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Smart grid deployment: from a bibliometric analysis to a survey

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ABSTRACT

Smart grids are one of the last decades' innovations in electrical energy. They bring relevant advantages compared to the traditional grid and significant interest from the research community. Assessing the field's evolution is essential to propose guidelines for facing new and future smart grid challenges. In addition, knowing the main technologies involved in the deployment of smart grids (SGs) is important to highlight possible shortcomings that can be mitigated by developing new tools. This paper contributes to the research trends mentioned above by focusing on two objectives. First, a bibliometric analysis is presented to give an overview of the current research level about smart grid deployment. Second, a survey of the main technological approaches used for smart grid implementation and their contributions are highlighted. To that effect, we searched the Web of Science (WoS), and the Scopus databases. We obtained 5,663 documents from WoS and 7,215 from Scopus on smart grid implementation or deployment. With the extraction limitation in the Scopus database, 5,872 of the 7,215 documents were extracted using a multi-step process. These two datasets have been analyzed using a bibliometric tool called bibliometrix. The main outputs are presented with some recommendations for future research.

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1. INTRODUCTION

The advent of electricity at the beginning of the 19th century marked the beginning of the second industrial revolution. Indeed, for more than 150 years, the industrial sector has known unprecedented growth and with it, the need for electrical energy. Some relevant factors have accentuated this growing need for energy. These include population growth, emerging economies, the cities' expansion, and the constant search for improving the quality of life, provided mainly by new technological processes and environmental issues and challenges [1], [2]. Unfortunately, the conventional electrical grid became less suitable to efficiently meet this need due to a low automation level in the distribution networks, a poor response to demand management, and a long transmission distance which causes numerous online losses during distribution [3], [4]. In addition, some critical incidents on the electrical grid have revealed important drawbacks of the grid and their impacts on human activities [5]. To overcome these deficiencies from the existing grid known as the traditional grid (TG) [6], the advancement of new information and communication technologies (NICT) was used to propose the concept of a smart grid. A smart grid according to the United States Department of Energy (DoE) [2], is an energy supply network that supports bi-directional power flow, it is distributed and automated in nature and permits real-time balancing of demand and supply via distributed and high-speed computing and communications. smart grid has been built on top of the traditional electrical grid. So, it has the primary conventional grid's features with some additional characteristics. As mentioned in [2] and [7], a bi-directional power flow property and a distributed generation profile are the main characteristics of the smart grid. Moreover, it is self-healing from power disturbance events (self-healing). In addition, Smart grid enables the active participation of consumers in demand response (DR) management and operates resiliently against physical and cyber-attacks as mentioned in [3], [8]–[11]. Thus, some countries such as China, the USA, and India have implemented the smart grid. At the same time, some notable institutions, such as the IEEE, defined some standards for the smart grid. Also, much research about smart grid evolved in the literature all over the world to understand smart grid's key functionalities, characteristics and advantages. Mainly, the work was focused on finding the suitable architecture through which smart grids (SGs) can be deployed. For instance, Petrovic *et al.* [12] and Ghasempour [13] studied how internet of things (IoT) can be used for an smart grid-based architecture.

Moreover, an in-depth overview of smart grid elements and key functionalities has been highlighted in studies [8], [14]–[16]. Useful backgrounds have been released in studies [17]–[20]. Therefore, we can evaluate the study level on the topic using bibliometric analysis. As in previous works, Kpoze *et al.* [21] conducted bibliometric research to evaluate the global trends of the research on smart grid architecture using documents published in the Web of Science (WoS) database from 2000 to 2022. Mainly, their study shows the most relevant work (authors and papers) and future research avenues on SG architecture. In the same vein, Ananthavijayan *et al*. [22] conducted a bibliographical survey about software architecture for smart grid systems. Indeed, bibliometric analysis requires a constant update of its insights.

Consequently, this paper provides an up-to-date overview of the evolution of smart grid research but specifically focuses on smart grid’s deployment by combining two databases: WoS and Scopus. Mainly, the paper emphasizes the trend of evolution of research on smart grid’s deployment, the most productive authors, sources, countries. Furthermore, the study presents a survey of the main technological approaches used to deploy smart grid, as mentioned in the literature. To give effect to the aforementioned directions, the following research questions are addressed:

- What is the current volume of literature published on smart grid deployment, and how has it changed over time?
- What are the top relevant authors and journals that have published the most cited papers on smart grid deployment, and what are their characteristics?
- What main concepts have been studied on smart grid deployment, and how are they related?
- What technological approaches are used in smart grid deployment and what is their contribution?
- What is the potential research agenda for the smart grid deployment?

The rest of this paper is organized as follows: the methodology of our study is presented in section 2. Section 3 presents the results and discussion. In section 4, we offer the recurrent smart grid deployment technology existing in the literature. Finally, the conclusion and future research agenda are parts of section 5.

2. METHOD

To achieve the first objective of this work which is to understand the research development level on smart grid deployment, we performed a bibliometric analysis on two datasets extracted from Web of Science and Scopus databases respectively. Bibliometric analysis is the statistical analysis of bibliographic data, mainly in scientific and technical literature. It measures the scientific activity in a subject category, journal, country, topic, or other areas of interest [23]. A search was done within the WoS database on May 12th, 2022, using the search string: “smart grid” AND (deployment OR implementation). As a result, 5,663 relevant documents were found and exported to BibTeX format. Using the same search string on the Scopus database on May 18th, 2022, we obtained a total of 7,015 documents. With the exportation constraints with the Scopus database, we could only export the first 5,872 documents in the BibTeX format using a multi-step extraction based on years. Then, the two datasets were analyzed using the biblioshiny interface of a bibliometric tool called bibliometrix [24]. Afterwards, for presentation reasons, the tables extracted from this analysis were processed in Microsoft Excel to produce more explicit graphs. Finally, we selected and read a number of papers published mainly between 2014 and 2022 in order to highlight the different technological approaches used in the deployment of smart grid. Figure 1 depicts the methodology used in this study. Key outputs are provided in the sections below. This diagram illustrates the methodology used for bibliometric study. The process was the same for both databases (Scopus and WoS). Then, several papers were read to make a synthesis of the technologies useful for the deployment of smart grid. The result is presented in section 4 of this paper.

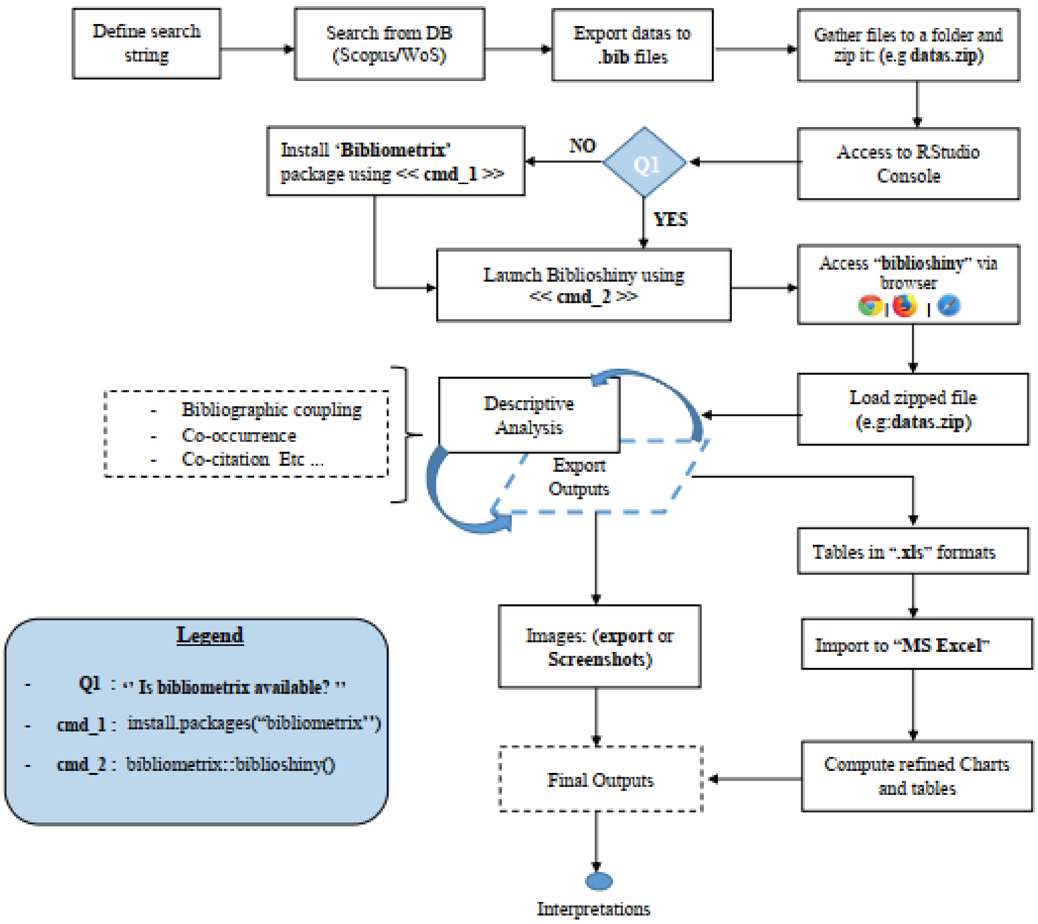


Figure 1. Methodology

3. RESULTS ANALYSIS AND DISCUSSION

This section provides an in-depth analysis of the findings derived from our bibliometric study, which involved an extensive examination of scholarly publications related to the deployment of smart grid. The results offer valuable insights into the current state of research on smart grid implementation, highlighting emerging trends and areas for future exploration. These findings are crucial for informing future research directions and policy decisions in the field of smart grid technology.

3.1. Main information: global overview

Figure 2(a) and Figure 2(b) show a short overview of the preliminary information about the datasets we extracted from the WoS and Scopus databases. Based on the output, we noticed fewer articles than other types of documents in the two datasets: 2,098 articles versus 3,234 proceedings papers in WoS and 2,182 articles versus 3,004 conference papers in the Scopus dataset. Moreover, documents of the WoS dataset are from 1978 different sources, while those of the Scopus dataset is from 2,170 sources. All this information shows how the Smart grid implementation topic has gained researchers' interest and excitement.

3.2. Annual scientific production and key sources production

Figure 3(a) and Figure 3(b) present a graph depicting the annual scientific production on smart grid implementation. In other words, it indicates the yearly number of papers related to smart grid deployment that have been published in the literature over time as indexed in WoS and Scopus databases. Here, we noticed that publications about Smart grid implementation started in 2006 in WoS with only one document and faced a few changes until 2008. From 2008 to 2009, the number of published documents doubled (10 to 23). Then, we observed an explosion of paper publications, which maintained increased growth rates up to 2015, the number of publications reached its first peak (586 documents). After that, it declined slightly from 586 in 2015 to 562 in 2016 before resuming growth till 2018, when the maximum number of 660 documents was published. This may be due to the trend of expanding new technologies in the industry worldwide during the last two decades. Thus, researchers have felt the urgency to renew the existing electrical network by integrating NICTs. Since 2018, although the publication has stayed important, the number decreased slightly: 554 in 2019, 568 in 2020, and 416 in 2021. The decrease period (2019–2021) corresponds to the coronavirus disease (COVID-19) pandemic. Thus, finding a vaccine was a global concern. The great majority of the research of this period was focused on that objective. This could explain the decrease in the number of publications in smart grid. However, by May 12th, 2022, the WoS database had already recorded 121 documents published on smart grid accounting for this year (2022), which is higher than the overall publications on the topic noted at the beginning of 2006.

Coming to the Scopus dataset, although we could not obtain the whole documents available in the database, it is noteworthy that the first 5,872 documents we extracted were published between 2013 and 2022, as shown in Figure 3(b). They represent 83.70% of the total (7015). Comparing our datasets between 2014–2022, we found out that the Scopus database has registered more documents than the Web of Science (4559 versus 5341, respectively). Also, the publication trend in Scopus seems the same as in WoS. However, the yearly documents registered in Scopus were superior to those reported in the WoS database except in 2015; WoS has registered 586 documents while Scopus has countered 547. Another critical point is that the two databases registered many records in 2018.

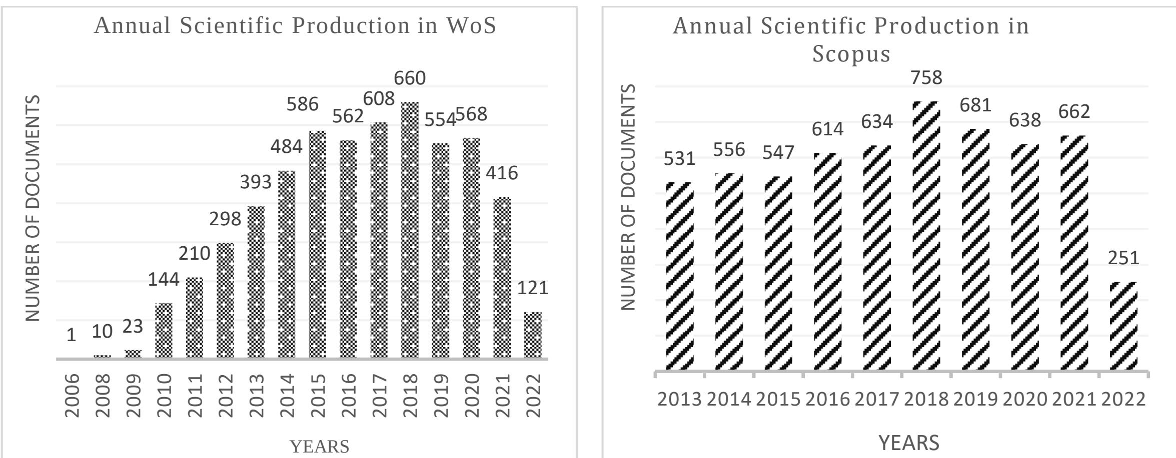
Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2006:2022
Sources (Journals, Books, etc)	1978
Documents	5663
Average years from publication	5.54
Average citations per documents	14.26
Average citations per year per doc	2.085
References	109480
DOCUMENT TYPES	
article	2098
article; book chapter	58
article; early access	23
article; proceedings paper	43
book	1
editorial material	8
editorial material; book chapter	3
news item	1
proceedings paper	3234
review	191

(a)

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2013:2022
Sources (Journals, Books, etc)	2170
Documents	5872
Average years from publication	4.58
Average citations per documents	13.93
Average citations per year per doc	2.377
References	171987
DOCUMENT TYPES	
article	2182
book	36
book chapter	204
conference paper	3004
conference review	176
editorial	9
note	2
retracted	1
review	255

(b)

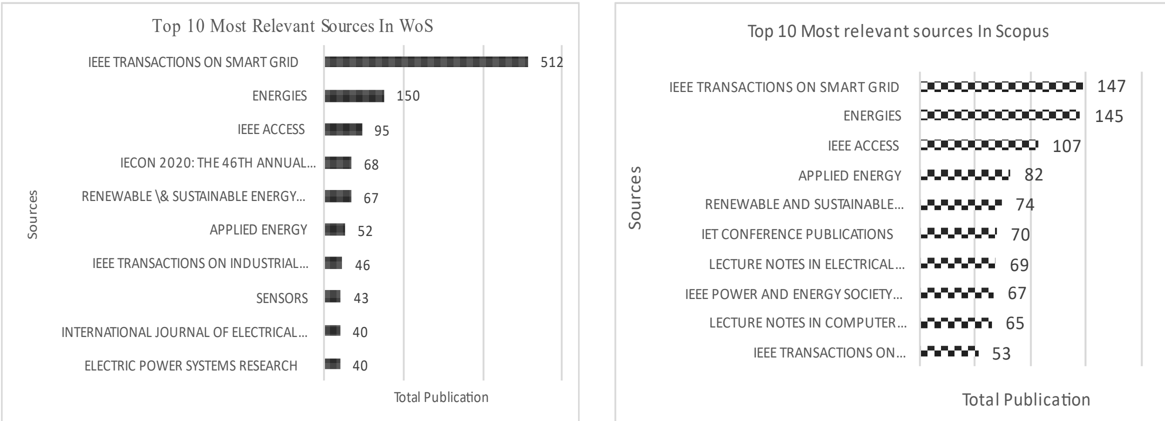
Figure 2. Main information about smart grid deployment documents published in two databases (a) main information for WoS and (b) main information for Scopus



(a) (b)

Figure 3. Annual scientific production: (a) in WoS and (b) in Scopus

What about the most relevant sources of smart grid deployment? Figure 4(a) and Figure 4(b) have helped us focus on this question by displaying the top 10 most pertinent sources of WoS and Scopus databases, respectively. The ranking is based on the total number of documents published by each source. Based on these figures, we can observe that whether with WoS or with Scopus databases, the first three positions are respectively occupied by the journals: "IEEE Transactions on Smart grid", "Energies", and "IEEE Access". This helps us to know that these journals are the most relevant in the literature concerning smart grid deployment. Also, it seems reasonable to see the journal "IEEE Transactions on Smart grid" rank the first position as it is known as a cross-disciplinary and internationally archival journal aimed at disseminating results of research on smart grid that relates to, arises from, or deliberately influences energy generation, transmission, distribution, and delivery [21].



(a) (b)

Figure 4. Top 10 most relevant sources (a) in WoS and (b) in Scopus

3.3. Source growth dynamics

Focusing on Table 1 and Table 2, we can observe how the document publication grows dynamically in the five main sources. The tables show how the paper's publication evolves yearly in the primary five sources among the ten we presented earlier. These sources have produced 892 documents for WoS and 555 documents for Scopus, as shown in Table 1 and Table 2 respectively. But "IEEE Transactions on Smart grid" has the highest growth. Also, in the WoS database, as shown in Table 1, none of the five most abundant sources has published the first document about our topic.

Table 1. Source growth dynamics in WoS

Year	IEEE Transactions on Smart grid	Energies	IEEE Access	IECON 2020 The 46th Annual Conference of the IEEE Industrial Electronics Society	Renewable and Sustainable Energy Reviews
2006	0	0	0	0	0
2007	0	0	0	0	0
2008	0	0	0	0	0
2009	0	0	0	0	0
2010	13	0	0	0	0
2011	10	0	0	0	1
2012	29	1	0	0	1
2013	37	3	0	0	1
2014	41	2	0	0	6
2015	40	5	3	0	12
2016	32	9	5	0	12
2017	59	21	9	0	8
2018	75	21	10	0	17
2019	59	19	14	0	2
2020	56	22	20	68	0
2021	44	33	25	0	5
2022	17	14	9	0	2
Total	512	150	95	68	67

Table 2. Source growth dynamics in Scopus

Year	IEEE Transactions on Smart grid	Energies	IEEE Access	Applied Energy	Renewable and Sustainable Energy Reviews
2013	21	1	0	2	2
2014	21	2	0	2	6
2015	20	4	3	5	13
2016	15	11	6	3	12
2017	26	19	9	14	9
2018	17	15	13	18	19
2019	8	22	14	14	1
2020	11	19	19	9	3
2021	4	35	29	8	4
2022	4	17	14	7	5
Total	147	145	107	82	74

3.4. Top 10 authors based on the number of documents

In this section, we present the rank of the 10 most relevant authors with the high number of documents about smart grid deployment or implementation recorded by WoS in Figure 5(a) and Scopus in Figure 5(b), respectively. Figure 5(a) shows that authors who have published at least forty documents hold the first four positions. But the author LIU has more publications with 56 papers. Wang and Zhang occupied the second and third positions with 48 and 46 papers, respectively. Observing Figure 5(b), we noted that the first four authors in the Scopus database have at least thirty-five documents. Zhang topped the list with 43 documents. An important point is the similarity between the two lists. Although we did retrieve all the available documents from the Scopus database, we can note that eight (8) authors of these lists are the same independently of their position. This information reveals that these authors have primarily published on smart grid deployment. Another remark is that most of these authors are from Asia.

(a) (b)

Figure 5. Top 10 most relevant authors (a) in WoS and (b) in Scopus

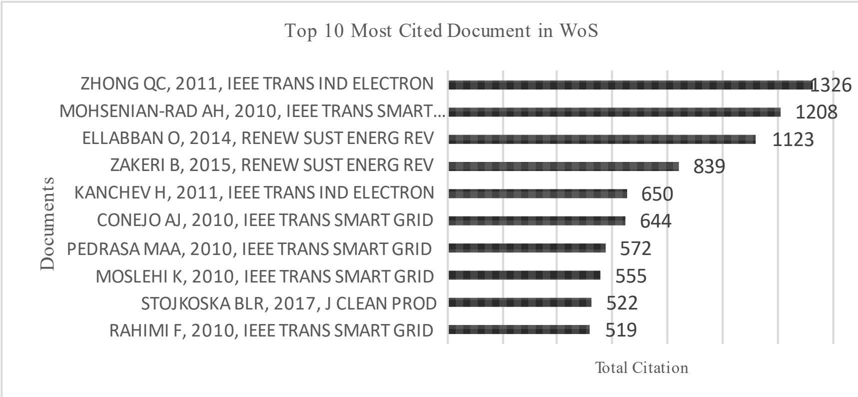
3.5. Top 10 most cited documents

Figure 6(a) presents the most globally cited documents in WoS about smart grid deployment. It reveals that Zhong and Weiss [25] is the most cited document with a total of 1,326 citations. It is followed by article in [26] with 1,208 citations. Finally, Ellabban *et al*. [27] stands in the third position with 1,123 citations.

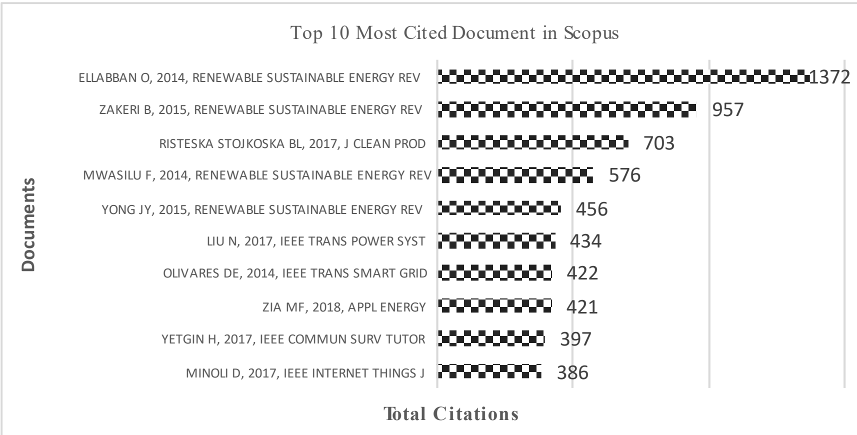
For the same purpose, the top 10 most cited documents in the Scopus database are highlighted in Figure 6(b). Here, we can observe that the most cited document is Ellabban *et al*. [27] with 1,372 citations. This document has been published by Ellabban *et al*. [27] in Renewable and Sustainable Energy Reviews. Notably, it ranks third in the WoS database, as shown in Figure 6(a).

3.6. Top 10 country scientific production and most cited country

Figure 7(a) and Figure 7(b) present the addressed topic's top 10 most productive countries. Except for some slight differences in the ranking, we can observe that the most productive countries are the same in the WoS and Scopus databases. However, in both cases, the USA, China, and India occupy the first three positions. This underlines how much the researchers of these countries are interested and focused on smart grids. The ten (10) most cited countries shown in Table 3 (for WoS) and Table 4 (for Scopus) indicate that the two most productive countries rank the first positions: USA and China. Also, it is noteworthy that compared to the most productive countries list, some countries such as Korea, Australia and Egypt appear in the top 10 most cited list.

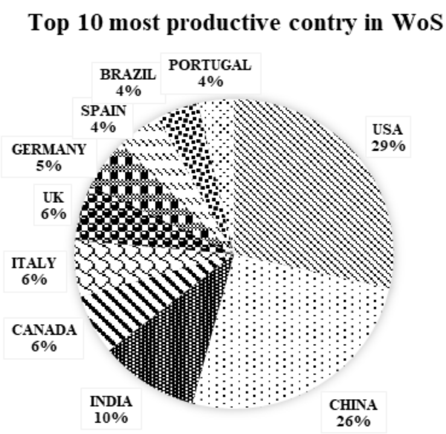


(a)

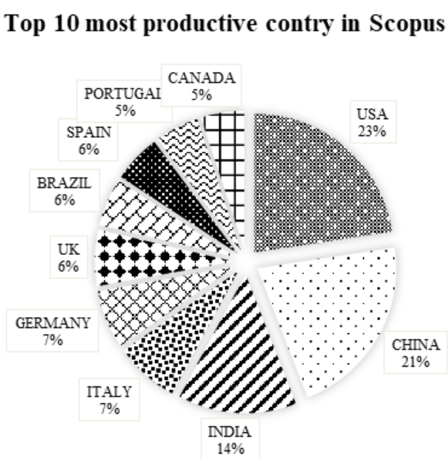


(b)

Figure 6. Top 10 most cited documents (a) in WoS and (b) in Scopus



(a)



(b)

Figure 7. Top relevant country production (a) in WoS and (b) in Scopus

Table 3. Most cited country in WoS

Rank	Country	Total Citations
1	USA	20,515
2	China	11,475
3	Canada	5,487
4	United Kingdom	3,445
5	Italy	2,729
6	Spain	2,541
7	India	2,438
8	Korea	1,997
9	Australia	1,710
10	Finland	1,473

Table 4. Most cited country in Scopus

Rank	Country	Total Citations
1	USA	7,691
2	China	7,091
3	Canada	2,439
4	United Kingdom	2,366
5	Italy	1,933
6	Spain	1,873
7	India	1,754
8	Korea	1,742
9	Australia	1,550
10	Finland	1,499

4. KEYS ENABLING TECHNOLOGIES FOR SMART GRID DEPLOYMENT: A SURVEY

In this section, we present categorization of different technologies that are used or can contribute to SG deployment. This categorization results from a survey based on the reading of documents dealing with technologies useful to SGs. As output, we mentioned five main technical approaches, which are: i) internet of things approach; ii) big data, machine learning, and deep learning approach; iii) multi-agent system approach iv) blockchain approach; and v) cloud computing approach.

4.1. IoT approach in smart grid

For developing the new smart grid, the IoT will be very useful for performing many automation and monitoring tasks. Moreover, IoT has broadly been used in most of today's systems. Thus, IoT has presented many characteristics and advantages which will be very profitable for smart grid. Ghasempour [13] notes that: smart grid is one of the most important applications of IoT. In the fourth section of the report, the author presents some main applications and services of IoT in smart grid. First, IoT will help to monitor the electricity generation of power plants and predict the necessary power to supply consumers. Second, it can be used to acquire electricity consumption and dispatch while protecting transmission lines and control equipment. Third, IoT can be used to measure different parameters on the customer side using smart meters. The author highlighted that, based on their findings, two types of integrated IoT architecture in the smart grid exist in the literature: 3-layers and 4-layers architectures. Globally, the layers' names sometimes differ, but their roles are almost identical. Finally, they provided some requirements and critical challenges about IoT integration into smart grid. In addition, Hossain *et al.* [28] pointed out that most useful IoT devices (such as smart meters) have already been developed. Energy generation and distribution automation are some IoT applications. Also, expanding the use of IoT in smart grid will contribute to meeting the increasing electricity demand and reduce energy wastage by creating a real-time tracker of distribution systems' supply and demand sides. Moreover, authors in [15], [29]–[32] have proposed a comprehensive survey on the IoT-based smart grid systems, which includes some existing architectures, applications, and prototypes.

4.2. Big data and machine learning approaches in smart grid

Also, the use of large monitoring devices, sensors, smart meters, phasor measurement units (PMUs), and the bi-directional communication enabled by the smart grid leads to the generation of a considerable quantity of data [28], [33], [34]. Mainly, according to [34], smart meters are a key source for data generation as they are used to automatically collect energy consumption data in the grid. This introduces the concept of Big data into the smart grid [34], [35]. This data will be drained from the control center. Based on the analysis of the stored data, utilities and policymakers can then make relevant decisions about billings, energy forecasting, grid fault predictions. Following this, machine learning (ML) technology is an ideal candidate for this purpose [36]. Hossain *et al.* [28] and Thilakarathne *et al.* [36] have justified and presented some ML and deep learning (DL) applications in the smart grid context. Specifically, Thilakarathne *et al.* [36]

mentioned that energy forecasting, protection and security are the main domains where ML and DL can broadly be used in smart grid.

4.3. Multi-agent system in smart grid

Multi-agent system (MAS) is another proposed smart grid-enabling technology. As mentioned in [37], an Agent is a system (as an entity) that can perform autonomous actions based on interacting with the environment and other agents. Its main characteristic is "autonomy" in making decisions and goals achievement. Thus, a MAS is a set of agents that work collaboratively to achieve a defined purpose. Reactivity, proactivity and sociability are other critical characteristics of an agent [37]. But why can MAS be used in smart grids? For this purpose, Yılmaz *et al.* [38] highlighted that the current grid structure, as it is known, has a limited ability to cope with fast cascading phenomena such as blockages and outages. Also, since most of the current grid is provided by centralized power plants, maintaining continuous stability in the grid is another critical challenge. Thus, based on the characteristics mentioned above, MAS can be used in a distributed way through the new Smart grid architecture (a distributed architecture) to provide more reactivity and proactivity of the grid management and control.

Regarding the same question, Merabet *et al.* [39] mentioned that MAS is used in different application fields because of their architectures, which are based on agents that provide a natural way to address current technological problems. Zhabelova *et al.* [37] proposed an agent with a distributed architecture named distributed grid intelligence (DGI) as a solution. The proposed architecture is a horizontal layered architecture based the on International Electrotechnical Commission (IEC) 61850 standard. It is made of two layers: a reactive layer and a reflective layer, controlled by a set of Beliefs. On the other hand, Yılmaz *et al.* [38] presents three applications that tackle Smart grid problems using MAS technology. These applications are based on the Java Intelligent Agent Component (JIAC) framework. The applications and their primary purpose are highlighted in Table 5.

Table 5. Overview of JIAC agents in smart grid applications [38]

Application Name	Main Goal
ILIas (*Intelligente Losungen zum Schutz vor Kaskadenef-¨fekten in voneinander abhangigen kritischen Infrastrukturen*)	Research and create intelligent and scalable management systems that provide prediction and reaction to cascading failure effects so that actions to stabilize the managed infrastructure can be taken
Gesteuertes Laden V2.0	Use electric vehicles as mobile and distributed energy storage to increase the utilization of wind energy and balance energy grids
Energy efficiency controlling (EnEffCo) project	Production processes of the automotive industry in terms of energy costs

Shawon *et al.* [40] presented a review of technological frameworks for the application of multi-agent systems and ICT infrastructure in smart grid. Mainly, they summarized five application areas of MAS in smart grid implementation which are: i) smart control, operation and management; ii) protection; iii) monitoring and diagnosis; iv) transactive energy management; and v) security. In studies [39] and [40], key applications of MAS in smart grid are presented. Also, 'MAS' can help give maximum autonomy to the distributed energy resources (DER) Microgrid units, achieving a high level of flexibility within smart grid. In addition, Merabet *et al.* [39] completed their work with some advantages of MAS in smart grid. One of these advantages is simulation. As the authors mentioned, smart grid has a highly dynamic infrastructure. Thus, experimentation is the best way to make functionalities verification and proof of concept before deployment. Unfortunately, implementations are sometimes unavailable for testing and verification as they are costly. So, MAS could contribute to smart grid simulation based on Agent characteristics, including collaborative interaction, negotiation, and autonomous decision-making. Therefore, Al-Hinai and Alhelou [41] proposed a decentralized multi-agent approach to address fault restoration in automated distribution networks. Using simulation-based analysis, they were able to highlight how MAS can efficiently improve fault restoration in an automated distribution network by minimizing the number of affected consumers as well as the duration of outages.

4.4. Blockchain in smart grid

Blockchain application in smart grids is presented by studies [42]–[49]. To understand how blockchain may be used in smart grid, the authors compared the smart grid functionalities and the existing blockchain applications. Based on the outputs, the authors mentioned a common blockchain application in smart grid: peer-to-peer energy trading. Specifically, Agung and Handayani [42] stressed that blockchain networks can be used to manage electricity transactions in smart grid. They justified their assumption that smart grid has introduced a new type of user known as the prosumer. A prosumer is a consumer who, in addition to the energy from the grid, can produce and store its energy using renewable energy sources (solar and wind). Then, he can share this energy with other consumers through the grid. Thus, it is possible to have an overview of the transaction history using a blockchain network and smart contract. Also, Alladi *et al.* [44] also completed the assumption by claiming that using a trading-based blockchain in the grid provides a decentralized and secure platform that enables a peer-to-peer (p2p) trade of energy between consumers and prosumers.

Another smart grid blockchain use case is security and privacy [44]. This idea is also shared by Arjomand *et al.* [43] and Erturk *et al.* [48] using cyber-physical infrastructure and grid enhancement terms. Blockchain will help in data aggregation and privacy preservation [44]. As smart meters are used in the grid to collect user consumption information, attackers could disclose 'users' private information by tracking electricity usage information. Alladi *et al.* [44] mentioned that other cryptographic technologies can be used in addition to blockchain to enable data privacy in smart grid. These technologies include zero-knowledge proof (ZKP), elliptic curve digital signature algorithm (ECDSA) and linkable ring signatures [49]. In addition to the use cases above, blockchain can contribute to electric vehicle charging in the smart grid [43], [44] and [48]. More specifically, the Arjomand *et al.* [43] referenced a document in which they claimed that blockchain would help electric vehicles reduce power fluctuations by finding their nearest available charging station through bidding for charging.

4.5. Cloud computing in smart grid

Cloud computing is an emerging computation model that provides on-demand facilities and shared resources over the internet. According to [50]–[53], cloud computing can be used in smart grid to store and manage the huge quantity of data generated by sensing devices of the grid. Mainly, Forcan and Maksimović [53] mentioned that the cloud could be combined with big data analytics for efficient load balancing in power production and supply. In [50], a survey of cloud computing applications in smart grid is presented. The main applications are demand response, micro-grid management, pick demand and dynamic pricing, real-time monitoring, power monitoring and early-warning system, information interaction using a mobile agent, and dynamic demand response. Furthermore, cloud applications in smart grid could contribute to improving some characteristics of smart grid such as confidentiality and privacy, distributed data management, and interoperability. However, there are some challenges with cloud computing applications in smart grid. These include issues of latency, locality and network congestion due to the continuous sending of large volumes of data to the cloud [53]. To overcome these issues, Bera *et al*. [50] and Forcan and Maksimović [53] argued the use of fog and edge computing. As they mentioned, edge computing and fog computing are suitable to overcome the issues as they allow decentralized and intelligent processing of data closer to the location they are generated.

5. CONCLUSION

This study, as its primary goal, was proposed to show an overview of the current research level about smart grid deployment. We could provide helpful insight regarding that purpose by using a bibliometric analysis on two data sets extracted from WoS and Scopus databases. The main insights include the annual scientific production, the most abundant sources, authors, countries and the most cited document and authors. For example, we find that whatever we consider WoS or Scopus datasets, the top two most productive countries are the same: USA and China. This means that researchers from these countries are most interested in the smart grid topic.

On the other hand, research from less developed countries is expected to fill the gap to provide more information about the challenges of smart grid deployment in each region of the world. Also, the three most abundant sources in the two databases are respectively: “IEEE Transactions on Smart Grid”, “Energies”, and “IEEE Access”. It is also noteworthy that the growth of the number of documents published per year in the two databases is slightly the same. But 2018 has encountered a high volume of documents. This study also highlighted the leading technologies (internet of things, artificial intelligence, blockchain, multi-agent systems, and cloud computing), which can be used to tackle most of the problems the smart grid faces. Future research could focus on real case studies of these technologies' usage in smart grid.

CONTRIBUTION

The goal of this study has been two-phased. Firstly, we have provided a cross overview of the research trend about smart grid deployment or implementation using two databases. Secondly, we presented key enabling technologies that can contribute to deploying smart grid. Using bibliometric analysis, our study provides insights to researchers, scholars, and decision-makers. First, by providing outputs such as the annual scientific production, we hope to help researchers, especially those in electrical and computer engineering, find smart grids an interesting research domain. Specifically, research about its deployment is still needed despite the significant literature contribution over the years. In addition, by presenting the most relevant sources, authors, and most cited documents, we hope to direct the researcher's choice when they need to find documents to learn more about the topic. Second, the results could help scholars (electrical and computer engineering scholars especially), adapt their course programs by pointing out key technologies suitable for smart grid deployment that have been presented in the literature. It could also be useful for decision-makers when designing an action plan for the next-generation electrical grid, the smart grid. This study also wishes to establish to the research community the fact that the smart grid domain is a rapidly evolving and thus promising field. Also, by using two relevant scientific databases, WoS and Scopus, our study has confirmed the assumption that smart grid deployment or implementation has gained interest from researchers over time. Finally, our study reveals that five technology approaches can mainly contribute to smart grid deployment: i) internet of things, ii) big data, machine learning and deep learning, iii) multi-agent systems, iv) blockchain and v) cloud computing.

LIMITATIONS

Behind the useful outputs and contributions of this study, some limitations can be pointed out. First, as we used keywords for the search, we could not cover all published documents about the topics. Also, although using two databases (WoS and Scopus) has expanded the scope of the study, it could eventually limit the search. Next studies could combine more databases. Second, as we could not extract all documents found in the Scopus database, comparing its outputs to WoS could present some bias. Finally, another limitation is that we selected some documents we read to offer key technologies suitable for smart grid deployment. Therefore, it could miss some papers presenting another concept or technology not broadly covered in the literature. A complete literature review on smart grid deployment will help tackle this limitation.

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