Social Adoption of Smart Grids: The Research Agenda

Samet Ayik
Department of Electrical and Electronics Engineering
Gazi University, Ankara, Turkey
samet.ayik@gazi.edu.tr

H. Nurgul Durmus Senyapar
Quality Coordinator
Assistant of Quality Coordinator
Gazi University, Ankara, Turkey
nurguld@gazi.edu.tr

Ramazan Bayindir
Department of Electrical and Electronics Engineering
Gazi University, Ankara, Turkey
bayindir@gazi.edu.tr

***Abstract*—**Smart grids (SGs) have enormous potential to increase efficiency and promote the incorporation of renewable energy sources and are a crucial component of the modernization of the electricity industry. However, their successful implementation and widespread adoption require a delicate balance of technological advancement and social acceptance. In this study, a comprehensive bibliometric analysis of smart grids literature from 2010 to 2023 was conducted. To achieve this, academic studies on SGs and publications on issues such as awareness in this area, benefits and barriers to the adoption of SGs were compared in terms of quantity and breadth. The quantity and subjects of research in the field and subfield were analyzed through bibliometric analysis. Our research indicates that the social aspect of SGs is frequently neglected. This apparent imbalance can pose significant obstacles to the seamless integration of smart grid technologies into society, highlighting the imperative need for interdisciplinary research in the field. By increasing awareness of SGs, interdisciplinary collaborations spanning disciplines such as engineering, social sciences, political science, law and communications can accelerate the adoption of this technology. These efforts are essential in our pursuit of a more sustainable and efficient energy environment, which will pave the way for an innovative and inclusive energy future.

Keywords— Adoption of Smart Grids, Barriers and Challenges, Bibliometric Analysis, Public Awareness, Social Acceptance

I. INTRODUCTION

The concept of the smart grid has emerged as a promising solution to address the challenges of modern electricity distribution and consumption [1]. As a highly advanced and integrated network the smart grid leverages cutting edge technology to enhance efficiency, security and reliability in power systems [2]. A smart grid is an advanced electrical grid that integrates various components such as digital communication, advanced metering infrastructure and automation systems to optimize the generation, distribution, sensors, smart sockets and consumption of electricity [3-5]. This modern grid aims to create a more resilient and adaptable power system, capable of meeting the increasing demand for electricity while accommodating the integration of renewable energy sources which can foster a sustainable and decarbonized energy future [6], [7]. Smart grids offer a wide range of benefits, spanning economic, environmental and technical advantages. These benefits contribute to a more efficient, sustainable and reliable electricity system for both consumers and utilities alike [8], [9]. Through the enablement of real-time monitoring and control of electricity usage, smart grids facilitate a higher degree of precision in power management, effectively curbing energy waste and leading to cost reductions for consumers [10]. Furthermore the enhanced integration of renewable energy sources not only amplifies the advantages of smart grids but also actively contributes to a greener and more sustainable energy future [11], [12]. From a technical standpoint, smart grids enhance the reliability and security of power systems so that it can reduce the frequency and impact of blackouts and outages [13], [14].

To prevent untimely and long term power outages to prevent power losses and massive extended blackouts due to grid failure caused by the aging of electrical grids, SGs offer an important solution in today's world that is dependent on electrical energy. SGs, which continuously monitor and balance demand and supply, prevent potential imbalances from causing damage to power plants and contribute to the decarbonization of the planet by resolving the issue of inconsistent renewable energy supply and supporting energy efficiency with bidirectional energy flow. With the assistance of smart devices, the digitalization and automation of distribution networks that permit interconnectivity enable real time monitoring of consumption. Smart grids also facilitate e-mobility, allowing electric vehicles to play a larger role in our transportation system. While it is true that smart grids are susceptible to cyberattacks and raise concerns regarding the monitoring of personal information due to their interconnected devices and networks. It is important to note that their deployment and adoption are taking place gradually allowing for the development of robust security measures and privacy safeguards [15]. This has a social dimension in addition to a technical one. This circumstance is inextricably linked to the adoption of innovations by significant segments of society.

An innovation is a substantially differentiated new or improved product or process that is made available to existing and potential users. It is not adequate to develop an innovation and transform it into products and services. Recently commercialized products, services or procedures must also be adopted and disseminated by consumers. To be considered innovative, a product, service or process must be new and widely adopted by consumers. Various factors such as the perception and behavior of individuals in society regarding the acceptability of innovation, social structure and communication, play a role in the innovation adoption process. Numerous variables affect the rate at which innovations are implemented by society. Even if new technologies seem advantageous in terms of private benefits and costs, if the social benefits and costs arising from externalities are not analyzed and known, it may not be possible to accept these innovations by society. It has been determined that technical, regulatory and policy, social and

institutional barriers negatively affect the adoption of SGs [16].

Samadi [17] proposed a smart pricing model aimed at maximizing social welfare, considering user preferences and energy consumption. They showed that the model was efficient, truthful and facilitated nonnegative transfer. Besides that, Liu [18] highlighted the economic and social benefits of integrating communication technologies with smart grids, stressing the need to address cybersecurity and privacy. At the same time, Verbong [19] analyzed stakeholder practices in the Netherlands and found that user inclusion is increasing despite institutional and technological barriers. They recommended innovative business models for user engagement. In other study, Ellabban [20] reviewed the potential social changes from smart grid technologies and emphasized the need for consumer engagement. Despite the significant attention it has received from a technical standpoint, there remains a noticeable gap in understanding its social implications. Wolsink [21] argued that current smart grid development neglects social factors, advocating for an institutional approach that encourages citizen cooperation and renewable energy use. In addition, Wolsink [22] critiqued existing social acceptance research, calling for a focus on public vs social acceptance and institutional change in energy innovation.

Smart grids, which offer great advantages in renewable energy integration, are used efficiently in China. Wang [23] performed bibliometric analysis of 3,558 published articles obtained from WOS to examine the status, development and trend of SG research in China, stated that most of the studies dealt with the issues of the wireless sensor network (WSN), internet of things (IoT), smart meter, big data and security, demand response, micro-grid, distributed generation and electric vehicle (EV) [24]. Different bibliometric analysis studies were conducted for publications in the field. In the study of [25], the core collection of the Web of Science database, which provides comprehensive citation data for global academic disciplines, was searched for articles on Smart Grid architecture between 2000 and 2022 and the resulting 3993 documents were analyzed using bibliometric tools [26]. The Bibliometric Analysis of Smart Public Governance Research was conducted by [27]. In addition, Shukla [28] analyzed Cyber Security Trends. However, no research compares the social aspects of SGs to the academic research published on SGs.

The purpose of this study is to demonstrate that although the technical and economic dimensions of SGs are commonly discussed, the social dimension is generally overlooked. Further examination of the potential social impacts of smart grids on consumers and society could facilitate uncovering factors that will accelerate society's adoption of SGs. The study will be conducted in two phases. The Web of Science database will be searched for all smart grid-related studies and bibliometric data will be collected. Subsequently, search terms will be modified to obtain studies addressing the social aspect of smart grids. The following research issues will be addressed by a thorough bibliometric analysis of the obtained data:

RQ.1: What is the scope and volume disparity between the published articles on smart grids and their social dimension?

RQ.2: Which areas do smart grid-related scientific investigations concentrate on?

RQ.3: What aspects of the smart grid's social dimension are addressed?

This study attempts to demonstrate that issues such as the social benefits, acceptability and awareness of the smart grid, as well as the obstacles and difficulties facing its adoption, are inadequately addressed in smart grid studies. By emphasizing the need for more socially oriented research and evaluation to guarantee the successful implementation and adoption of smart grid technologies, widespread adoption of smart grids, which are presented as the energy model of the future, can be achieved.

II. METHODOLOGY

For this study, in which research questions will be answered with bibliometric analysis of articles dealing with smart grids and their social dimension, mapping analysis was performed using the R-Studio application. For this purpose, bibliometric data was obtained by performing two different searches in the WoS database. In the first search, all publications on smart grids were accessed and in the second scan, publications on the social dimension of smart grids were accessed. Although the first publication on SGs in WoS was published in 1991, the first study on the social dimension was published in 2010, almost 20 years later. The year limit has been determined as 2010-2023 to harmonize the search results carried out in May 2023.

Search word for articles on Smart Grid articles (results shown in figures labeled "a"): "smart grid*".

Search words for articles on social dimensions of smart Grids (results shown in figures labeled "b"): "smart grid*" AND "social benefit*" OR "smart grid*" AND "societal benefit*" OR "smart grid*" AND "social barrier*" OR "smart grid*" AND "social accept*" OR "smart grid*" AND "social challenge*" OR "smart grid*" AND "social adopt*" OR "smart grid*" AND "social aware*" OR "smart grid*" AND "social dimension*".

A large number of binary combinations containing the term "smart grid" were analyzed to determine the social benefit, acceptability and awareness dimensions of SG, as well as the barriers and challenges to its adoption. While attempting to reach studies on the social dimension of smart grids with the eight keyword groups determined, it is intended to exclude studies on the technical dimension from the scope and to specifically identify only studies on social adoption.

The number of publications, publication year, journal, author, institution and country of origin were extracted from both sets of search results. Utilizing bibliometric visualization tools, such as key information, annual scientific production, most frequently used terms and co-occurrence analysis, the status, patterns and trends of the literature were determined. In addition, a keyword analysis was conducted to determine the frequency of the most frequently used terms in the literature. The results of the analysis are interpreted and the implications for future research on the social aspect of smart grids are discussed.

III. ANALYSIS AND RESULTS

In our research, academic articles on smart grids were analyzed by comparing them to articles focusing on the social dimensions of smart grids. In the Web of Science database, bibliometric data of academic studies published between 2010 and 2023 were compiled for this purpose. Table 1 displays the

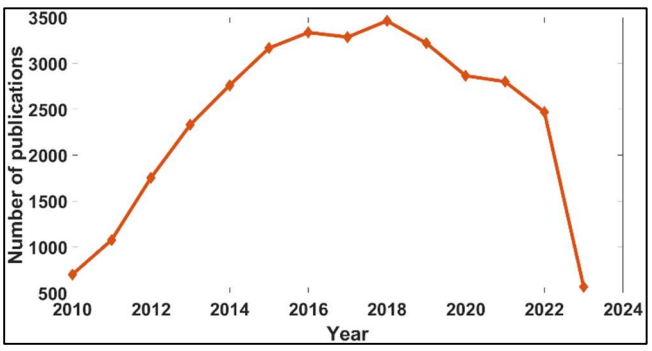
principal findings of the investigation. Consequently, 52218 authors in 7329 sources accessed a total of 33782 documents, 13538 of which were articles, during the specified period. In contrast, only 384 authors in 81 sources accessed 116 documents, 53 of which were articles, regarding the social dimension of SG.

The percentage of academic studies addressing the social dimension was determined to be 0.35 percent of the complete document. In addition to the fact that the number of publications addressing the social dimension is so low, it is noteworthy that while academic studies on technological innovations are on the rise, SG studies are declining. Considering the growth rate of studies over the past 13 years, it was determined that the number of publications in the social field remained unchanged.

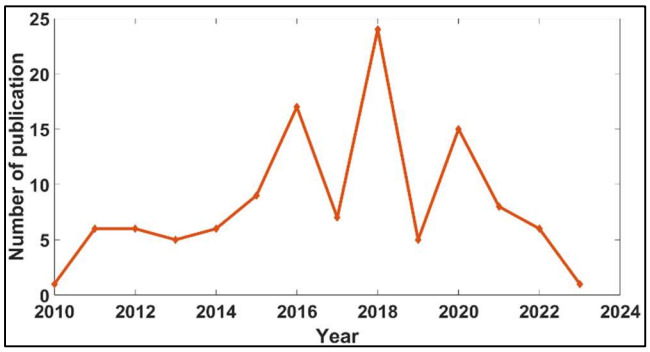
TABLE I. MAIN INFORMATION

Description	Result 1 (Figures "a")	Results 2 (Figures "b")
Main Information About Data		
Timespan	2010:2023	2010:2023
Sources (Journals, Books, etc)	7329	81
Documents	33782	116
Annual Growth Rate %	-1.46	0
Document Average Age	6.07	6.01
Average citations per doc	16.43	27.58
References	512765	5542
Document Contents		
Keywords Plus (ID)	9061	324
Author's Keywords (DE)	48616	443
Authors		
Authors	52218	384
Authors of single-authored docs	1407	8
Authors Collaboration		
Single-authored docs	1864	12
Co-Authors per Doc	3.79	3.64
International co-authorships %	25.07	31.03
Document Types		
Articles	13538	53

To compare both search results, graphs were created regarding the production of the studies according to the years. Figure 1a shows the trend of research on smart grids over the years. Figure 1b shows the annual graph of studies addressing the social dimension of SGs. In the first graph, it is observed that the studies on smart grids have increased steadily and rapidly over the years, especially since 2010, reached the highest level in 2016 and have been in a downward trend since this year. Examining the trend of publications on the social dimension of SGs over the years reveals fluctuations, with increases in 2016, 2018 and 2020 followed by a decline beginning in 2020.



a.



b.

Fig. 1. Annual scientific productions a. SGs General b. SGs Social

Figure 2, which allows us to find the answer to RQ.1 along with Figure 1, shows the information as a bar graph to provide a clearer representation of the discrepancy between these two data sets. On closer inspection, a crucial divergence can be seen between the two dimensions.

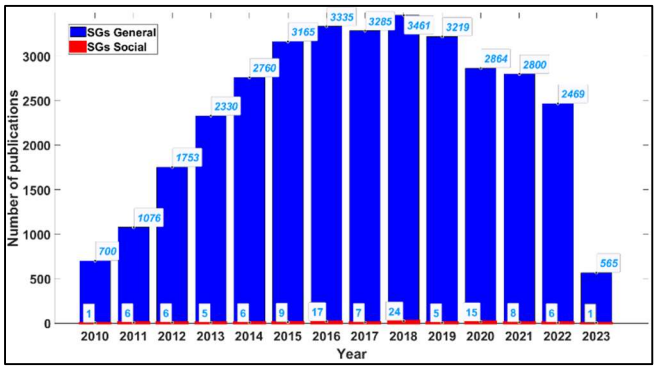
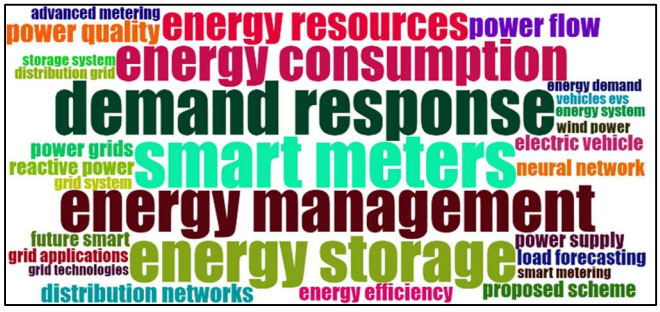


Fig. 2. Number of studies by year

Figures 3 and 4 visually present the response of RQ.2 and RQ.3. Figures 3a and 3b depict the most frequently occurring terms in documents concerning smart grids and the social aspect of smart grids, respectively. Demand management, smart meters, demand response and energy storage are conspicuous in the Word Cloud of SG articles, as shown in Figure 3a. Power transmission, distribution networks, power quality, as well as grid systems, applications and technologies for the technical dimension are studied frequently. Intriguingly, while the terminology associated with the technical aspect of smart grids is more prevalent, the social aspect of these issues is also crucial. Figure 3b demonstrates that the majority of research on the social dimension of smart grids focuses on social acceptance and social benefits. The broad scope of the publications and a large number of terms and phrases included in the Word Cloud indicate how numerous facets of life SGs have an impact.

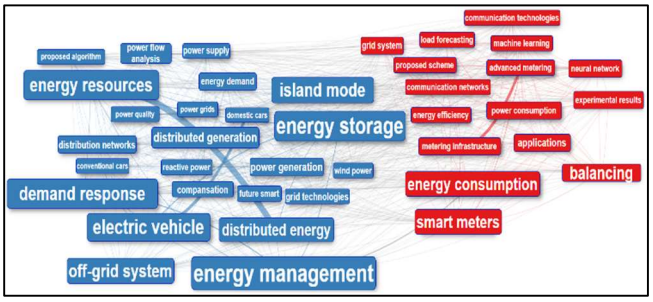


a.

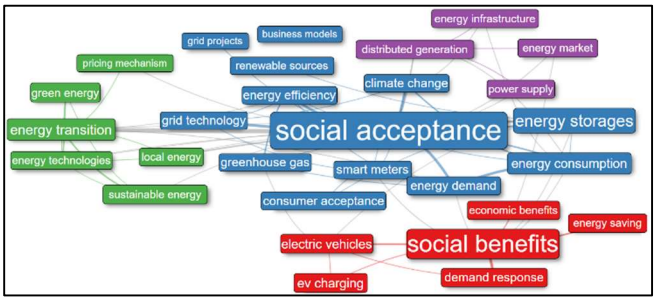
b.

Fig. 3. Most relevant words a. SGs General b. SGs Social

Co-occurrence network analysis was applied to determine the most frequently mentioned terms in the titles of the studies by using the binary search results for the study. As a result of the analysis, as can be seen in Figure 4a, it has been revealed that the most used terms in smart grid research are terms such as "energy management", "energy storage", "demand response" and "power systems". However, in Figure 4b, it is seen that the words related to the social dimension are mostly concentrated on sociological, economic and environmental issues.



a.



b.

Fig. 4. Co-occurrence network a. SGs General b. SGs Social

IV. Conclusion

Smart grids are one of the most important components of sustainable energy management. The need for stable and efficient energy is exacerbated by the exponential growth of digitalization in both pace and scope. At this moment, it is evident that SGs will continue to develop and become ubiquitous, while academic research will continue to examine the topic. Nonetheless, the fact that SGs must be adopted by significant portions of society to increase their use is frequently overlooked. While addressing the technical and economic aspects of SGs, it is evident that a lack of research into the social aspect can delay their adoption. In our study, a comprehensive literature review on smart grids from 2010 to 2023 is presented. By conducting a bibliometric analysis of qualified academic studies published in journals indexed in the Web of Science database, trends and patterns revealing the imbalance in the attention given to these two aspects of smart grid development have been identified.

From 2010 to 2023, our findings indicate a strong emphasis on the technical aspects of smart infrastructure. This is due to rapid technological advancements and the need to modernize existing utility infrastructure to increase efficiency, reliability and sustainability. Researchers and engineers focused on developing innovative power generation, distribution and management solutions, as well as integrating renewable energy sources and promoting energy conservation. During this period, the social aspects of smart grids received considerably less attention. This is a cause for concern, as the successful implementation and adoption of smart grid technologies require the support and acceptance of numerous stakeholders, including policymakers, utilities and end users. Because potential barriers such as public resistance, privacy concerns and a lack of awareness of the benefits of smart grids are not adequately addressed, a lack of focus on social aspects may impede the effective integration of smart grid technologies into society.

The bibliometric analysis of articles on all topics and social aspects of smart grids reveals a striking disparity between the number of studies concentrating on technical aspects and those investigating social aspects. Although the literature on smart grids is extensive, less than 1% of studies have been conducted on the social dimension of the topic. The findings indicate that additional research is required to comprehend the social factors, such as consumer acceptability, stakeholder engagement and institutional barriers that influence the development and implementation of smart grids. The results highlight the need for more interdisciplinary research and collaboration between the technical and social sciences to address the social challenges of smart grid applications and realize this technology's maximum potential.

The fact that the growth rate of social dimension studies by SGs is nil indicates that interest in the topic has not increased. Nonetheless, it is notable that academic research on SGs is declining. It is possible that the transition from academic discovery to commercial application in smart grid processes contributed to a decline in scientific research. As these processes become commercialized, academics will be able to transfer their focus to newer, less-explored fields. Second and perhaps more importantly, it is possible that the public's delayed adoption of smart grids has led to a decline in interest in smart grid work. In this way, the decline in academic interest in SGs, which have a low adoption rate due to the lack of social dimension research, retards innovation and advancement in this field. This lack of assimilation may indicate a need to place greater emphasis on the social aspects of smart grids to increase public acceptance and uptake.

Considering these findings, it is crucial to acknowledge the significance of addressing both technical and social factors in smart grid research and development. To achieve this, future research should incorporate interdisciplinary approaches and methodologies to bridge the divide between these two domains. This could involve collaboration between engineers, social scientists and policymakers to identify potential obstacles to the adoption of smart grids and develop strategies to surmount them. In addition, education and awareness programs should be implemented to enlighten the

public about the benefits of smart grid technologies, dispel myths and encourage their adoption.

In addition, regulatory frameworks and policies must be considered. Considering the social, economic and environmental implications, policymakers should be encouraged to develop and implement policies that facilitate the integration of smart grid technologies. This includes addressing data privacy, cybersecurity and equitable access to the benefits of smart grids. By doing so, a more holistic and balanced approach to smart grid development can be achieved, ensuring that these innovative solutions are not only technologically advanced but also socially accepted and adopted.

It is recommended to provide a more balanced approach to smart grid research and development that considers both technological innovation and social factors necessary for the successful implementation and widespread adoption of SGs. This imbalance must be corrected for smart grid technologies to revolutionize the energy industry and create a more sustainable and prosperous future for all.

REFERENCES

[1] O. Majeed Butt, M. Zulqarnain and T. Majeed Butt, "Recent advancement in smart grid technology: Future prospects in the electrical power network," Ain Shams Eng. J., vol. 12, no. 1, pp. 687–695, Mar. 2021, doi: 10.1016/j.asej.2020.05.004.

[2] A. Kumari and S. Tanwar, "Secure data analytics for smart grid systems in a sustainable smart city: Challenges, solutions and future directions," Sustain. Comput. Inform. Syst., vol. 28, p. 100427, Dec. 2020, doi: 10.1016/j.suscom.2020.100427.

[3] G. Dileep, "A survey on smart grid technologies and applications," Renew. Energy, vol. 146, pp. 2589–2625, Feb. 2020, doi: 10.1016/j.renene.2019.08.092.

[4] X. Fan et al., "Battery Technologies for Grid-Level Large-Scale Electrical Energy Storage," Trans. Tianjin Univ., vol. 26, no. 2, pp. 92–103, Apr. 2020, doi: 10.1007/s12209-019-00231-w.

[5] R. Rajarajeswari, D. Suchitra, S. G. Fernandez and G. L. M. Rao, "A Novel Demand Side Management Scheme for Residential Buildings Using Smart System," Int. J. Renew. Energy Res. IJRER, vol. 11, no. 4, Art. no. 4, Dec. 2021.

[6] H. N. D. Şenyapar, "A bibliometric analysis on renewable energy's public health benefits," J. Energy Syst., vol. 7, no. 1, Art. no. 1, Mar. 2023, doi: 10.30521/jes.1252122.

[7] T. Nasir et al., "Recent Challenges and Methodologies in Smart Grid Demand Side Management: State-of-the-Art Literature Review," Math. Probl. Eng., vol. 2021, p. e5821301, Aug. 2021, doi: 10.1155/2021/5821301.

[8] U. Zafar, S. Bayhan and A. Sanfilippo, "Home Energy Management System Concepts, Configurations and Technologies for the Smart Grid," IEEE Access, vol. 8, pp. 119271–119286, 2020, doi: 10.1109/ACCESS.2020.3005244.

[9] A. I. AlKassem, "The Integration of Intermittent Renewable Energy Sources to Smart Grid: A Comprehensive View," Int. J. Renew. Energy Res. IJRER, vol. 12, no. 3, Art. no. 3, Sep. 2022.

[10] S. Z. R. Hussain, A. Osman, M. A. Moin and J. A. Memon, "IoT Enabled Real-time Energy Monitoring and Control System," in 2021 9th International Conference on Smart Grid (icSmartGrid), Jun. 2021, pp. 97–102. doi: 10.1109/icSmartGrid52357.2021.9551208.

[11] A. I. Osman et al., "Cost, environmental impact and resilience of renewable energy under a changing climate: a review," Environ. Chem. Lett., vol. 21, no. 2, pp. 741–764, Apr. 2023, doi: 10.1007/s10311-022-01532-8.

[12] S. Arfa, mohsen B. Ammar, M. A. Zdiri and H. H. Abdallah, "Multi-source renewable energy exchange management system for off-grid home load," Int. J. Renew. Energy Res. IJRER, vol. 12, no. 3, Art. no. 3, Sep. 2022.

[13] D. Sarathkumar, M. Srinivasan, A. A. Stonier, R. Samikannu, N. R. Dasari and R. A. Raj, "A Technical Review on Self-Healing Control Strategy for Smart Grid Power Systems," IOP Conf. Ser. Mater. Sci. Eng., vol. 1055, no. 1, p. 012153, Feb. 2021, doi: 10.1088/1757-899X/1055/1/012153.

[14] I. Srivastava, S. Bhat and A. R. Singh, "Smart Grid Communication: Recent Trends and Challenges," in Next Generation Smart Grids: Modeling, Control and Optimization, S. R. Salkuti and P. Ray, Eds., in Lecture Notes in Electrical Engineering. Singapore: Springer Nature, 2022, pp. 49–75. doi: 10.1007/978-981-16-7794-6_3.

[15] S. Sagiroglu, "Big Data And Cyber Security Issues In Smart Grids," in 2021 9th International Conference on Smart Grid (icSmartGrid), Jun. 2021, pp. 16–16. doi: 10.1109/icSmartGrid52357.2021.9551232.

[16] F. Norouzi, T. Hoppe, L. R. Elizondo and P. Bauer, "A review of socio-technical barriers to Smart Microgrid development," Renew. Sustain. Energy Rev., vol. 167, p. 112674, Oct. 2022, doi: 10.1016/j.rser.2022.112674.

[17] P. Samadi, H. Mohsenian-Rad, R. Schober and V. W. S. Wong, "Advanced Demand Side Management for the Future Smart Grid Using Mechanism Design," Ieee Trans. Smart Grid, vol. 3, no. 3, pp. 1170–1180, Sep. 2012, doi: 10.1109/TSG.2012.2203341.

[18] J. Liu, Y. Xiao, S. Li, W. Liang and C. L. P. Chen, "Cyber Security and Privacy Issues in Smart Grids," Ieee Commun. Surv. Tutor., vol. 14, no. 4, pp. 981–997, 2012, doi: 10.1109/SURV.2011.122111.00145.

[19] G. P. J. Verbong, S. Beemsterboer and F. Sengers, "Smart grids or smart users? Involving users in developing a low carbon electricity economy," Energy Policy, vol. 52, pp. 117–125, Jan. 2013, doi: 10.1016/j.enpol.2012.05.003.

[20] O. Ellabban and H. Abu-Rub, "Smart grid customers' acceptance and engagement: An overview," Renew. Sustain. Energy Rev., vol. 65, pp. 1285–1298, Nov. 2016, doi: 10.1016/j.rser.2016.06.021.

[21] M. Wolsink, "The research agenda on social acceptance of distributed generation in smart grids: Renewable as common pool resources," Renew. Sustain. Energy Rev., vol. 16, no. 1, pp. 822–835, Jan. 2012, doi: 10.1016/j.rser.2011.09.006.

[22] M. Wolsink, "Social acceptance revisited: gaps, questionable trends and an auspicious perspective," Energy Res. Soc. Sci., vol. 46, pp. 287–295, Dec. 2018, doi: 10.1016/j.erss.2018.07.034.

[23] Y. Wang et al., "SPDS: A Secure and Auditable Private Data Sharing Scheme for Smart Grid Based on Blockchain," IEEE Trans. Ind. Inform., vol. 17, no. 11, pp. 7688–7699, Nov. 2021, doi: 10.1109/TII.2020.3040171.

[24] C. Wang, T. Lv and X. Deng, "Bibliometric and Visualized Analysis of China's Smart Grid Research 2008–2018," Front. Res. Metr. Anal., vol. 5, 2020, [Online]. Available: https://www.frontiersin.org/articles/10.3389/frma.2020.551147

[25] A. M. Kpoze, J. Degila, H. Soude and S. Fosso Wamba, "Smart Grid Architecture: A Bibliometric Analysis and Future Research Directions," Feb. 2022, pp. 441–448. doi: 10.1109/ICIPTM54933.2022.9754210.

[26] A. Kpoze, J. Degila, H. Soude and S. F. Wamba, "Smart Grid Architecture: A Bibliometric Analysis and Future Research Directions," 2022 2nd Int. Conf. Innov. Pract. Technol. Manag. ICIPTM, pp. 441–448, Feb. 2022, doi: 10.1109/ICIPTM54933.2022.9754210.

[27] P. Vujković, D. Ravšelj, L. Umek and A. Aristovnik, "Bibliometric Analysis of Smart Public Governance Research: Smart City and Smart Government in Comparative Perspective," Soc. Sci., vol. 11, no. 7, Art. no. 7, Jul. 2022, doi: 10.3390/socsci11070293.

[28] G. Shukla and D. S. Gochhait, "Cyber Security Trend Analysis using Web of Science: A Bibliometric Analysis," Clin. Med., vol. 7, no. 06, 2020.