emphasis
Marzband, M. et al.	[158]	2018	Test system	DG and ESSs	DAP	An advanced retail electricity market for active distribution systems and home microgrid interoperability based on game theory	Electric Power Systems Research	74	Propose an advanced retail electricity market based on game theory for the optimal operation of home microgrids and their interoperability within active distribution grids
Mcpherson, M. et al.	[159]	2018	Ontario (Canada)	ESSs	No information	Deploying storage assets to facilitate variable renewable energy integration: The impacts of grid flexibility, renewable penetration, and market structure	Energy	72	Evaluate the utility of storage assets given different electricity system configurations, market paradigms, and management schemes using a production cost model
Arghandeh, R. et al.	[160]	2014	Detroit (USA)	ESSs	DAP and RTP	Economic optimal operation of Community Energy Storage systems in competitive energy markets	Applied Energy	70	Propose means of taking advantage of the fluctuating costs of energy in competitive energy markets
Zhou, Y. et al.	[161]	2017	Test system	DG and ESSs	DAP and intraday	Optimal scheduling of aggregated thermostatically controlled loads with renewable generation in the intraday electricity market	Applied Energy	67	Propose a two-level scheduling method that helps an aggregator to optimally schedule its flexible thermostatically controlled loads with renewable energy
Shojaabadi, S. et al.	[101]	2016	Test system	EVs	TOU	Optimal planning of plug-in hybrid electric vehicle charging station in distribution network considering demand response programs and uncertainties	IET Generation, Transmission, and Distribution	63	Present a mathematical model to determine the optimal site and size of PHEVs charging stations in the distribution grids
Heydarian-Forushani, E. et al.	[162]	2014	No information	No information	DAP and intraday	Risk-Constrained Offering Strategy of Wind Power Producers Considering Intraday Demand Response Exchange	IEEE Transactions on Sustainable Energy	62	Propose a comprehensive stochastic decision-making model for wind power producers' participation in a competitive market

An overview of Sample 2 is provided in Table A5.

Table A5. Main information from sample 2. Source: own study using data from Bibliometrix.

Description	Results
Timespan	2007:2022
Sources	87
Articles	296
Average years from publication	3.74
Average citations per document	24.55
Average citations per year per document	4.395

Table A6. Methods and most significant results of the papers assessed more closely.

Article	Method	Most Significant Results
Dong, Z. et al. [2]	The authors apply a series of forecast toolboxes, including OptiLoad, OptiWind, and OptiSolar, and formulate the objective function as the distribution company's profit from energy transactions, system planning, and operation cost savings	Results demonstrated that although lead–acid batteries are cheaper, they present significant drawbacks that limit their risk mitigation potential, such as low charge power and high weight. Yet, profits/benefits of around 10% were achieved by the authors. Li-ion batteries are expected to be more promising in the future. However, their high cost is currently a bottleneck.
Dong, Z. et al. [69]	The methodology is based on a learnable partheno-genetic algorithm and aims to minimize the total distribution costs of the EV route while satisfying the constraints of battery capacity, charging time, EV demands, and the effects of vehicle loading on the vehicle's electricity consumption	A profit factor of 1.67 was obtained by the charging station. The authors conclude that the number and location of charging stations can impact the EVs' route and cost significantly. Moreover, EV charging also impacts the operation level of the power system.
Siano, P. et al. [70]	Stochastic mixed-integer linear programming problem for the participation of a DER aggregator in the day-ahead market in the presence of demand flexibility	The authors verify that the proper interactions between local energy systems are essential to increase the aggregator's profits. Such interactions can take advantage of the synergies between DERs. An expected aggregator's profit of 2342.66 EUR/day was achieved, even considering the few electricity consumers (17 consumers of distinct classes).
Lopes, J. et al. [71]	Logical algorithm that conducts power flow simulations for varying EV penetrations to verify its impact on the grid	It is demonstrated in the case study that the grid can withstand 10% EV penetration without changes. The authors assess not only the technical implications of EV integration but also market aspects. Moreover, they argue that large-scale diffusion of EVs should not occur instantly. Instead, EVs should be adopted first by commercial transportation service providers (e.g., taxis) and be gradually extended to the general public. This strategy increases the adaptation time of the system operator and enables potential improvements in market design and system operation.
Qian, K. et al. [72]	The authors assume the charging cost as the objective function to be minimized. The model takes into account the risk associated with the starting time of batteries, charging, and the initial state of charge	The authors demonstrated that a fleet composed of 10% of EVs is enough to increase the peak power demand by 17.9%. This draws attention to the high power demand that EV charging represents. Such demand increase has substantial implications in electricity markets (electricity price increase) and must be thoroughly evaluated in practice.

Table A6. *Cont.*

Article	Method	Most Significant Results
Tomic, J. et al. [73]	The model is developed based on newly introduced equations for the value of V2G regulation, revenue, cost, and electrical power capacity for V2G	The authors study existing USA electricity markets and conclude that V2G applications can be profitable for the company that owns the fleet when certain conditions are met (low value of regulation). Annual profits of up to 260,000 USD were obtained for a particular company.

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