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Review

Digitalization in Energy Production, Distribution, and Consumption: A Systematic Literature Review

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Abstract: For this study, we conducted a systematic review of the literature on digitalization in energy production, distribution, and consumption over a sufficiently long period in order to reveal the trends and particularities of this phenomenon at the sectoral level. For the systematic review of the literature, representative articles on the subject indexed in the Web of Science and Scopus databases were selected using the PRISMA 2020 flow diagram. As a result of the systematic review of the literature, a significant number of articles on the subject of digitalization in the energy sector were found—both over the entire period considered and especially in the last five years—indicating the magnitude of the digitalization process in this field. The impacts of digitalization in the energy production, distribution, and consumption sectors materialized in the aspects of health, safety, and environmental improvement; process improvements; and cost reductions. The most important technologies used in the digitalization process include data mining and machine learning, smart grid/smart metering/smart home, Internet of Things, cybersecurity, and automation solutions (e.g., robotics, drones, and distribution automation).

Keywords: energy; digitalization; production; distribution and consumption

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1. Introduction

Due to the accelerated decrease in natural resources, as well as the high-risk environmental impacts associated with fulfilling current energy production needs, a core focus has been placed on energy efficiency and climate-change mitigation. Although mankind has started producing energy from renewable sources in greater percentages each year, the majority of energy sources still rely on the extraction of natural resources; more precisely, 84% of energy produced at present comes from fossil fuels, and, as we continue to burn more, the total production has increased from 116,214 to 136,761 TWh over the last 10 years [1].

In this context, the increased digitalization in energy production, distribution, and consumption brings the infrastructure required to achieve the EU 2030 and 2050 targets to the foreground. The existing challenges are based upon reaching a total energy consumption of 956 Mtoe and a primary energy consumption of 1273 Mtoe in the EU by 2030, as stated by the EU's Renewable Energy Directive, paving a pathway toward a binding national energy efficiency standard.

According to the stated rules, each country has its own milestones—albeit with the same trajectory—to meet the requirements of extensively decreasing the impact of its footprint on the global environment. The core interest for analysis in our review of the specialized literature was articles published within the last decade by worldwide specialists attempting to find solutions to empower high-efficiency cross-country co-generation.

As each country's existing policy measures follow primary energy savings in GWh per year, the usage of digitalization in energy production, distribution, and consumption was also found to have an impact on carbon dioxide direct emissions, taking into consideration the co-generation impact of energy production fueled by fossil fuels, with less than 270 g

CO_2 per 1 kWh of energy output from combined generation as we look toward economic growth decoupled from resource use. Moreover, savings were found to be feasibly made not only in production, but also in distribution; for example, tons of CO_2 was saved in 2022 through the choice of intermodal transport.

One of the major existing challenges is the decarbonization of the EU's energy system, which is critical to reaching the 2030 climate objectives and the EU's long-term strategy of achieving carbon neutrality by 2050. The report is set at 1.5 °C and scaled down to the national level based on the interactions between economic sectors, energy consumption, and emissions, as depicted in Figure 1.

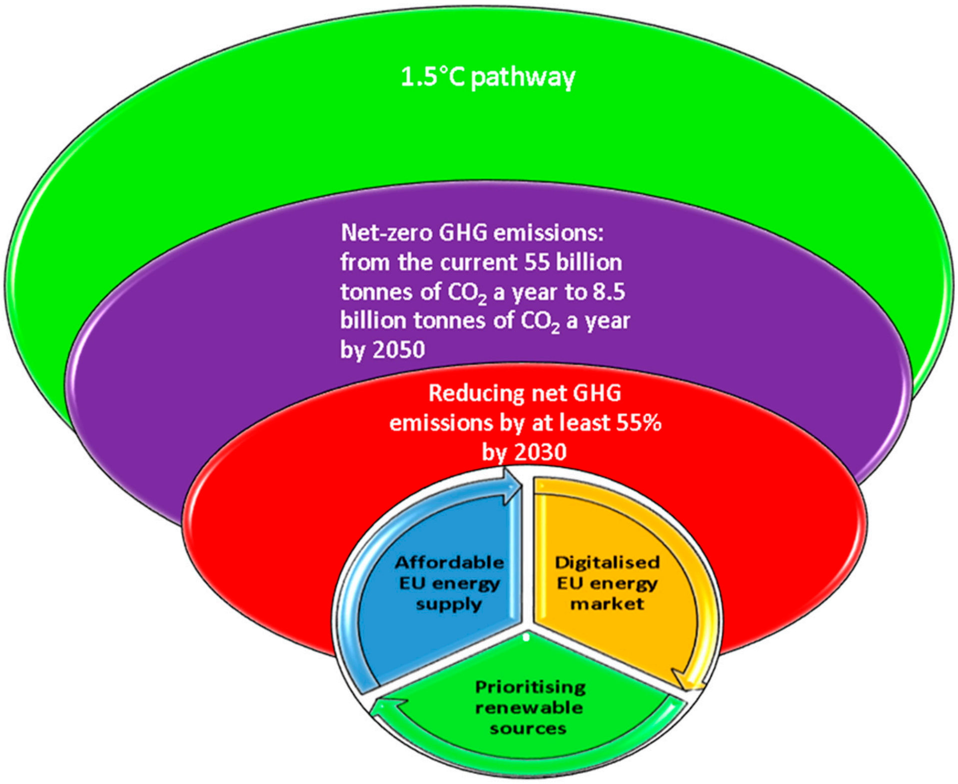

Figure 1. Trajectory toward decarbonizing the EU's energy system.

As we went deeper into analyzing the importance of digitalization in energy production, distribution, and consumption by looking into the existing interests of specialists who have published their fieldwork research in the Web of Science and Scopus databases, we determined the servitization of the energy sector [2] to be a second major existing challenge for reaching energy-saving targets [3] and for the decarbonization target itself. This is because, by promoting energy efficiency in the built environment through training and education [4], we can address the challenges posed by an evolving energy grid [5], thus spurring cross-country companies to implement digitized services.

From our analysis, we understand that some countries are still struggling with the major existing challenge of all—the lack of unconditional access to energy across all national territories—and, in this context, in the search for energy needed for homes, workplaces, hospitals, and other national institutions, whether the energy is produced greenly or produced in the classic manner comes is a secondary concern, as long as the citizens are taken care of.

As one of the strongest challenges of all, access to energy will continue to be primarily looked at closely. Meanwhile, for countries that have overcome this deficiency, the major future challenge will be teaching all their citizens to reuse, reduce, repair, and recycle products, not just to reach the 1.5 °C milestone, but in order to continuously lead a green energy usage life. Therefore, the most important future challenge will rely on consciously aiming all of our daily actions toward the green energy pathway.

In order to overcome such challenges, specialists have conducted comparisons of power approaches for the testing of smart grid controls [6] in order to classify energy-demand time series [7], as the need for generic data models describing flexibility in power markets [8] has grown extensively over the past 10 years. Furthermore, our analysis indicated that, over the past decade, green vehicle digitalization for the next generation of connected and electrified transport systems [9] has occupied a central role in growing toward a net zero GHG (greenhouse gas) emissions target through the 2030 stage to 2050; that is, with a long-term focus.

As co-generation relies upon the fact that all countries should bring their own intakes for further promotion of sustainable consumption and production (SCP) within the scope of national action plans in the near future, the target for a heightened digitized infrastructure has grown into national policies regarding short- and long-term development. Additionally, by looking at the material footprint (MF) of each country that supports the co-generation, we can understand that the quantity of material extraction required to meet the consumption of a country can be decreased through the introduction of digitized infrastructure. Considering the total material footprint as the sum of the material footprint for biomass, fossil fuels, and metal and non-metal ores, we can rise above the question: How much natural resources are essential to decouple economic growth from resource use?

By analyzing the Domestic Material Consumption (DMC) as a production-side measure which does not account for supply chain inputs or exports, a country may have a lower DMC value if it outsources a large proportion of its materials. Decreasing the DMC poses a third major existing challenge which, to some degree, can be achieved by promoting education on lowering waste and on reusing and recovering materials, as well as predominantly using renewable resources.

As per our analysis of challenges related to short- and long-term energy production, distribution, and consumption, the results indicated that the evaluation of a country's sustainable public procurement (SPP) implementation level, scope, and comprehensiveness is typically based on regulatory frameworks, implementation support, and monitoring of the share of products and services purchased sustainably, following an increase in positive actions and a decrease in negative impact factors (see Figure 2). As a result, developing a fully integrated, interconnected, and digitalized EU energy market will increase energy efficiency, renewable sources, greenhouse-gas-emission reductions, and digital interconnections, which can be promoted by continuous research and innovation in the energy production, distribution, and consumption sector.

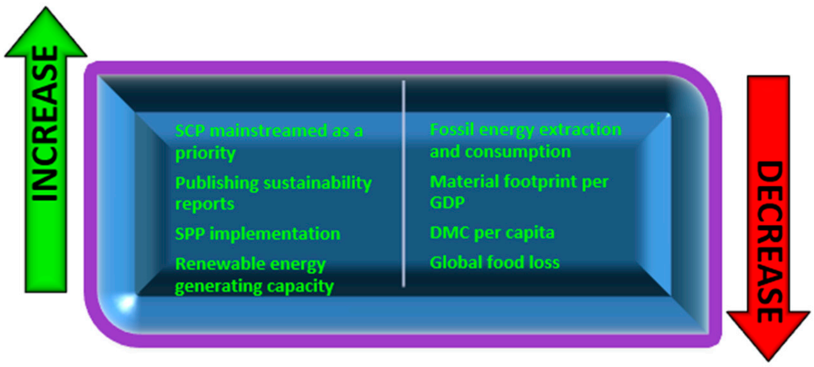

Figure 2. Sustainable infrastructure goals: strengthening responsible consumption and production.

In addition, in terms of impact, we may note the positive results resulting from raising the level of transparency of public services and decreasing the discretion level within the provision of public services. As energy distribution is perceived as a public service, another advantage of digitalization and e-government is that it is a central element contributing to the reduction of petty corruption [10].

Going further to assess the future roles of digitalization in energy production, distribution, and consumption, the researched studies reveal that, at present, the digitalized energy conservation of industrial buildings and materials [11] should be promoted and sustained in each country, primarily through education and accessibility. In this way, post-, pre-, and non-payment accessibility conflicts can be rationalized through the digitalization of energy access [12]. Agile digitalization evolution in the energy sector, taking into account innovative and disruptive technologies [13], goes above and beyond the optimal digital scheduling model using artificial intelligence [14]. Energy-related fields can obtain improvements by focusing on Open Innovation [15], allowing for the decoupling of economic aspects from resource use through digital transformations [16]. From our current analysis, prospects for digitalization within industrial complexes [17] appear as a sine-qua-non prerequisite for the implementation of methodologies in well-described and mapped industrial environments.

In this context, setting forth the digital collection of energy consumption and production data [18] within a cloud collaboration value chain based on degree analysis [19] can promote SMART energy management systems [20,21], as well as providing a basis for resource conservation [22].

Taking into consideration the global interest in digitalized future energy systems, various countries have opened collaboration pathways to promote and educate public and private companies to embrace innovation in terms of digitalization [23–25].

With respect to how sustainable energy may empower the decoupling of the economy from natural resource use in the future, a comparative analysis of new trends in energy digitalization was conducted [26], and efficiency models were sketched. Furthermore, studies have focused on how to empower resource saving technologies [27], for example, as a direction for ensuring the growth of energy efficiency and energy security [28].

When analyzing the studies published in the energy field over the last decade, as indexed in the Web of Science and Scopus databases, we noted that cross-checking among industries has been implemented, and production, distribution, and consumption frameworks are constantly under improvement. Targeting an increase in energy efficiency by 2030 and 2050 [29], multiple countries have stated that infrastructure, supply chain strategy, and communication [30] play key roles in the successful implementation of directives, agendas, and plans, as well as continuous monitoring for reaching net-zero GHG emissions and economic decarbonization.

As per the conducted review of the literature, digitalization [31–33] in energy production, distribution, and consumption must also be accessible and easy to implement for the final users and consumers. A new generation of users may be raised with the knowledge that the decoupling of economic growth from resource use is a long-term strategy that can ensure the viability and stability of the environment. Research over the past 10 years has already contoured the infrastructure for renewable resource use and co-generation fundamentals, and it should be kept in mind that education for future generations starts now. The current state-of-the-art and potential for future research [34] open pathways for clearly reaching the 2030 and 2050 net-zero GHG emissions goals.

By virtue of pro-environmental behavior becoming a core focus, the need to promote knowledge transfer to the next-generation users of energy production highlights the impact of higher education and the diffusion of information and communications technology [35]; this includes periodically publishing sustainability reports, as transparent state-of-evolution materials, and is related to one of the key future challenges, i.e., the use and development of AI- and IoT-based infrastructure as a means of more effectively achieving the 2030 and 2050 green targets [36].

Thereby, in order to summarize the state of progress toward decoupling the economy from resource use, machine learning, information modeling, business modeling, and data hub usage approaches may prove efficient [37,38]. In terms of consumers, this promotes employment in protecting consumers in regard to digitized multisource energy systems [39], with consumer data-protection concerns being one of the main causes of lacking digitization usage (after accessibility), as such systems are not yet trusted completely.

Pursuing methods and techniques for energy efficiency based on the in-depth analysis [40], we prominently observed that the blockchain and Value Chain Management approaches may be used in order to promote green distribution models [41]. Such approaches were found to be capable of administering cross-country co-generation efforts, bearing in mind that each country must follow its individual sustainable energy policies [42,43].

By analyzing the interests of energy specialists that have published their research in the Web of Science and Scopus databases, we found that future generations are expected to closely rely [44] on the Social Internet of Things (SIoT), which was developed to enable a systematic model for the smart integration [45] of digitalization in energy production, distribution, and consumption domains. This context is bound with predictive control [46], as countries are already setting goals for future smart cities [47], in which energy distribution and trade models [48] are utilized for core predictive management [49]. Furthermore, from the analysis conducted, we discovered that many countries have a general need for demand forecasting to promote decentralized energy management [50]; in particular, such forecasting is necessary to estimate the minimum energy requirement for transitioning to a net-zero GHG in 2050. Some studies have gone even further, sketching 3D indicators to guide AI applications in the future energy sector [51,52].

Although the pathways to the energy 2030 and 2050 goals have been disrupted by the COVID-19 pandemic, seen through the lens of the Sustainable Development Goals (SDGs) [53], it has been revealed that the decreased travel in this period had a huge role in repairing the environment, demonstrating once more that co-generation undertaken with a focus on decarbonizing the energy sectors is feasible, albeit with great socioeconomic impacts on current and future generations [54].

The COVID-19 post-pandemic implications for energy security [55] have been well-analyzed, and specialists have stated that addressing Internet of Things (IoT)-related adoption challenges in renewable energy [56] can contribute to the expansion [57] of improved energy and recourse efficiency, as well as the environmental safety of processes [58]. As the levy on consumers grows, mainly due to decreased accessibility and natural resources, digitalization in energy production, distribution, and consumption brings a challenging pathway toward efficiency into focus.

Thus, in light of the discussion above, consideration of energy consumption in the post-COVID-19 world [59], marked with a series of data protection and accessibility insecurities, allows for the analysis of cross-border perspectives on future power system control centers for energy transition [60] in which accessibility barriers are to be removed and key techniques to new power systems dominated by renewable energy [61] are to be increased. These factors become more important as we approach the first GHG milestone (in 2030) and move slowly toward assessing the potential of Industry 4.0 in helping to achieve the 2050 decarbonization targets [62].

Future data-driven implementations considering privacy preservation [63] suggest that full investment in digitalization performance predictions is crucial [64], as knowledge of its roles in energy production, distribution, and consumption will outline a comprehensive framework for system upgrading [65]. Applying modern information technologies in the search for operational energy resources [66] can prevent energy loss and undesired waste [67,68], such as when conducted in a hierarchical order considering priority corridors, as shown in Figure 3.

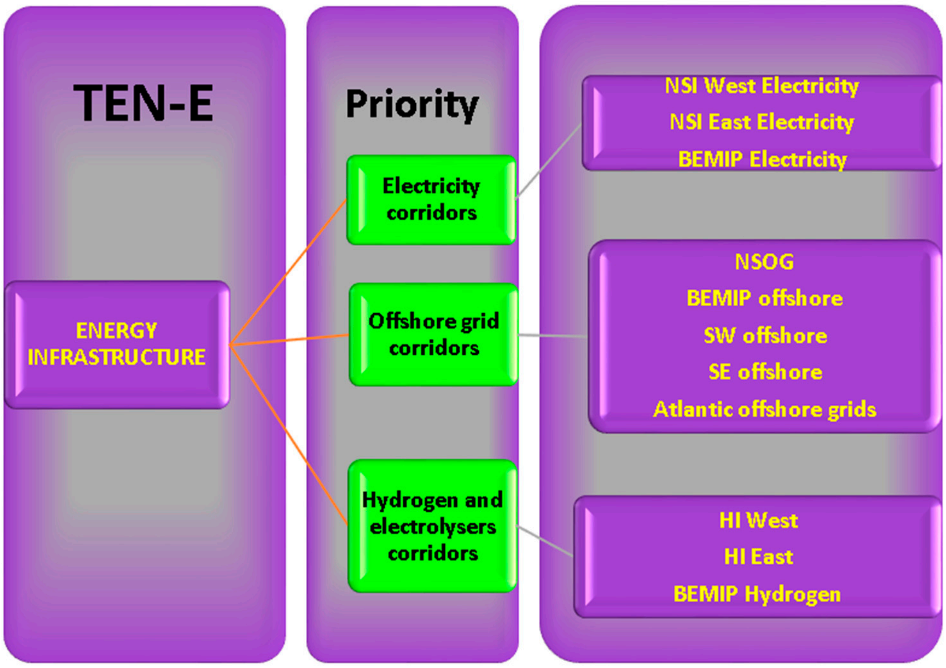

Figure 3. Energy infrastructure analysis using priority corridors.

With regard to the above, the use of artificial intelligence techniques in the management of enterprises in the energy sector [69] can provide flexible production [70], thus achieving efficiency [71] and improving energy distribution and consumption [72]. Large consumers [73] and stakeholders have a key demand for these frameworks for community energy storage [74], with increased focus on growing accessibility and reducing material footprints; this is in line with the existing challenges in energy, engineering, and consulting [75,76].

To satisfy the needs of these large consumers and stakeholders, the EU provides guidelines on energy infrastructure, thus supporting cross-country co-generation, as per the TEN-E Regulation. The EU has strengthened priorities on corridors for emissions reduction objectives by promoting the integration of renewables and new clean energy technologies into the energy system, including electricity corridors, offshore grid corridors, and hydrogen and electrolyzer corridors, within which the heightened usage of digitalization can assist in overcoming accessibility barriers, as explained previously.

The main advantages that are brought by IT-based solutions in terms of environmental sustainability [77] include analyzing performance in circular economy business scenarios [78] and helping to move toward a centralized control-and-monitoring system utilizing the IoT paradigm [79]. Our review of the literature highlighted that such an approach will enhance cross-country cooperation in reaching the 2030 and 2050 energy milestones [80], as web-based energy information systems [81] can empower energy-efficient business [82]. In this context, the decoupling of economic growth from resource use becomes attainable.

Through analyzing the main actual and future challenges related to digitalization in the energy sector, the ICT perspective provides modalities through which the energy distribution can be altered [83]; for instance, starting with the most common change that is well-known at present, rapid innovation is implemented in the electric-vehicle charging system sector with each year that passes [84,85].

The last decade of research into digitalization in the field of energy production, distribution, and consumption mainly describes the headway made regarding temporary solutions [86,87], such as autonomous vehicles [88] or compressed driving cycles [89], which substantiate the relationships between technology, urbanization, and electricity consumption [90], serving as a prediction of the future smart-city era.

Digitalization has acquired a core focus regarding renewable energy procurement [91], IoT-enabled technologies [92], smart technology applications [93], and environmentally sustainable technologies [94], which all play key roles in the successful implementation of directives, agendas, and plans, as well as continuous monitoring to reach net-zero GHG emissions and economic decarbonization.

The past 10 years of research on the implementation of smart applications—for example, using IoT-based techniques [95] and data modeling [96] for energy efficiency empowerment [97]—has opened collaborative pathways to educate the public and private environment about how to embrace innovativeness, in terms of digitalization, in order to sustain the most accessible forms of co-generation.

Furthermore, highly complex forms of energy production, such as the hybridization of triboelectric–electromagnetic generators [98], has led to the possibility of a state-of-the-art energy infrastructure [99,100]. In this way, society, through education, perseverance, and continuity, may leave behind its fossil fuel dependence to embark on a low-carbon path [101]. As we observed through the analysis in the presented review of the literature, over the last decade, specialists worldwide have endeavored to empower high-efficiency co-generation.

The review of the literature that was conducted for the presented study displayed that the promotion of digitalization for energy production, distribution, and consumption can be expected to result in smart sustainability in future decades [102], through first targeting the 2050 goal [103] and advances in monitoring of the condition of natural resources used for decoupling. In such a way, the environmental pressure corresponding to economic growth may be decreased [104].

From the perspective of approaching digitalization in energy production, distribution, and consumption, some conceptual delimitations are necessary; in particular, digital transformation includes three stages: digitization, digitalization, and digital transformation [105].

Digitization involves the encoding of analogue information into digital information, such that it can be stored and transmitted by computers [106]. Digitalization describes how digital technologies can be used to change business processes [107]. Digital transformation is defined as "a change in how a firm employs digital technologies, to develop a new digital business model that helps to create and appropriate more value for the firm" [108], and it involves adapting business strategies to the new digital reality, with an immediate impact at the operational and process levels [109].

As can be seen from the previously published studies, existing and future challenges are determined by the elements that contribute to the initiation and especially to the acceleration of digitalization processes in the production, distribution, and consumption of energy. These include problems such as the scale of the digitalization phenomenon; the role of digitalization in the production, distribution, and consumption of energy; the evolution of the assimilation of digitalization technologies; and the effects of digitalization.

Considering the nature of previous approaches and the amplification of digitalization processes globally and in the energy sector, the main purpose of this study was to conduct a systematic review of the literature on digitalization in energy production, distribution, and consumption over a sufficiently long period, such that the trends and particularities of this phenomenon could be revealed at the sectoral level, with regard to the results of the main specialized publications.

The realization of a systematic review of the literature regarding the digitalization process in energy production, distribution, and consumption included the following objectives:

- Identification of the main databases and sources of publications most relevant to the energy digitalization process;
- Extracting the articles that refer to the subject of the review of the literature over the last ten years from these databases;
- Analyzing the most relevant articles regarding digitalization in the energy value chain;

- Identifying the particularities, trends, and roles of digitalization from the perspective of producers, distributors, and consumers.

Considering the objectives of the study, the analysis of the specialized literature aimed to answer the following questions:

- How has the number of publications in mainstream journals on the subject of digitalization in the energy sector evolved?
- How are the publications in the fields of energy production, distribution, and consumption distributed in the analysis period (2012–2022)?
- What is the impact of digitalization on energy production, distribution, and consumption?
- What types of technologies are used in the digitalization process in the energy sector?
- What are the impacts of these technologies on energy production, distribution, and consumption?

Therefore, a systematic review of the literature regarding the digitalization process in energy production, distribution, and consumption was carried out, taking into account a very large number of articles published on this topic, thus allowing for a detailed analysis of the particularities of this process.

The period taken into account was long enough to allow for the observation of trends in the evolution of the digitalization phenomenon from the perspective of the magnitude of its appearance in the specialized literature.

2. Materials and Methods

In order to study how the main aspects, trends, and implications of digitalization in energy production, distribution, and consumption were highlighted in the specialized literature, several databases containing publications on this topic were initially analyzed. The period chosen for the study was 2012–2022, considering that the most important changes in the digital transformation of organizations in the field of energy have occurred over the last ten years. The main stages of the study focused on digitalization in energy production, distribution, and consumption were—according to the elements presented in Figure 4—as follows:

(1) A preliminary analysis of the available databases was performed, including several databases that contain articles relevant to the topic of the study: sciencedirect.com, Scopus, Web of Science, Springer, and Google Scholar. The preliminary analysis focused on the databases in which journals/articles with similar or close content to the topic of digitalization in production, distribution, and energy consumption were most likely to be indexed.

(2) A selection of the most relevant databases was conducted based on the following criteria: The relevance of the database to the scientific community, the number of articles on the topic of digitalization in energy, the notoriety of the journals in which the articles were published, and the number of accessible items. Based on these criteria, the Web of Science and Scopus databases were selected, in which the most prestigious journals in the field of energy and digitalization are indexed. In addition, both the sciencedirect.com and Springer databases were considered to contain several articles already indexed in Web of Science and Scopus. Some previous studies have shown that Google Scholar provides the most comprehensive coverage, with similar coverage to Web of Science and Scopus; however, Google Scholar does not have a strong quality-control process and simply corrals any information that is available on academic-related websites [110]. For this reason, we chose Web of Science and Scopus as representative databases.

(3) An identification of the most relevant articles in the selected databases was performed using digitalization and energy as key search terms. In the Web of Science database, the initial search was performed using the following syntax for the topic of the articles (title and abstract): "digitalization" AND "energy". The initial search yielded 589 articles published in journals indexed in Web of Science (Clarivate Analytics). In the process of identifying relevant articles for research in the Scopus database, we followed three steps. The first step was to filter the articles according to the keywords "digitalization and energy".

The second step involved filtering them by "Date of publication", excluding articles that were not in the range 2012–2022. The third step involved filtering them by document type and keeping documents that were articles. Initially, 685 articles were identified in the Scopus database.

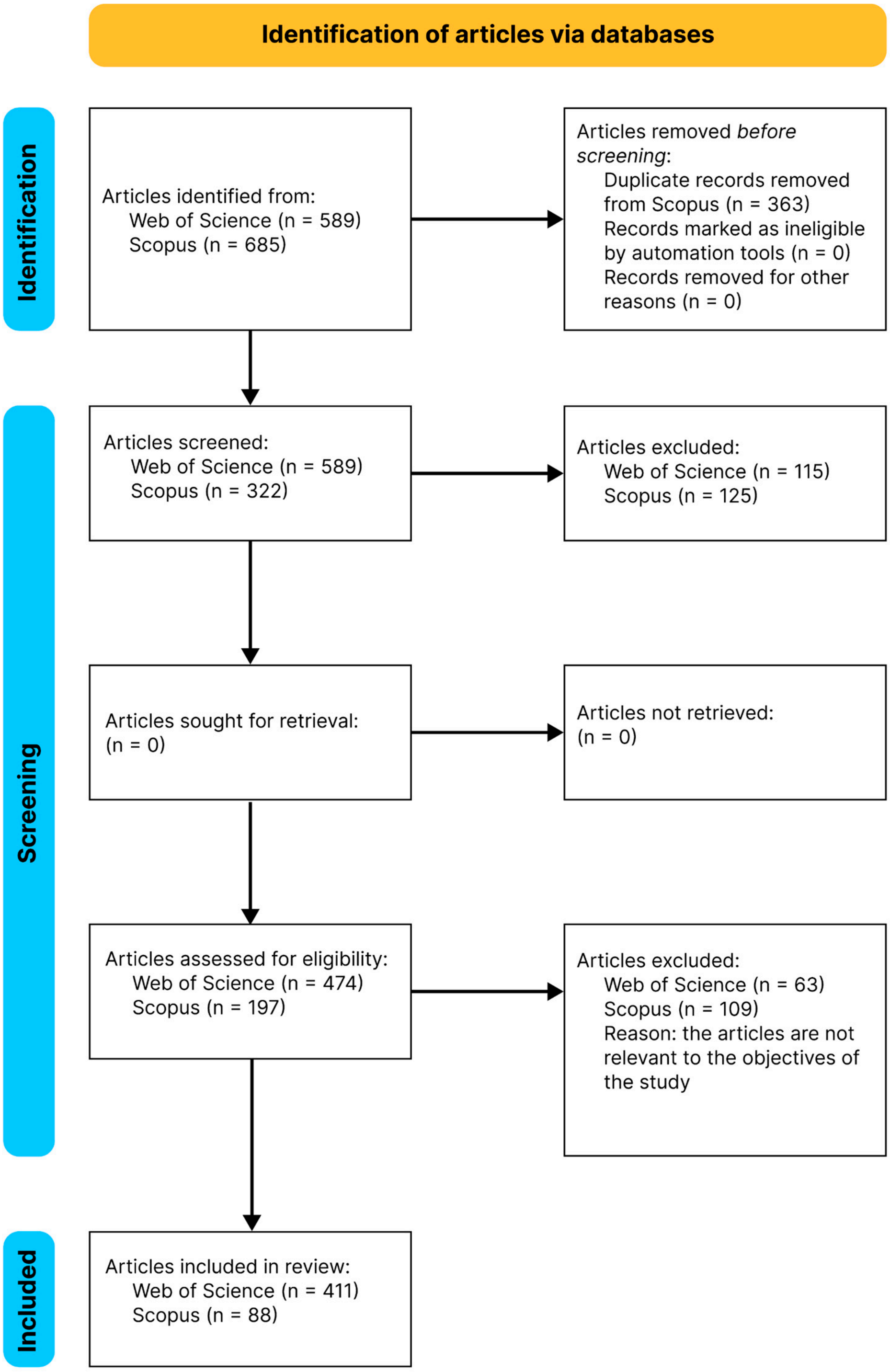

Figure 4. The main stages of the systematic review of the literature (according to PRISMA 2020 flow diagram for new systematic reviews, including searches in databases).

(4) A comparison of the articles from the Scopus database with those from the Web of Science and removal common articles (i.e., removing duplicate records) were performed. Following the application of these filters, 363 duplicate articles from the Scopus database

were removed and 322 articles from the Scopus database were retained for the screening phase. The articles in Web of Science were all retained (589 articles). The relatively small number of articles remaining in Scopus can be explained by the fact that the rest of the articles indexed in Scopus were also indexed in Web of Science.

(5) Screening of the articles and the removal of non-relevant articles from the Web of Science and Scopus databases were performed. This involved the exclusion of those articles that appeared in the databases that included the words "digitalization" and "energy" but which were not relevant to the topic of digitalization in energy production, distribution, and consumption. After the exclusion process, 411 articles remained from Web of Science and 88 from Scopus. Separate analyses were conducted for Web of Science and Scopus, as articles relevant to the study objectives were found in the Scopus database which did not appear in Web of Science. In addition, certain articles from the journals indexed in Scopus were analyzed, revealing certain particularities and effects of digitalization in the field of energy distribution in more detail, or offering a series of additional explanations of the particularities of digitalization in terms of energy consumption. All of this provided a broader perspective on digitization processes in the energy field, compared to if the analysis had been limited to articles from Web of Science or if we had only performed a cumulative analysis of articles from the two databases. That is why a separate analysis was also necessary for articles appearing only in Scopus.

(6) An analysis of articles from the Web of Science and Scopus databases was carried out in October and November 2022 and was completed on 28 November 2022, taking into account the number of articles published, both annually and over the entire analysis period (2012–2022); the number of articles on production, distribution, and consumption; the potential impact of articles; and the typology of technologies used in the digitalization process in the energy field. The considered impacts of digitalization included cost reduction; improving health, safety, and the environment; process improvement; reducing capital expenditure; and increasing production.

(7) A comparative analysis of the articles appearing in the two databases was carried out in order to reveal the similarities and differences that marked the approaches to the digitalization process in the two databases.

(8) A formulation of conclusions based on the analyses performed on the indexed articles in the selected databases was performed. During the formulation of conclusions, we kept in mind all of our goals for the contributions of this study in relation to the state of knowledge and research on the issue to date. The findings of this study included a number of future research directions/directions that we wish to address, especially given the limitations of the existing research.

Although the number of publications on digitalization in the energy sector has increased significantly in recent years and meta-reviews have begun to appear in this field, we opted to conduct a systematic review of the literature for three reasons:

- Not all previous systematic review (or meta-review) studies have focused on such a long period (e.g., covering the last ten years);
- Certain results and effects of digitalization cannot be highlighted only through the study of previous systematic reviews;
- There are relatively few meta-review publications that capture the stages of energy production, distribution, and consumption as a whole.

Furthermore, we did not use a Critical Assessment Skills Program (CASP) for the systematic review of the literature, as our study did not involve an assessment of the applicability of the results of previous studies at the local level or on the local population. Moreover, not all previous studies included a geographical location, and, therefore, the third section of the CASP Checklist would have been difficult to achieve.

3. Results

3.1. Articles Published in Journals Indexed in Web of Science

The number of publications in each journal indexed in Web of Science is presented in Table 1. Only journals that had five or more articles published on the subject of digitalization in energy production, distribution, and consumption are explicitly presented in this table. The other journals—although they comprised the majority of published articles—are not explicitly listed.

Table 1. The number of publications in each journal indexed in Web of Science [1].

Journal Name	Number of Publications
Energies	45
Sustainability	22
Energy Research & Social Science	13
Applied Energy	12
Energy Policy	11
IEEE Access	10
Journal of Cleaner Production	9
Renewable & Sustainable Energy Reviews	9
Energy Reports	9
Environmental Science and Pollution Research	7
Sensors	7
Applied Sciences—Basel	6
Chemical and Petroleum Engineering	5
Elektrotechnik und Informationstechnik	5
International Journal of Electrical Power & Energy Systems	5
Resources Conservation and Recycling	5
Others	231

[1] Based on data available in Web of Science.

From the data presented, it can be seen that most of the published articles were in the journals *Energies, Sustainability, Energy Research & Social Science, Applied Energy,* and *Energy Policy*. Together, these journals included almost a quarter of the articles published on the subject of digitalization in energy. When we analyzed the structure of the publications in the journals indexed in Web of Science, we found the following:

- Two journals (*Energies* and *Sustainability*) included over forty or twenty articles, respectively, published on the analyzed topic. As such, these two journals comprised more than 16% of the articles published on this topic;
- Four journals included between ten and thirteen articles published on the analyzed topic (*Energy Research & Social Science*, *Applied Energy*, *Energy Policy*, and *IEEE Access*). Together, the number of publications in these journals represented 11% of the publications on this topic;
- Ten journals included between five and nine articles published on the topic of digitalization in energy, and the number of publications in these journals represented 16.30% of the total number of articles on this topic;
- The rest of the journals included four articles or less are published on the analyzed topic, and the number of articles published in these journals represented more than half of the analyzed articles.

It can also be seen that the journals in which the most articles on digitalization in energy production, distribution, and consumption are published were of three types:

- Journals in the area of energy and fuels (*Energy*, *Energy Research & Social Science*, *Applied Energy*, *Energy Policy*, *Renewable & Sustainable Energy Reviews*, *Energy Reports*, and *International Journal of Electrical Power & Energy Systems*);
- Journals in the area of informatics, electronics, and digitalization (*Sensors*, *Elektrotechnik und Informationstechnik*);
- Journals in the area of environmental science or environmental protection (*Sustainability*, *Journal of Cleaner Production*, *Environmental Science and Pollution Research*, and *Resources Conservation and Recycling*).

The distribution of magazines by field indicated that the topic of digitalization in the production, consumption, and distribution of energy is not only the prerogative of those specialized in energy, but also includes those from other fields such as environmental protection or automation/electronics.

The number of publications in each year by sector is presented in Table 2. For all sectors analyzed (production, distribution, and consumption), most articles were clustered in the period 2020–2022. During this period, more than 80% of all articles that were present in journals indexed in the Web of Science database were published.

Table 2. Number of publications/year in each sector [1].

Specification	Number of Publications/Year										
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Production	1		1	1	3	2	7	12	20	42	47
Distribution	2				1	2	3	4	10	21	17
Consumption	1	1	1	2	2	8	15	10	43	60	72
Total	4	1	2	3	6	12	25	26	73	123	136

[1] Based on data available in Web of Science.

Most of the articles published in journals indexed in Web of Science with digitalization in the field of energy as their subject—in particular, more than half of the total—had energy consumption as their main theme. These were followed by those—with almost a third of the total—that considered the production and distribution of energy as their subject. The relevant data are presented in Figure 5.

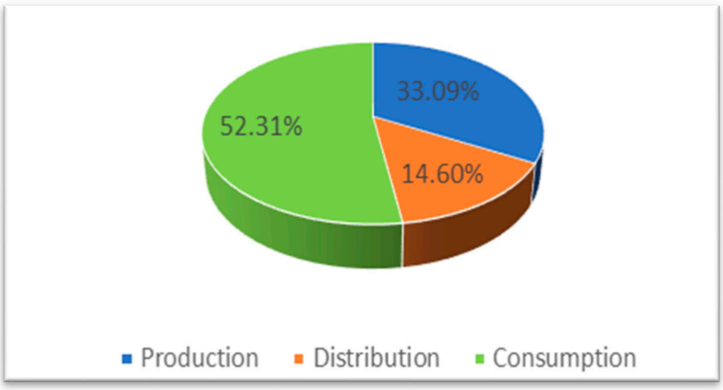

Figure 5. Sectoral distribution of articles published in the Web of Science database on the topic of digitalization in energy.

The articles published in Web of Science that were focused on digitalization in energy consumption concerned both consumption in households and in economic activities [111–114]. In the field of energy production, digitalization is considered an important process not only from the perspective of the use of renewable energies [115], but also in terms of sustainability [116], energy efficiency [117], and improving energy production [118,119]. In the field of distribution, digitalization is a key factor of change and sustainability [120,121].

The analysis results regarding the impact of digitalization in energy production, distribution, and consumption are presented in Table 3. In the energy production sector, most of the articles on digitalization posed health, safety, and environmental improvement as a key impact, followed by those aimed at improving processes and increasing production.

A relatively identical situation also occurred in the field of energy consumption, where the impact on health, safety, and environment improvement was followed equally by process improvement and cost reduction. Notably, process improvement was considered the main impact of digitalization on energy distribution in most of the Web of Science articles related to distribution.

Table 3. The impacts of digitalization with respect to energy production, distribution, and consumption [1].

Specification	Impact (Outcome)				
	Reducing Costs	Health, Safety, and Environmental Improvement	Process Improvement	Reducing Capital Expenses	Increasing Production
Production	9	31	26	6	15
Distribution	5	8	22	3	0
Consumption	32	66	32	4	0
Total	46	105	80	13	15

[1] Based on data available in Web of Science.

In energy production, the impact of digitalization on environmental improvement is manifested both in terms of renewable energies [122], as well as in terms of sustainability [123]. Furthermore, in the field of energy production, an important impact of digitalization is its contribution to ensuring energy security through its acceptability and sustainability [124].

In the field of energy consumption, the impact of digitalization on household consumption is manifested through microgrid systems, smart homes, residential solar power generation systems, and non-intrusive load monitoring. The number of articles focused on the technologies used in the digitalization process indexed in Web of Science each year is presented in Table 4. Most of the technologies used in the digitalization process appeared, as a share of the articles indexed in Web of Science, within the last four years of the analysis period (with approximately 88% of the total articles published). In the other years, publications on the type of technologies used in the digitalization process were relatively few when compared to the number of publications over the entire period considered.

Table 4. The number of articles indexed annually in the Web of Science database during 2012–2020 focused on the technologies used for digitalization [1].

Type of Technology/Years	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
BDA, data mining, and machine learning	0		0	1	0	2	0	3	4	17	11
Cloud computing	0		0	0	0	0	1	0	0	3	0
Cybersecurity	1		0	0	0	1	1	0	2	4	3
Blockchain	0		0	0	0	0	0	1	1	3	5
Virtual reality	0		0	0	0	0	0	0	0	1	1
Digital twin	0		0	0	0	0	0	0	1	3	6
IoT	0		0	0	0	0	2	0	2	8	7
Artificial intelligence	0		0	0	0	0	0	0	1	2	3
Visualization	0		0	0	0	0	0	0	0	1	1
Robotics technologies (mobile robotics/autonomous mobile robotics)	0		0	0	0	0	0	0	0	0	0
Radio frequency identification	0		1	0	0	0	0	0	0	2	0
CRM	0		0	0	0	0	0	0	0	1	0
Intelligent agents, agent-based systems	0		0	0	0	0	0	0	0	0	1
Middleware technologies	0		0	0	0	0	0	0	0	0	0
Business intelligence (data warehousing)	0		0	0	0	0	0	0	1	4	3
Remote sensing/GIS	1		0	0	0	0	0	1	3	3	1
3D printing, 3D streaming, virtualization	0		0	0	1	0	0	0	0	1	2
Automation solutions (robotics, drones, distribution automation)	0		0	0	0	0	2	1	1	2	4
Social media	0		0	0	0	0	0	0	0	1	1
Minigrids/micrograds	0		0	0	0	0	0	0	1	0	2
Smart grid/smart metering/smart home	1		0	0	1	0	4	3	9	11	2
Virtual power plant	0		0	0	0	0	1	0	0	2	0
Intelligent distribution power router	0		0	0	0	0	0	0	0	2	0
Mobile applications, wireless networks, 5G networks	1		0	1	0	0	0	0	1	2	3
Others	0		0	0	0	0	1	0	2	3	1
Total	4	0	1	2	2	3	12	9	29	76	57

[1] Based on data available in Web of Science.

The frequencies of appearance of the technologies specific to digitalization are presented in Figure 6.

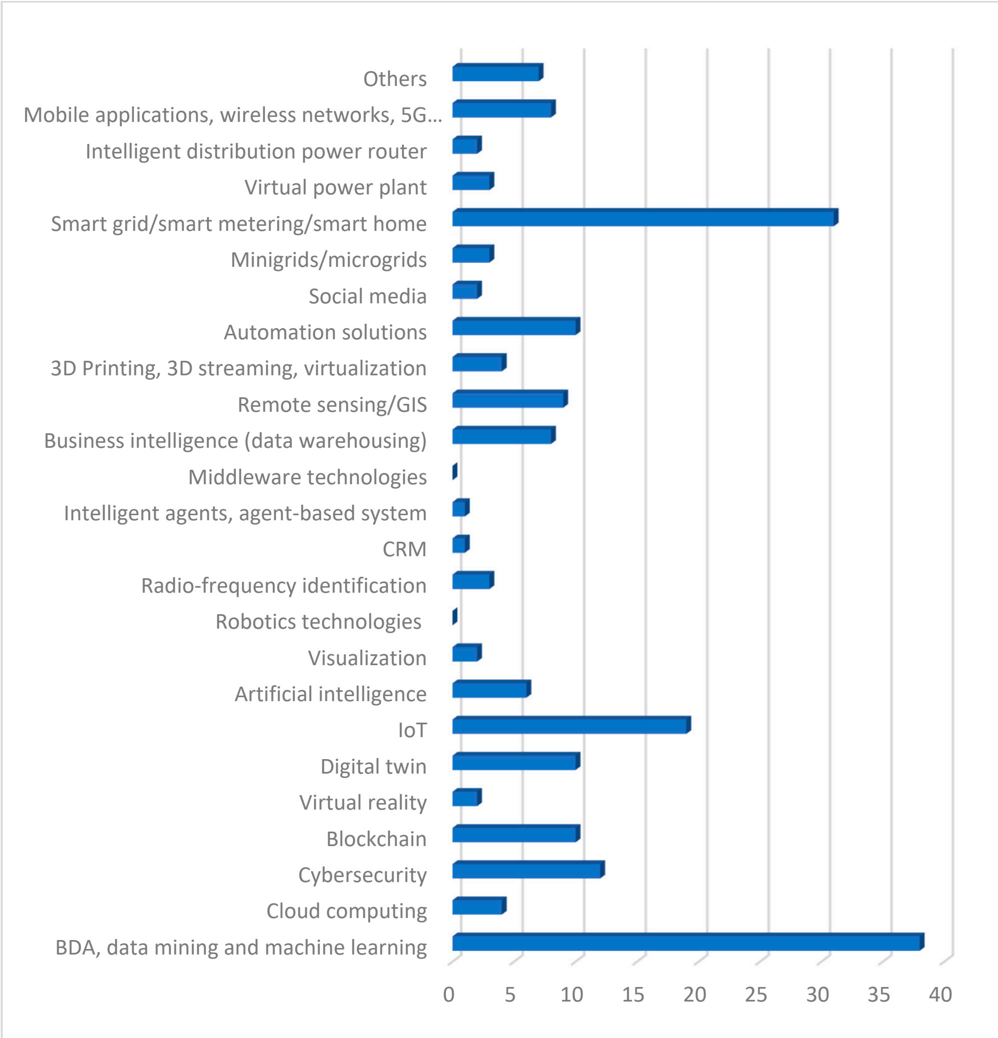

Figure 6. The frequency of appearance of technologies specific to digitalization in studies published during the period 2012–2022.

If we consider the entire analysis period, the largest number of articles referred to BDA, data mining, and machine learning (19.49% of all articles published in the period 2012–2022), followed by those related to smart grid/smart metering/smart home technology, representing 15.90% of all analyzed publications. On the other hand, topics such as robotics technologies or middleware technologies did not appear explicitly in the articles selected for analysis.

The distribution of the technologies and systems used by the energy sector is presented in Table 5. Energy consumption was the sector in which the most articles appeared regarding BDA, data mining, and machine learning; cloud computing; cybersecurity; IoT; automation solutions (robotics, drones, and distribution automation); mobile applications, wireless networks; and 5G networks. The most-used technologies in the field of energy production (as a majority share in the number of articles on a particular technology) were blockchain, artificial intelligence, business intelligence, 3D printing, 3D streaming, and virtualization. In the energy distribution sector, most articles were focused on smart grid/smart metering/smart home technology.

Table 5. Distribution of the technologies and systems in energy sectors [1].

Type of Technology	Number of Publications		
	Production	Distribution	Consumption
BDA, data mining, and machine learning	15	3	20
Cloud computing	0	0	4
Cybersecurity	3	1	8
Blockchain	5	2	3
Virtual reality	1	0	1
Digital twin	3	2	5
IoT	2	2	15
Artificial intelligence	3	1	2
Visualization	0	0	2
Robotics technologies (mobile robotics/autonomous mobile robotics)	0	0	0
Radio-frequency identification	0	0	3
CRM	0	0	1
Intelligent agents, agent-based system	0	0	1
Middleware technologies	0	0	0
Business intelligence (data warehousing)	4	2	2
Remote sensing/GIS	3	1	5
3D printing, 3D streaming, virtualization	3	0	1
Automation solutions (robotics, drones, distribution automation)	2	0	8
Social media	2	0	0
Minigrids/microgrids	1	0	2
Smart grid/smart metering/smart home	5	17	9
Virtual power plant	1	1	1
Intelligent distribution power router	1	1	0
Mobile applications, wireless networks, 5G networks	1	3	4
Others	3	2	2
Total	58	38	99

[1] Based on data available in Web of Science.

The impact of each type of technology in the energy field is presented in Table 6. From the perspective of the technologies used, it can be seen that the number of articles indexed in Web of Science that revealed an impact on the improvement of processes in the energy field was greater than that of articles that revealed the impact of technologies on health, safety, and environmental improvement. However, health, safety, and environmental improvement had the most significant impact when using BDA, data mining, and machine learning; blockchain; 3D printing; 3D streaming; virtualization; remote sensing/GIS; and automation solutions (robotics, drones, and distribution automation) technologies. The use of BDA, data mining, and machine learning; IoT; business intelligence (data warehousing); and smart grid/smart metering/smart home technologies had the most significant impact on process improvement. Cost reduction was the key impact when using cybersecurity.

Previous research has revealed that the attitudes/opinions of managers differ regarding the use of new technologies in the energy field. In Romania, the use of Big Data and Big Data Architecture is considered absolutely necessary to move toward the implementation of the Data-Driven Organizational Model in the energy field [125]. The most important barriers in the vision of Romanian managers regarding a Data-Driven Organizational Model are a lack of vision and the absence of specific competence and skills, as well as support from employees, although the impact of BDA on the processes in the organization is obvious [126]. However, the area of application of BDA and machine learning has expanded significantly in recent years, being present in the context of not only energy production, but also distribution and consumption [127,128].

Table 6. The impact of each type of technology in the energy field [1].

Type of Technology	Impact (Outcome)				
	Reducing Costs	Health, Safety, and Environmental Improvement	Process Improvement	Reducing Capital Expenses	Increasing Production
BDA, data mining, and machine learning	10	12	12		4
Cloud computing	2		2		
Cybersecurity	5	2	3		2
Blockchain	3	4	2		1
Virtual reality		1	1		
Digital twin	2	3	3	1	1
IoT	4	6	7		2
Artificial intelligence	2	1	2		1
Visualization		1	1		
Robotics technologies (mobile robotics/autonomous mobile robotics)					
Radio-frequency identification	1	1			1
CRM			1		
Intelligent agents, agent-based system			1		
Middleware technologies					
Business intelligence (data warehousing)	1	3	4		0
Remote sensing/GIS	2	3	2	1	1
3D printing, 3D streaming, virtualization	1	2	1		
Automation solutions (robotics, drones, distribution automation)	1	4	3	1	1
Social media		1	1		
Minigrids/microgrids	1	1	1		
Smart grid/smart metering/smart home	6	10	13	1	
Virtual power plant		1			1
Intelligent distribution power router			1	1	0
Mobile applications, wireless networks, 5G networks		4	2	2	
Others	2	3	1	1	
Total	43	63	64	8	15

[1] Based on data available in Web of Science.

Cybersecurity technologies have been proven to be important and critical infrastructural elements in energy production and distribution, but there is also an increasing tendency to expand their use in the energy consumption field [129,130]. Smart grid/smart metering/smart home technologies have been used more and more in various areas, such as transmission networks [131], electricity storage [132], and the digitalization of buildings and cities [133,134].

An analysis of the technologies used in the digitalization process in energy production, distribution, and consumption revealed the existence of some key technologies used in these areas: BDA, data mining, and machine learning; cybersecurity; smart grid/smart metering/smart home; IoT; and automation solutions (robotics, drones, and distribution automation). The extent of use of these technologies has increased greatly over the last five years when compared to the early years of the period 2012–2022. However, there remain a number of technologies that were less used or whose potential remained insufficiently explored in the analyzed articles or insufficiently exploited, such as social media or middleware technologies.

3.2. Articles Published in Journals Indexed in Scopus

In the process of identifying relevant articles for research in the Scopus database, we followed five steps. The first step was to filter the articles according to the keywords "digitalization and energy". The second step involved filtering them by "Date of publication", excluding articles that were not in the range of 2012–2022. The third step included filtering them by document type, keeping documents that were articles. The fourth step involved removing articles that were also in the Web of Science database. The last step concerned an examination of their content and the removal of articles that were not relevant to the research. Following the application of these filters, 88 articles remained for review.

The number of publications in each journal indexed in Scopus is presented in Table 7. Only journals that had two or more articles published on the subject of digitalization in energy production, distribution, and consumption are presented in this table. Similar to the Web of Science, the other journals—although they comprised the majority of the published articles—are not explicitly listed here.

Table 7. The number of publications in each journal indexed in Scopus.

Journal Name	Number of Publications
International Journal of Energy Economics and Policy	7
International Journal of Energy Production and Management	3
International Journal of Supply Chain Management	3
Electricity Journal	2
Fabriksoftware	2
International Journal of Recent Technology and Engineering	2
Journal of Modern Power Systems and Clean Energy	2
Sustainable Energy, Grids and Networks	2
World Electric Vehicle Journal	2
Others	63

[1] Based on data available in Scopus.

When we analyzed the structure of the publications in the journals indexed in Scopus, we determined the following:

The *International Journal of Energy Economics and Policy* included seven articles published on the analyzed topic, comprising approximately 8% of the articles published.

- In eight journals, between three and two articles were published on the analyzed topic. The number of publications in these journals represented 20.45% of the publications on this topic;
- The rest of the journals had only one article published on the topic under analysis. The number of articles published in these journals represented 71.59% of the total.

The journals in which most articles on digitalization in energy production, distribution, and consumption were published were of three types:

- Journals in the area of energy and economics (*International Journal of Energy Economics and Policy*, *International Journal of Energy Production and Management*, *Electricity Journal*, *Journal of Modern Power Systems and Clean Energy*, *Journal of Modern Power Systems and Clean Energy*, and *Sustainable Energy, Grids and Networks*);
- Journals in the area of informatics, electronics, and digitalization (*Fabriksoftware* and *International Journal of Recent Technology and Engineering*);
- Journals in the area of logistics and electric vehicles (*International Journal of Supply Chain Management* and *World Electric Vehicle Journal*).

The number of publications each year by sector is presented in Table 8. When analyzing the articles present in the journals indexed in Scopus, we found that most of them were clustered in the period 2019–2022, representing more than 85% of the articles.

Table 8. Number of publications per year in each sector [1].

Specification	Number of Publications per Year										
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Production					1			2	3	2	3
Distribution					2	1		5	7	5	9
Consumption		1				1	4	7	5	18	12
Total	-	1	-	-	3	2	4	14	15	25	24

[1] Based on data available in Scopus.

Figure 7 illustrates that 54.55% of articles published in the journals indexed in Scopus were on the subject of consumption, 32.95% were on distribution, and 12.50% were on production.

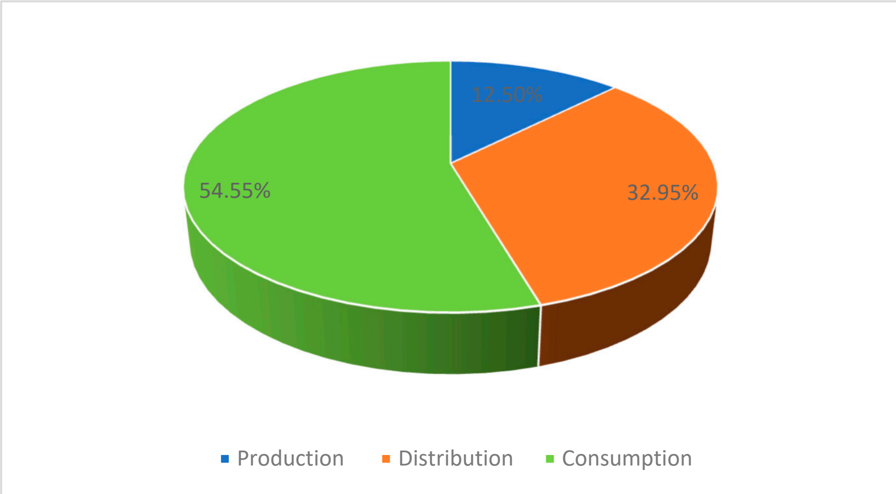

Figure 7. Sectoral distribution of articles published in Scopus on the topic of digitalization in energy.

The articles published in Scopus that had digitalization in energy consumption as their subject mainly concerned the development of smart cities [135–137]. Meanwhile, in the field of energy distribution, smart grid development was at the forefront [138–140].

In the field of energy production, digitalization was considered an important process from the perspective of the use of renewable and sustainable energy [70,77,141].

Data on the impacts of digitalization by production, distribution, and consumption sectors are presented in Table 9. For all sectors analyzed (i.e., production, distribution, and consumption), most articles published in journals indexed in Scopus were focused on process improvement, representing 50% of the articles. These were followed by those that considered the impacts of health, safety, and environmental improvement (23.86%); reducing costs (19.31%); increasing production (4.54%), and reducing capital expenses (2.27%).

Table 9. The impacts of digitalization in the energy production, distribution, and consumption sectors [1].

Specification	Impact (Outcome)				
	Reducing Costs	Health, Safety, and Environmental Improvement	Process Improvement	Reducing Capital Expenses	Increasing Production
Production	1	3	3		4
Distribution	2	3	24		
Consumption	14	15	17	2	
Total	17	21	44	2	4

[1] Based on data available in Scopus.

The number of articles indexed in Scopus each year focused on technologies used in the digitalization process is presented in Table 10. Considering all technologies analyzed, most articles focused on the Internet of Things, representing 20.89% of all articles. This was followed by smart grid/smart metering/smart home (17.91%); BDA, data mining, and machine learning (10.44%); blockchain (8.95%); and the other types of technology (cloud computing, cybersecurity, digital twin, artificial intelligence, visualization, business intelligence, automation solutions, mobile applications, wireless networks, 5G networks, and others; 41.49%).

Table 10. The number of articles focused on technologies used for digitalization indexed annually in Scopus during 2012–2020 [1].

Type of Technology/Years	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
BDA, data mining, and machine learning		0			1	0	0	2	0	3	1
Cloud computing		0			1	0	1	0	0	0	1
Cybersecurity		0			1	0	0	1	2	1	
Blockchain		0			0	0	0	1	2	0	3
Virtual reality		0			0	0	0	0	0	0	0
Digital twin		0			0	0	0	0	0	1	1
IoT		1			1	0	0	5	1	2	4
Artificial intelligence		0			0	0	0	1	0	1	3
Visualization		0			0	0	0	0	1		
Robotics technologies (mobile robotics/autonomous mobile robotics)		0			0	0	0	0	0	0	0
Radio-frequency identification		0			0	0	0	0	0	0	0
CRM		0			0	0	0	0	0	0	0
Intelligent agents, agent-based system		0			0	0	0	0	0	0	0
Middleware technologies		0			0	0	0	0	0	0	0
Business intelligence (data warehousing)		0			0	0	1	0	0	2	0
Remote sensing/GIS		0			0	0	0	0	0	0	0
3D printing, 3D streaming, virtualization		0			0	0	0	0	0	0	0
Automation solutions (robotics, drones, distribution automation)		0			0	0	0	0	0	0	2
Social media		0			0	0	0	0	0	0	0
Minigrids/micrgrids		0			0	0	0	0	0	0	0
Smart grid/smart metering/smart home		0			2	1	0	3	0	1	5
Virtual power plant		0			0	0	0	0	0	0	0
Intelligent distribution power router		0			0	0	0	0	0	0	0
Mobile applications, wireless networks, 5G networks		0			0	0	0	0	0	1	0
Others								2	1	1	2
Total	0	1	0	0	6	1	2	15	7	13	22

[1] Based on data available in Scopus.

Articles including IoT technology aimed to improve the process of energy saving [79,95]; research related to smart grid/smart metering/smart home technology was focused on improving the energy distribution [48,83]; BDA, data mining, and machine learning were considered to facilitate improved energy efficiency [18,72]; and the use of blockchain technologies aims to improve security [97] and achieve the decentralization of the electricity supply [30]. The distribution of the technologies and systems by energy sector is presented in Table 11. Analysis of each sector (i.e., production, distribution, and consumption) indicated that most types of technologies used were present in the distribution sector (with a percentage of 53.73%), followed by the consumption (40.29%) and production (5.97%) sectors. In the distribution sector, there was a high interest in the use of smart grid/smart metering/smart home and blockchain technologies, with 41.6% of the articles focused on these technologies. Concerning the consumption sector, the focus was on IoT technology, helping to improve processes and increase energy efficiency [18]. In articles in the production sector, a limited number of technologies were identified, predominantly focusing on cybersecurity [142].

The impacts associated with each type of technology in the energy field are presented in Table 12. The analysis of articles indexed in the Scopus database revealed that a large number of technologies were found to have an impact on process improvement.

Table 11. Distribution of the technologies and systems by energy sector [1].

Type of Technology	Number of Publications		
	Production	Distribution	Consumption
BDA, data mining, and machine learning	1	3	3
Cloud computing	0	2	1
Cybersecurity	2	2	1
Blockchain	0	6	0
Virtual reality	0	0	0
Digital twin	0	2	0
IoT	0	4	10
Artificial intelligence	0	3	2
Visualization	0	1	0
Robotics technologies (mobile robotics/autonomous mobile robotics)	0	0	0
Radio-frequency identification	0	0	0
CRM	0	0	0
Intelligent agents, agent-based system	0	0	0
Middleware technologies	0	0	0
Business intelligence (data warehousing)	0	0	3
Remote sensing/GIS	0	0	0
3D printing, 3D streaming, virtualization	0	0	0
Automation solutions (robotics, drones, distribution automation)	0	1	1
Social media	0	0	0
Minigrids/microgrids	0	0	0
Smart grid/smart metering/smart home	0	9	3
Virtual power plant	0	0	0
Intelligent distribution power router	0	0	0
Mobile applications, wireless networks, 5G networks	0	0	1
Others	1	3	2
Total	4	36	27

[1] Based on data available in Scopus.

Table 12. The impact of each type of technology in the energy field [1].

Type of Technology	Impact (Outcome)				
	Reducing Costs	Health, Safety, and Environmental Improvement	Process Improvement	Reducing Capital Expenses	Increasing Production
BDA, data mining, and machine learning	2	2	3	0	0
Cloud computing	1	1	1	0	0
Cybersecurity	0	1	4	0	0
Blockchain	0	1	5	0	0
Virtual reality	0	0	0	0	0
Digital twin	0	0	2	0	0
IoT	4	5	4	1	0
Artificial intelligence	1	1	3	0	0
Visualization	0	0	1	0	0
Robotics technologies (mobile robotics/autonomous mobile robotics)	0	0	0	0	0
Radio-frequency identification	0	0	0	0	0
CRM	0	0	0	0	0
Intelligent agents, agent-based system	0	0	0	0	0
Middleware technologies	0	0	0	0	0
Business intelligence (data warehousing)	0	1	2	0	0
Remote sensing/GIS	0	0	0	0	0
3D printing, 3D streaming, virtualization	0	0	0	0	0
Automation solutions (robotics, drones, distribution automation)	0	1	1	0	0
Social media	0	0	0	0	0
Minigrids/microgrids	0	0	0	0	0
Smart grid/smart metering/smart home	2	2	8	0	0
Virtual power plant	0	0	0	0	0
Intelligent distribution power router	0	0	0	0	0
Mobile applications, wireless networks, 5G networks	1	0	0	0	0
Others	1	1	3	0	1
Total	12	16	37	1	1

[1] Based on data available in Scopus.

In this case, the most-used technologies were smart grid/smart metering/smart home; blockchain; Internet of Things; cybersecurity; and BDA, data mining, and machine learning. Concerning the improvement of health, safety, and the environment, the Internet of Things technology was the most prevalent, followed by BDA, data mining, and machine learning and smart grid/smart metering/smart home technologies. All of these technologies have the ability to promote energy efficiency, security, carbon dioxide reduction, and improved quality of life.

3.3. Comparative Analysis: Web of Science vs. Scopus

In order to formulate appropriate conclusions regarding the main aspects of the digitalization process in energy production, distribution, and consumption, we considered an integrative comparative analysis between the articles published in the Web of Science and Scopus databases to be necessary.

Although the number of articles considered significantly differed, the dynamics of specialized publications were relatively similar in the databases. In both Web of Science and Scopus, the number of publications on the topic of digitalization in production, distribution, and energy consumption registered a slight quantitative jump in the period 2017–2018, while the period 2019–2020 marked an acceleration of the pace of publication in the field, with dozens of articles published annually and indexed in these two databases. Details regarding the evolution of the number of publications on the topic of digitalization in energy production, distribution, and consumption are presented in Figure 8.

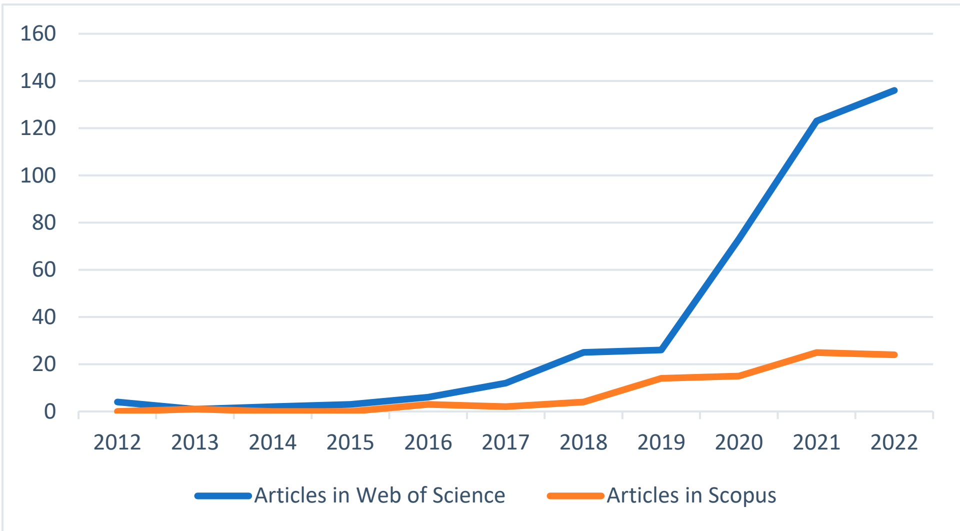

Figure 8. Evolution of the number of publications on the topic of digitalization in energy production, distribution, and consumption in the period 2012–2022 in the Web of Science and Scopus databases.

The situation was also relatively similar when considering the weight of the number of publications distributed in the field of energy consumption, according to Table 13. In the two databases, most articles had digitalization in energy consumption as their theme (more than half of all articles published during 2012–2022). There were also differences between the distribution of publications in the two databases. Thus, in Web of Science, publications focused on digitalization in energy production had a greater weight, while, in Scopus, there were more articles dedicated to digitalization in energy distribution.

Table 13. Sectoral share of the number of publications in Web of Science and Scopus [1].

Sector	Web of Science	Scopus
Production	33.09%	12.50%
Distribution	14.60%	32.95%
Consumption	52.31%	54.54%

[1] Based on data available in Web of Science and Scopus.

As can be seen from Figure 9, the impacts of digitalization in production, distribution, and consumption were approached relatively differently from the perspective of publications in Web of Science and Scopus. Notably, in the articles indexed in Web of Science, the main effect of digitalization in energy was health, safety, and environmental improvement, followed by process improvement; meanwhile, in the articles indexed exclusively in Scopus, the most important element of impact was process improvement, followed by health, safety, and environmental improvement. Cost reduction was the third most important effect of digitalization in production, distribution, and energy consumption for both databases, from the perspective of the number of published articles. In a smaller number of articles, increasing production and reducing capital expenses were indicated as impact elements.

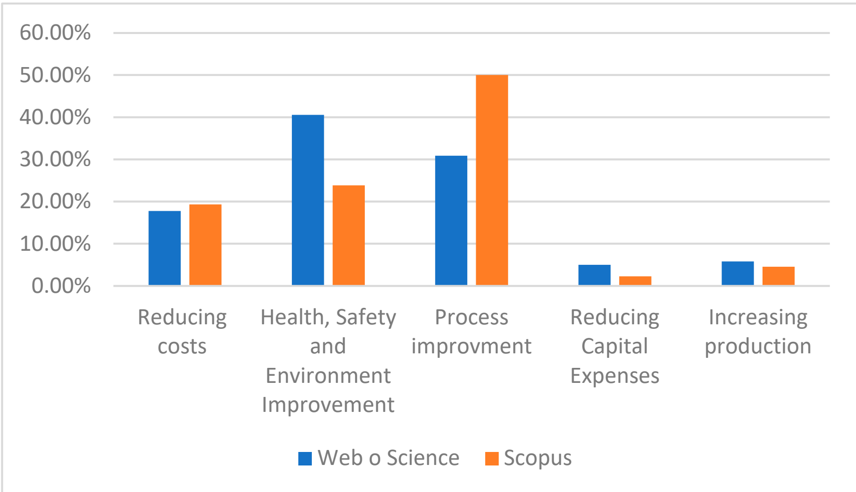

Figure 9. Impact of digitalization in energy production, distribution, and consumption in the Web of Science and Scopus databases for the period 2012–2022.

In both databases, there were articles referring to the technologies used. The most important technologies used, from the perspective of overall publications, are indicated for both databases in Table 14. It can be observed that, in both databases, smart grid/smart metering/smart home technologies had a very high weight (coming in second place for articles in both Scopus and Web of Science).

Table 14. The most important technologies used, from the perspective of publications indexed in Web of Science and Scopus [1].

Type of Technology	Web of Science	Scopus
BDA, data mining, and machine learning	17.37%	10.45%
Smart grid/smart metering/smart home	16.32%	17.91%
IoT	10.00%	20.89%
Cybersecurity	6.32%	7.46%
Automation solutions (robotics, drones, and distribution automation)	5.26%	2.99%

[1] Based on data available in Web of Science and Scopus.

Different technologies are represented in the two databases. Notably, Internet of Things technologies were mentioned twice more frequently in articles published in Scopus than in those in Web of Science, while BDA, data mining, and machine learning were mentioned much more frequently in articles published in Web of Science. Cybersecurity had a similar weight in both databases, while automation solutions were mentioned with greater frequency in the articles published in Web of Science. In the two databases, certain technologies were consistently mentioned less or not at all, including robotics technologies (mobile robotics/autonomous mobile robotics) and middleware technologies. These do not seem to have had a significant impact on energy production, distribution, and consumption to date, given the rate at which they are represented in publications in this field.

4. Discussion

The digitalization process, which has become increasingly prevalent over the last decade globally, is increasingly making its way into the energy sector, as well. The analysis carried out in this study, which took into account the most relevant articles indexed by the Web of Science and Scopus databases, indicated that, both over the last ten years as a whole and especially in the last five years, there has been a marked increase in the number of articles with the common themes of digitalization and energy, and this is a good indicator of the extent of the digitalization process in energy production, distribution, and consumption fields. This trend seems to confirm the results of previous studies which have revealed, through the impact of this subject in the specialized literature, the extent of the digitalization process [16,141].

The process of digitalization influences the entire value chain in the energy sector, from the acquisition of raw materials to the consumption of energy. The evolution of the number of published articles demonstrated that, from this perspective, the increase in scientific interest in digitalization is primarily reflected in terms of energy consumption. This can be explained by the advantages that the digitalization process brings to end consumers, with a reduction in cost being among the most visible. The concern for the digitalization of end consumers and regulatory authorities (through specific policies and strategies) has also been revealed by other studies in the literature [142]. On the other hand, digitalization in energy production has been especially treated from the perspective of renewable energies [115], energy efficiency [117], and improving energy production [118,119]. Digitalization is also increasingly influencing energy distribution processes. The impact of digitalization in the energy sector, namely on all components of the value chain, is most prominently materialized in health, safety, and environmental improvements, followed by process improvements and cost reductions. The results regarding the impact of digitalization related to publications indexed in Scopus and Web of Science confirm some previous results published in the literature [16]. Even if the order is not the same for the stages of production, distribution, and consumption, the potential impacts of new types of technologies specific to digitalization are relatively similar.

The results of the comparative analysis of the articles indexed in Web of Science and Scopus indicated that the most-used types of technologies are the same as those described in other studies [16], even if they did not follow the same ranking. In addition, compared to other previous studies, the number of articles analyzed here was much larger, leading to higher frequencies of digitalization-specific technologies that are also used in the production, distribution, and consumption aspects of electricity. Compared to other previous studies, the literature review presented in this article focused only on three stages of the value chain: production, distribution, and consumption. Other studies have additionally considered transaction or storage as specific stages. In our view, these can be easily integrated into the three stages considered here.

From the perspective of the impact of the main types of technologies used, there were small differences between publications indexed in Web of Science and Scopus. Although the typology of the synthesized effects was identical, in the case of certain technologies, health, safety, and environmental improvements prevailed as a potential major impact;

meanwhile, in the case of others, process improvement was the main effect. The dynamics of effects in different categories of publications also depended on the frequency/accuracy of their appearance in different articles. The fact that certain technologies did not appear in any of the articles seems to indicate that they have not yet been assimilated—even in an incipient form—into the production, distribution, and consumption of energy.

5. Conclusions

The main objective of the present study was to reveal the main particularities of digitalization in production, distribution, and energy consumption. The realization of the literature review involved the identification and analysis of the content of articles indexed in the Web of Science and Scopus databases. In the case of articles from Scopus, those that were also in Web of Science were removed, and articles indexed only in this database were taken into account.

The results of the literature review revealed that, from the perspective of the number of articles published and indexed in Web of Science and Scopus, the scope and dynamics of the digitalization process experienced accelerated growth both over the entire analysis period (2012–2022) and over the last five years in particular. Such a publication trend was identified both in the case of articles indexed in Web of Science and those indexed in Scopus. Furthermore, the increased interest in digitalization was evident for all considered components of the energy sector value chain (production, distribution, and consumption).

Our comparative analysis of the digitalization approach indicated that, in the context of articles indexed in Web of Science, the most significant impact was that regarding health, safety, and environmental improvement, followed by process improvement; meanwhile, in Scopus, the most important impact concerned process improvement. Another significant impact was the reduction of costs, especially as a result of the effects of digitalization processes in terms of energy efficiency and energy saving.

In the literature, the most frequently mentioned types of technologies in both databases were BDA, data mining, and machine learning; smart grid/smart metering/smart home; Internet of Things; cybersecurity; and automation solutions (robotics, drones, and distribution automation). Notably, in the case of energy production, distribution, and consumption, technologies specific to digitalization were found to be insufficiently explored and used. This was the case for robotics technologies (mobile robotics/autonomous mobile robotics) or middleware technologies, which were either not mentioned or mentioned in very few articles indexed in the Web of Science and Scopus databases.

Despite its scope and the large number of articles considered, the research carried out had certain limitations. Among these, the most important were the fact that not all the analyzed articles could be related to the considered types of technologies, certain types of impacts did not appear or appeared very rarely in publications targeting certain components of the value chain, and the multiple impacts of certain types of technologies used in the energy sector. All of these limitations, although having a relatively minor influence on the presented results, provide lines of research for future studies, particularly research focused exclusively on certain stages of the value chain and on future technologies.

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