Journal of Open Innovation: Technology, Market, and Complexity

MDPI

Article

Energy Sector Enterprises in Digitalization Program: Its Implication for Open Innovation

Yulia Valeeva [1], Marina Kalinina [1], Lilia Sargu [2], Anastasia Kulachinskaya [3,*] and Svetlana Ilyashenko [4]

1 Department of Economics and Production Management, Kazan State Power Engineering University, 420066 Kazan, Russia; valis2000@mail.ru (Y.V.); esp_mvkalinina@mail.ru (M.K.)
2 Department of Economics, University of European Studies of Moldova, MD-2001 Chișinău, Moldova; lsargu@mail.ru
3 Graduate School of Industrial Economics, Peter the Great St. Petersburg Polytechnic University, 195251 St. Petersburg, Russia
4 Base Chair of the Trade Policy, Plekhanov Russian University of Economics, 115093 Moscow, Russia; ilyashenko.sb@rea.ru
* Correspondence: a.kulachinskaya@yandex.ru

Abstract: The digital economy implies structural transformation in many industries, including the energy sector, without considering the state specifics of the industry, for which full-fledged digitalization can be harmful. The aim of the study is to develop a methodology and to determine the level of digitalization in the energy sector in an intercountry context. Based on the methods of comparison and analysis, the work analyses the concept of "digitalization" and defines the indicators applied to the assessment of digitalization. The developed methodology is based on the index method, which makes it possible to assess the rating of countries by the level of digitalization in the energy sector. The article discusses modern technological development and socio-economic aspects that determine theoretical research and the development of digitalization in the energy sector. The reasons and stages of digitalization in the energy sector are highlighted. Using the comparison method, the analysis of existing approaches to assessing the digital energy of enterprises is carried out. End-to-end technologies are highlighted, as well as their practical application at the enterprises of the energy sector. An analysis of the key areas for the development of digital energy is presented. Conclusions are made about the feasibility of developing microprograms and the main directions of digitalization are highlighted.

Keywords: digital energy; digitalization; industrial enterprises; stages of digitalization; barriers to digitalization; digital energy; open innovation

Citation: Valeeva, Y.; Kalinina, M.; Sargu, L.; Kulachinskaya, A.; Ilyashenko, S. Energy Sector Enterprises in Digitalization Program: Its Implication for Open Innovation. *J. Open Innov. Technol. Mark. Complex.* **2022**, *8*, 81. https://doi.org/10.3390/joitmc8020081

Received: 22 February 2022
Accepted: 25 April 2022
Published: 29 April 2022

1. Introduction

The transformation of the energy sector is currently affecting all energy systems of the countries of the world. Such a transformation is due to the implementation of the principles of sustainable economic development, since energy policy is associated with measures to ensure climate and energy sustainability, as well as socio-economic characteristics of a particular territory [1]. Accordingly, the main tasks of the energy sector are to ensure not only reliability, but also the economic, technological, social efficiency of the entire heat and energy saving of the country, and also to act as the key driver of the economic development of the territory. The main instrument of the tasks set is the innovativeness of the energy system, digitalization and integration of territorial production complexes, the involvement of consumers in a single energy system [2]. In conditions of the transition to the development of new sources of renewable energy, the issues of digitalization are becoming more relevant. According to the Global Wind Energy Council [3] in the world Energy, as of 2020, wind turbines with a capacity of more than 600,000 MB are installed; the main wind energy producers are China over 220,000 GB, the USA over 98,000 MB, and

Germany over 60,000 kg. International Solar Energy Association Wood Mackenzie Power and Renewables notes that more than 2.2 million solar power plants have been installed by 2020. At the same time, in the United States, it is planned that by 2023 this figure amounted to 4 million solar power plants. China is the world leader in the production of electricity from renewable energy sources: at the beginning of 2020 generation was about 800 GW—twice as much as in the United States, which ranks second in the world [4]. Therefore, the management of consumption over time is an important tool for the mobility of the energy sector in the framework of the implementation of programs that are renewable from electricity. Taking into account that the vector of many countries, especially European ones, is aimed at the development of renewable energy sources (RES), the ongoing studies made it possible to determine and evaluate the possibilities of combined or sequential use of solar and wind energy, depending on the characteristics of the territory with high spatial and temporal resolution, and the daily progress of the use of energy sources, depending on the month and on the time scale. The results obtained allow for optimizing the production of electricity and heat [5]. Research on the imitation of natural ways of converting wastewater into drinking water in the form of steam as an unconventional energy resource is becoming promising. In addition, the use of solar energy using advanced materials for the production of filters allows us to create new designs with photocatalytic filters for water purification [6].

Another important direction in the transformation of the energy sector is the expansion of the range of applications of solar energy in the food industry and other industries [7].

Countries with a high level of wind potential with state support allow the development of new innovative RES projects [8]. In the development of the energy sector, a large role is played by small companies that produce RES in areas with large wind potential. At the same time, when developing a strategy for transforming the energy sector, it is important to take into account internal and external factors and the problems of operating large and small energy enterprises [9]. The digitalization of production processes and the use of end-to-end technologies in the implementation of the above innovations will make it possible to minimize the costs of the energy sector and provide competitive services to end consumers.

For example, in [10], findings show that the global experience of digitalization is quite positive, including the creation of various information systems, but this does not cover the fuel and energy balance as a whole.

At the same time, it is important to keep in mind that digital development is associated with national culture, as well as the mentality of the population of a particular territory [11].

It is also worth noting that the energy sector requires new approaches to its arrangement due to increased requirements for environmental protection [12].

There are a number of works devoted to renewable energy sources [13–15], but they are also more informative and general.

Thus, the issues of the practical application of digitalization tools in the activities of enterprises in the energy sector, studies of transformation assessment are not enough disclosed in modern literature, which predetermines the relevance of this study.

The main purpose of the presented article is a comprehensive disclosure of the features of digitalization in relation to the energy industry, an assessment of the digitalization of the energy sector in the context of countries based on the developed methodology, and the identification of contributing and negative factors of digitalization.

The object of the research is the energy sector in a country context, and the subject of the research is the process of digital transformation.

The scientific significance of the presented study lies in the following provisions. The main stages and prerequisites for the digitalization of the energy industry are determined, its content and the resulting effects are indicated. Digitalization affects all areas of activity and involves the integration and transformation of the energy system, and allows an understanding of socio-economic effects (the authors proposed specific indicators). The study of existing approaches to the content of digitalization made it possible to determine the main directions of digitalization and the introduction of end-to-end technologies.

To develop activities and further directions of digitalization, approaches to studying the readiness of countries in this transformation are summarized. This has allowed the authors to single out five groups of indicators that give an objective assessment of the digitalization index of the energy sector of a particular country. Approbation of the methodology and the results obtained formed the basis of factor analysis with the allocation of limiting and contributing factors. The scientific transformation of the proposed methodology is the compilation of existing approaches, considering important components of digitalization such as human capital and environmental sustainability in the country.

In the digital economy, information, and methods of managing and using it are determinants of the efficiency and development of the real sector of the economy. The activities of the energy sector are directly related to other industries; therefore, the digital divide in agribusiness and energy enterprises occurs in all countries and is a pressing issue [16]. Digital imbalance in industry affiliation negatively affects the socio-economic position of the territory or the region under study [17]. Digital imbalances have a positive or negative effect on information flows and the establishment of communications in society, providing socio-economic consequences for these processes.

The growth in the use of digital technologies in the workplace leads to a demand for new digital skills in three areas (General ICT Skills, Professional ICT Skills, Complementary Skills) [18–21].

The results of the main prerequisites for digitalization were:

- Digitization of the current operating model. The most advanced companies are rethinking or building from scratch back-office processes to realize the potential of robotization: robotic automation of processes, digitalization of internal interfaces (“joints”) and interaction with the consumer, increasing the availability of data and their use in decision-making, digitalization of personnel management tools, and updating IT infrastructure. In power distribution, the first candidates for digital transformation are processes that involve many repetitive actions: connecting new consumers, maintaining the network, managing investments, equipment data, and losses [22]. Using advanced analytics, a company must have a plan to “cleanse” and standardize data collected from multiple sources. Sources and data models must be interconnected with each other.
- It is necessary to build up the competence of employees in the use of advanced analytics because the introduction of technologies, for example, “smart” counters [23], significantly increases the amount of data compared to manual collection, and in-depth analysis of these data cannot be carried out using standard tools (for example, Excel tables).
- Utilities should also partner with financial, e-commerce and telecommunications players in order to expand their portfolio of products and revenue streams. The diffusion and development of technologies depends on the specific region, on the availability of state support and the company’s willingness to invest.
- Important support for the existing system in order to add power generation capacity, continue the asset management strategy through big data analytics and centralize remote maintenance, ensure system stability in real time, automate, and digitize processes, implement customer interaction platforms, and use predictive analytics by customer, as well as offering smart home products and energy management services [24].

The article is divided into several parts as follows. In the first part, a literary review of the features of the energy sector transformation towards the development of RES, and an overview of digitalization tools, as well as the main prerequisites for the digitalization of the sector, are outlined. The second part presents the research methodology, data collection for the formation of a methodology for assessing the digital readiness of the energy sector of different countries. The results indicate the final values of testing the methodology. The discussion presents the achieved results differing from the existing studies. In the final part, the conclusions of the research are presented with further recommendations for promising areas for study.

2. Materials and Methods

This article uses general theoretical methods of scientific knowledge, such as synthesis, deduction, induction, and analysis, as well as a set of statistical and index methods. The comparison method made it possible to generalize the existing approaches to the essence of digitalization in the energy sector, the factors influencing its transformation and the system of indicators for its assessment.

Information base. Data from international energy and economic organizations (International Energy Agency, etc.); research by domestic and foreign scientists.

We will highlight the main stages of digitalization of energy sector enterprises and the resulting effects.

Having considered the prerequisites for the digitalization of an enterprise in the energy sector, we have identified 7 stages presented in Table 1, which indicates that digitalization is penetrating all the activities of enterprises. As part of the last 7 stage, a separate area that provides the initial basis for the digital transformation of the organization of production assets management is the implementation of production asset management (EAM) systems based on the creation of intelligent maintenance and repair (service) systems. Information subsystems for organizing product sales, organizing procurement activities, and document flow are also generally automated. At the same time, the main task of digitalization of an energy enterprise is the consolidation of information subsystems, avoiding disparate solutions, the creation of a unified system-platform for resource management, as well as logistic, contractual, planning and accounting analytics. The second task, no less important and allowing us to precisely declare the digital transformation of business, is the deep integration of systems. Taken together, these should not represent disparate platforms, but they should be very tightly integrated with the main core of resource management. The resulting synergistic effect of digitalization is global and is not limited to the considered narrow sphere of production, transport, distribution, sale, and consumption of energy resources. The goal of digital transformation is not in solving individual narrow-profile tasks, which were mentioned above, but in the onset of a new technological order that provides qualitatively new conditions for human life.

Table 1. Stages of digitalization of energy in Russia (developed by the authors).

Period, Years	Content of Digitalization	The Resulting Effect
1950–1960	The use of computers for solving applied industrial problems	Gradual transition from the fragmentary use of computers in solving individual engineering problems to systems
1970–1980	The first wave of industrial automation [25]	The tasks of operational planning have been solved
1980–1990	The emergence of personal computers	Expansion of functional tasks
1990–2000	Development of the Internet	Development of competitiveness, expansion of spheres of influence, interaction. Economic effect
2000–2010	Development of human-substituting technologies. Automation [26]	Current trends in the development of software and hardware. Reducing the amount of work required to produce certain goods and provide services

Table 1. *Cont.*

Period, Years	Content of Digitalization	The Resulting Effect
2010–2019	Transformations—growing advances in the development of advanced technological areas, including AI, robotics, blockchain, virtual and augmented reality technologies, and several others	Improvement of the technical base, the impact on the efficiency of the use of production assets and capacities, an increase in the share of materialized and a decrease in living labour per unit of output [27]
2019–present	Transition to the online format of managers and employees of the energy sector	Digitalization of business processes, which allows organizing the work of the energy grid's employees at a remote location [28]

3. Analysis

The energy sector has its own internal focus, and it is important to set digitalization objectives within the sectorial aspects. Therefore, Austrian researchers presented studies of the digitalization of the energy sector было [29] in relation to a hydroelectric power plant, highlighting digitalization in personnel management, big data for analysing the data of installed sensors using digital twins of stations, which allow prediction of the failure of important elements and components and for optimizing efficient operation. This makes it possible to increase labour productivity by 15% and reduce the number of employees by 3% (Table 2).

Table 2. Economic effect of using big data in energy (developed by the authors).

	Index	Interest
Big data	Increase in share price	2 times [26]
	Increased team satisfaction	40% [30]
	Reduced operating and capital costs	20% [31]
	Reduced investment	15%
	Extending asset life	10% [32]
	Ensuring the growth of revenue from core activities	10% [33]
	Increased staff productivity	10%
	Reduced maintenance costs	VL-10%, PS-20%
	Providing EBTDA Growth	30% [34]
	Increase in operating income	40%

The issues of digitalization of the Energy Sector are considered from different aspects. Thus, several scientists believe that digitalization should be viewed through the prism of 3–4 levels of physical, infrastructural and business [35–39]. In some works [36], it is indicated that the digitalization of energy is developing in 14 directions.

Based on the analysis of the literature, we will consider the main components and content of digitalization in the energy sector. According to the report of the National Research University "Higher School of Economics", digital transformation implies the sectorial principle of supporting the introduction of new technologies on the principle of introducing any and through the forced introduction of a variety of technologically diverse solutions that are in demand in a given sector of the economy or social sphere [40].

We agree with the materials of the Ministry of Energy of the Russian Federation, which indicate that digitalization makes it possible to manage complex energy systems. It contributes to the development of a wide range of new technologies and opens up access to the markets of the future [41,42].

Table 3 presents the main approaches to the content of digitalization in the energy sector.

Table 3. The essence of digitalization in the energy sector according to the criteria identified by the authors of the article (developed by the authors).

Criterion	Author	Summary Definition
Effective communication tool	Paul Michaelman [43]	The need for fundamental changes in thinking stereotypes, working methods, management of organizations
Competitiveness in digitalization	Paul Michaelman [43]	The organization uses digital technologies to update and diversify business processes
New business models connecting the physical and digital worlds	Dmitry Kholkin [44]	Smart machines are beginning to shape and use digital models of the physical world
Economic activity, commercial transactions and professional interactions built on new principles by using it	HSE Report [35]	The change and the development of a set of production, economic relations in the industry based on digital approaches and tools
Digitalization -	Anna Obukhova Ekaterina Merzlyakova Irina Ershova, Kristina Karakulina [45]	The process of introducing modern digital technologies into production process and enterprise management process;

Summarizing the above content characteristics of digitalization, in our opinion, one should understand the process of converting information and measurement results into a numerical format that allows processing, storing, and transmitting in electronic form, as well as the introduction of end-to-end technologies in management and the production process of an enterprise.

The scope of digitalization is wide enough. Summarizing the main directions of digitalization development in Table 3, we will draw the main conclusions:

1. Digitalization is an approach that aims to create a digital picture of the surrounding world, but in a format suitable for computer processing.
2. Digital twins—a constantly updated digital model of an object, which receives data from special sensors, it becomes possible to simulate its behaviour in the real world to help save resources. This helps to improve the quality of the product, reduce costs, time costs, and promptly meet customer requirements.
3. The factory of the future is based on the "communication" of smart equipment and all systems of the enterprise with each other: each object receives its own digital model and provides data transmission. This allows us to move to a completely new state of production—the Industrial Internet of Things (IIoT)—which is being actively developed all over the world.
4. Technologies based on cyber-physical solutions and full automation of production are the basis of the next industrial revolution—Industry 4.0. The world of the Internet of Things (IoT) implies the ability to influence physical objects by changing their digital counterparts.
5. The development of a smart grid approach to systems for the production, transport and distribution of heat energy through the "Thermis" software and hardware complex developed by "Schneider Electric" is a combination of GIS and SCADA by means of mathematical modelling in real time determines the optimal temperature of the coolant supply to the network and allows, by fine-tuning the pressure and flow rate,

to further reduce losses while ensuring uninterrupted heat supply to consumers (Table 4).

Table 4. End-to-end digitalization technologies in the energy sector (developed by the authors).

No.	End-to-End Technologies	Practical Use
1	The emergence of a digital platform in any industry significantly reduces transaction costs [46]	The displacement by machines of ineffective transactions requiring routine human participation from economic and social life
2	Smart grid approach to heat production, transport, and distribution systems [28]	Implementation of smart heating network, metering, and metering possibility of expanding the range of services provided to consumers
3	Internet of Big Things Shindler Group [47]	A system for monitoring physical objects via the Internet, collecting data on the base of installed equipment in real time. Based on the information collected, specialists improve the quality of their products
4	Machine learning [48]	One of the most effective and rapidly developing solutions to the problem of processing an ever-increasing amount of data
5	Electronic identity [49]	Significant potential to simplify several processes in energy markets
6	Digital coordination [50]	Coordination of energy market participants
7	Application programming interface [51]	Key element of automated integration of control systems, data collection and analysis
8	Blockchain [52,53]	Simplifying and expanding the integration of renewable energy and electric vehicles
9	Cybersecurity [54]	Safe implementation of digitalization tools
10	Digital design, mathematical modelling and product or product lifecycle management (Smart Design) [55]	These technologies are used for the design and operation of complex technical facilities, such as fields, power plants, etc. Digital twins optimize the operation and maintenance of infrastructure. The level of use of this technology will increase significantly
11	Smart Manufacturing Technologies [55]	Automation systems (ERP, MES, MDM) and lifecycle management technologies for energy infrastructure facilities. They allow integrating the work of all participants in a single environment, including production facilities, design and construction companies, and service companies
12	Manipulators and manipulation technologies [55]	Manipulators in the power industry are used at complex facilities, where work is associated with high risks for workers, as well as in the event of accidents and incidents
13	TK sensors and digital components for human-machine interaction	Extraction of energy resources and maintenance of energy infrastructure facilities (for example, hydroelectric power plants) can be associated with high risks for personnel, interfaces for human–machine interaction can be used, which expand the control of the use of robots
14	Computer vision [56]	Automation of control over the fulfilment of safety requirements by power plant personnel and employees servicing power lines. Based on computer vision, the survey by robotic systems of rooms and areas of quarries, deposits, pipelines, power lines and power plants to search for various kinds of problems, especially in places that are dangerous or inaccessible to people
15	Natural language processing [57]	With the help of neural networks, they provide monitoring of objects and transport (transfer) of energy resources, as well as the identification of emergency situations due to an accurate analysis of the characteristics of an information message, their preliminary processing, and the formation of an event identification model. Automation of supporting processes using chatbots, which requires specialized dictionaries
16	Speech recognition and synthesis [58]	"Freeing" the hands of a worker who is at high-altitude work on a power transmission tower or in a mine, who needs to simultaneously record any information

Table 4. *Cont.*

No.	End-to-End Technologies	Practical Use
17	Recommender systems and intelligent decision support systems [59]	Used to optimize the distribution of electricity to networks and consumers, to manage capacities for storing and transporting electricity, to monitor equipment operation and to repair it "as it is", in order to optimize the processes of extracting fossil energy resources and to reduce downtime in the operation of mining equipment
18	Advanced AI methods and technologies [60]	Using smart sensors and other devices, data from objects and mathematical models for making decisions based on AI technologies. The Internet of Energy allows for flexible interaction between consumers and energy suppliers, including without human intervention. AI can reduce the volatility of electricity generation from renewable sources, improve forecasting of electricity generation (based on weather data), supply and demand, as well as improve the efficiency of energy infrastructure facilities, including micro grids

Thus, the accelerated development of digital technologies and the observed leap towards Industry 5.0, based on the synergy of man and machine [61], creates new challenges to increase the sustainability and efficiency of electricity production. The main factor in the development of Industry 5.0 is the adaptation of existing digital technologies to the individual needs of consumers.

4. Results

Currently, quite a few models have been developed for assessing the digitalization of countries. To identify the most general and priority areas of assessment, we will summarize a number of approaches (Table 5).

Table 5. Approaches to the study of the level of readiness of digitalization of objects [62].

An Approach	Description
MIT Digital Business Center	Based on the analysis of more than 400 large companies from various industries, three key areas of digital transformation were identified: customer experience (Transforming Customer Experience), operational processes (Transforming Operational Processes) and business models (Transforming Business Models) [21]
Digital maturity model	Deloitte [22] 27 assesses digital opportunities on 5 key dimensions: consumers, strategy, technology, production, structure, and culture of the organization (Customer, Strategy, Technology, Operations, Organization and Culture). The five main dimensions are subdivided into 28 sub-dimensions, which in turn are broken down into 179 metrics against which digital maturity is assessed. The emphasis is on the Business Strategy, which determines the focus of the transformation
Digital Transformation Index	(Digital Transformation Index), developed by the analytical agency Arthur D. Little, has a greater number of enlarged areas of assessment [24]: (a) strategy and leadership (Strategy and Governance); (b) products and services (Products and Services); (c) customer management; (d) Operations and Supply Chain; (e) corporate services and control (Corporate Services and Control); (f) information technology (Information Technology); (g) Workplace and Culture
Model for assessing digital abilities	(Digital Business Aptitude—DBA) by KPMG [63] combines 5 areas of assessment: Vision and Strategy, Digital Talent, Digital First Processes, Agile Sourcing and Technology, Governance
Digital piano	Similarly to 7 notes, 7 transformation categories (Transformation Category) are distinguished, which make up the most important elements of the organization's value chain: business model (Business Model), organizational structure (Structure), employees (People), processes (Processes), IT capabilities (IT Capability), Offerings, Engagement Model [3]

Having considered in detail the above methods, we will define an algorithm for assessing the digitalization of countries' readiness using the index method. For a more complete assessment, it is proposed to divide the system into 5 groups of indicators.

Table 6 shows the approaches to the study of the level.

Table 6. The system of indicators for assessing the readiness for digitalization of countries in the energy sector (developed by the authors).

Indicator	Index	Source of Information
Human capital	The total number of educational institutions in the subject area of Engineering Electrical and Electronic in the top 500 of the ranking, pcs	THE https://www.timeshighereducation.com/world-university-rankings (accessed on 22 August 2021)
	Share of jobs in the MRE segment (including renewable energy sources with hydropower) of the total labour force, %	IRENA Industry Associations https://www.irena.org/ https://www.np-sr.ru/ru/organizacii-informacionnogo-fonda/mezhdunarodnoe-agentstvo-vozobnovlyaemoy-energetiki-irena (accessed on 19 August 2021)
Reliability and quality of power supply	SAIFI (Average System Outage Frequency Index)	World Bank https://www.worldbank.org/ (accessed on 18 August 2021)
	Share of spare capacities in total energy capacities	World Energy Yearbook https://yearbook.enerdata.ru/ (accessed on 17 August 2021)
Availability of electrical energy	The ratio of the average wage in the country (net) to the price of energy efficiency for the population, $/kW * h	State Statistics Service of Enerdata countries https://yearbook.enerdata.ru/ (accessed on 22 August 2021)
	Availability of fuel and energy for the population	Federal Statistical Authority https://yearbook.enerdata.ru/ (accessed on 22 August 2021)
Operational and investment efficiency	Global world ranking of countries and territories in terms of foreign direct investment in nominal (absolute) value, expressed in US dollars at current prices (the rate of change in the value of the indicator from the reporting period to the previous one).	• World Bank Group • International Monetary Fund • United Nations Conference on Trade and Development (UNCTAD).
"Environmental sustainability and political and infrastructural readiness of the country for digitalization", the environment today, first of all, forms the political image of the country, which is necessary	CO_2 emissions per capita, t/person	World Bank https://www.worldbank.org/ (accessed on 22 August 2021)
	Regulatory indicator for sustainable development in the field of renewable energy,	Transparency International https://transparency.org.ru/ (accessed on 21 August 2021)
	Energy intensity of GDP	World Justice Project https://worldjusticeproject.org/ (accessed on 20 August 2021)

Group 1—"human capital", characterizes the level of professional industry training and the structure of labor force employment in the energy sector, the more people are employed in this industry, the higher the level of emergence of industry transformation initiatives;

Group 2—"reliability and quality of power supply", the lower the reliability, the more difficult it is to make a decision on any reforms without solving the main problems of the industry;

Group 3—"availability of electrical energy", the higher the prices for electrical energy, the lower the competitiveness of the economies, which means that it is easier to decide for transformation. For the population, the issue of access to energy efficiency is also important, and for business, the inertia of connecting new consumers is low;

Group 4—"operational and investment efficiency", the development of MRE provides an incentive for the emergence of new players in the market of generating companies for which debt financing is important. In addition, it is difficult to develop the energy sector of the new paradigm without foreign investment; the country's openness in this matter is also assessed;

Group 5—"environmental sustainability and political and infrastructural readiness of the country for digitalization", the environment today, first of all, forms the political image of the country, which is necessary. "Structure of the electric power system", it is easier to start digitizing the industry; on the other hand, in the absence of a sufficient volume of large-scale gas generation and hydro generation, problems may arise in balancing the electric power system. Without the desire to create a new regulatory framework, transformation will not happen, just as without equal conditions for the vision of business for all potential investors.

The main advantage of this technique is the selection of a set of indicators, the value of which is determined centrally, publicly presented on the websites of economic regulators and official statistical bodies. In addition, the human factor, and indicators of sustainable development of territories, are taken as important points. In determining a set of indicators, the approach was partially used [62].

To build an integral index of digitalization of countries, you first need to find the partial indices for each region in the five blocks indicated above.

For this, the indicators are normalized. Since they are all calculated as a percentage, rationing is made according to the formula

$$UGTij = Xij/100 \quad (1)$$

where

UGTij—private index of the i-th block for the j-th region;

Xij—indicator of the i-th block for the j-th region.

Since the analysis uses data for 2016–2020 years, after standardization of indicators for all years, the average private index is calculated for each country in five years as an arithmetic mean. To obtain the integral index of digitalization of the country (IC), the average partial indices obtained for five blocks are summed up. Furthermore, countries are ranked based on the obtained value of the overall digitalization index. The larger it is, the higher the country is in the ranking. Evaluating the results of calculations of the integral index of digitalization by country, they can be ranked.

As part of the approbation of the proposed methodology, at the first stage, the calculations of indicators were made in the period from 2016 to 2020. This is based on the official data, presented on the websites of organizations and rating agencies. Then, at the second stage, the arithmetic means are calculated at a specific indicator, the results of which are presented in Table 7.

UHC is an integral indicator for assessing the readiness of countries for digitalization in the energy sector, obtained by the index method; Cheka is an indicator of human capital; NDE—indicators of reliability and quality of power supply; DEE—indicator of the presence of electrical energy; OIE—indicator of operational and investment efficiency; EH is an indicator of environmental sustainability and political and infrastructural readiness of the country for digitalization.

Table 7. Data for calculating the integral indicator of readiness for digitalization of the energy sector of the countries of the 1st group (developed by the authors).

	UHC	Cheka	NDE	DEE	OIE	EH
Switzerland	4.27	0.98	0.74	0.78	0.95	0.82
Sweden	4.24	0.96	0.77	0.76	0.94	0.81
Canada	4.16	0.91	0.77	0.75	0.93	0.8
UAE	4.08	0.87	0.76	0.72	0.93	0.8
Singapore	4.02	0.88	0.72	0.72	0.91	0.79
France	3.99	0.90	0.72	0.7	0.91	0.76
New Zealand	3.86	0.81	0.7	0.7	0.89	0.76
Czech	3.82	0.78	0.69	0.71	0.89	0.75

Table 8 shows the results of the group indicators, as well as the sum of these indicators, the integral indicator of the digitalization readiness of the energy sector in the countries that are in the first group was calculated.

Table 8. Results of the rating of readiness for digitalization of energy of countries in three groups (developed by the authors).

1st Group	UHC	2nd Group	UHC	3rd Group	UHC
Switzerland	4.27	Finland	3.81	Korea	4.05
Sweden	4.24	United Kingdom	3.8	Azerbaijan	4.03
Canada	4.16	USA	2.79	Belarus	4
UAE	4.08	Dinoy	3.77	Slovenia	3.98
Singapore	4.02	Portugal	3.74	Irak	3.91
France	3.99	Spain	3.72	Kazakhstan	3
New Zealand	3.86	Russia	3.7	Indonesia	3
Czech	3.82	Australia, etc.	3.69	Uzbekistan, etc.	2.9

The energy industry as one of the components of the real sector of the Swiss economy is a highly digitized point. This is confirmed by the third position in the international ratings of the IMD World Digital Competitiveness Rating (2020).

Switzerland is a leader in the implementation of green energy in the provision of smart cities. This result allowed us to take a leading position.

In second place Sweden. Sweden is one of the leading countries in the field of digitalization, which has become the main driver of the country's economic development in recent years. The share of value added by the information and communication technology (ICT) sector in Sweden is one of the highest among the OECD countries; moreover, the country is one of the ten largest exporters of ICT services in the world.

Canada is in third place. Nuclear energy is an important part of Canada's energy sector. Few know that Canadian nuclear power accounted for about 4% of global nuclear energy production in 2018 (sixth largest in the world). This is in a country where about 0.5% of the world's population lives. Here are 10 interesting facts about nuclear power in Canada: 1. Canada has several nuclear reactors. Today, 19 of the 22 nuclear power reactors built in Canada are in operation and located at several stations, mainly in Ontario.

United Arab Emirates—fourth place. The UAE government has made digitalizing its economy a priority in order to improve government efficiency, industry creativity and in order to provide international leadership. The UAE ranks first among the Arab countries of the Middle East and North Africa in terms of digital adaptation. According to this indicator, the Emirates are approaching the advanced states of the world. In addition, the UAE has the highest level of digital identity, which is measured using various indicators, such as access to services, electronic signature, etc.

Singapore is in fifth place. Singapore is on the heels of the leaders of the Asian venture capital market. $324 million was the volume of venture capital investments in Singapore last year, which is almost 10 times more than in Hong Kong, at $37 million. According to the Asian Venture Capital Journal, $5.5 billion was invested by venture investors in China by the end of the first half of 2015. Singapore is still far behind both China and India with $3.3 billion in venture capital investments. If, for example, in Singapore, such a transition took place in the first half of the 1960s, then in Malaysia, Thailand, the Philippines and Indonesia—and in the 1980s in Vietnam and China—this took place in the 1990s and in Cambodia, Laos and Myanmar in the 2000s (Table 8).

France—sixth place. France is one of the leaders in digitalization. France already has a well-developed traditional infrastructure: roads, water lines, housing, and communal services and even parking spaces. However, the state is not going to stop there and is now engaged in the development of digital infrastructure, hoping to increase productivity, create new jobs and improve the quality of life of its citizens in general.

As part of the approbation of the methodology, at the first stage, the primary indices or indicators were calculated for each country for the period from 2016 to 2020. These analytics were carried out for 30 countries, and three groups of countries under study were identified.

The first group includes countries with an integral indicator from 3.8 to 5.2. These are countries with a high level of preparedness for digitalization, having the results of digital projects with a high level of economic efficiency in the field of energy.

The second group is from 3.65 to 3.8. This is a group with an average level of readiness for digitalization of enterprises in the energy sector of the countries. At the same time, they have positive results in the development of digitalization projects for enterprises in the energy sector.

The third group is less than 4.05. The third group includes countries with a low level of digitalization. There is great potential, but perhaps insufficient funding and support from the state in the implementation of digital projects in the energy sector.

Russia took 23rd position in terms of the level of digitalization in the Energy Sector. In Russia, as in leading countries, large companies are the leaders in digitalization. In contrast, small- and medium-sized enterprises (SMEs) are lagging behind in adopting new digital solutions. In general, highly concentrated industries dominated by large businesses with access to significant investment resources are showing greater progress in digitalization. At the same time, in various industries, the introduction of digital technologies, and even more so digital transformation, require different investments, including in terms of volume and in the timing of implementation. Digitalization of energy is associated with the proliferation of distributed smart energy systems and corresponding resource consumption patterns. In the electric power industry, one of the features is the uneven consumption of electricity. New digital solutions for managing energy systems and distributed energy technologies help balance supply and demand more efficiently and quickly and distribution of energy AI is most widely used by organizations in the mining complex (66.7%), the financial sector (46.4%), and in the energy sector (40%). In the electric power industry, digital transformation is aimed at improving the reliability of power supply, limiting the rise in electricity prices, as well as developing new formats (services) of interaction with consumers. The focus in this segment is the phased formation of smart grids at the national and local levels. Energy generation, distribution, transmission, and consumption are monitored in real time thanks to smart devices, and energy suppliers and consumers are testing various 'demand management' schemes. Moreover, projects are being implemented in the field of management and monitoring of the reliability of power supply. Platforms are being created for the collection, processing and use of big data (for applied and research purposes); the tasks of predictive strategic and investment planning are being solved [64].

At the same time, it is possible to single out factors that contribute to and negatively affect digitalization in the energy sector (Table 9).

Table 9. Factors contributing to, and negatively affecting, digitalization in the energy sector (developed by the authors).

Constraints	Contributing Factors
Illiterate expenditure of working time [65]	Improving the quality of life
Enhanced control at various nodes of the enterprise	The emergence of economic and social effects
Job cuts	The emergence of human substitutes control systems
Redefining familiar business models [66]	Emergence of new business models
Not fully ready for digital solutions	Ensuring accessibility in the promotion of goods and services
Lack of qualified employees [67]	Increasing the transparency of economic transactions and ensuring the possibility of their monitoring

Within the framework of this study, an analysis of the economic effects was carried out that allows one to obtain digitalization in the energy sector. These results are presented in Table 10.

Table 10. Table of results of digitalization in the energy sector (developed by the authors).

Direction	Results
Intelligent consumption management [68]	In 2014, the market was estimated at $5 billion, the prospects for an increase by 2020—5 times
Integration of renewable energy sources [69]	The increase in the share of renewable energy sources in the balance will require greater inter-system integration with the expansion of the use of digital technologies
Intelligent charging of electric vehicles	Smart charging is impossible without digital infrastructure. It will reduce the power required for EV by 2040 from 140 to 75 GW (assuming the number of EVs is 150 million)
The emergence of low-power distributed power sources	Digitalization will allow integrating sources using technologies such as: blockchain, microgrids and virtual power plants
Virtual Power Plants	RES, in combination with batteries, by using digital technologies, can ensure the reliability of power supply
Intelligent grids [65]	Reduce the need for the construction of standby power plants, expand the possibilities for the integration of renewable energy sources and reduce the need to turn them off during periods of excess generation
Blockchain	In the future, it seems possible to create a self-regulating, autonomous, and self-balancing power system with millions of producers and consumers and automation of payments through microtransactions
Intelligent consumption management [66]	Dynamic variable rates are better suited for load management than rigid variable rates

In addition to the existing methods, this study made it possible to clarify and determine the level of readiness for digitalization in the energy sector in different countries. At the same time, it should be noted that it is scientifically significant in that this methodology allows one to assess not only the level of digitalization, but also the degree of readiness of the country. In the long term, the country can increase these indicators, because the rating data are a potential result in the further development of digitalization of the industry under study. The main object of the study was Russia, which takes a confident position on the degree of readiness point. It is important to note that the study of this aspect requires a further consideration of the comma, including in the context of specific regions of the studied countries, in order to develop appropriate management decisions and in order to conduct effective analytics.

5. Discussion, Open Innovation in Energy Sector with Digital Transformation

Connection of innovations and digital activity of enterprises in the energy sector. Considering the features of the innovation of energy companies, it should be noted that innovations can provide a certain breakthrough in the emergence of new areas of activity, expanding the accumulated positive experience, which allows for a high level of development of society, the basic values of an individual or employees of an organization, and an increase in the competitiveness of enterprises in the sector. Digitalization is one of the tools used for innovation. It is important to note that the analyzed countries are at different stages of the energy sector digital transformation. The results of a country's digital readiness assessment indicate that the first group of countries were leaders in introducing innovations into the activities of energy companies, including the digitization of production and management processes. Tutak, M. and Brodny, J. conducted an assessment of the digital maturity of countries on the implementation of industry 4.0 technology. The study was of a global nature and concerned the entire real sector of the economy. In the presented analytics of the article, the focus is on the indicators of the energy sector country's digital readiness [70].

However, it should be noted that the results of the evaluation of the first group of countries coincide. Sweden and Finland are leaders in the digital maturity of their economies, as indicated by our results in the energy sector. The leaders are Western European countries with extensive experience in implementing digital technologies, innovations, and in changing corporate culture. The most common implemented technologies of Industry 4.0 are the Internet of things, artificial intelligence. Germany (4.06) belongs to the first group and has a high level of digital readiness of the energy sector. This is due to such factors as the introduction of state support for digital transformation in the Digital Energy Program for 2008–2013. In 2016, the law "On Digitalization" was introduced. Since 2018, innovation days have been held, at which the best results of digitalization in the energy sector are presented. If we consider the results of digitalization in dynamics, then in 2009 the NEXT virtual power plant was introduced; in 2013—cloud technologies by the Senec power plant; in 2014—Freinhofer cybersecurity; in 2017—Leonism trading; in 2018—business process automation E.ON etc. [71].

We note the correlation of the digital readiness of the energy sector with the assessment of the efficiency of the energy infrastructure of countries presented in the study by M.Yu. Shabalov and co-authors. The level of infrastructure development was assessed through the degree of use and implementation of renewable energy, the level of use of information technologies, digital technologies, the quality of materials science and the modernity of energy equipment, the introduction of energy-saving technologies and the share of non-renewable energy.

The US and Canada are in the best positions, as there is a high level of investment in the energy sector, and a low depreciation of the energy infrastructure, respectively. The investment gap is much larger compared to Russian companies. The second position is occupied by Asian countries, which have a lower level of depreciation in their energy infrastructure than the United States, but at the same time they have high investment needs, so there is a large infectious gap in the energy sector [72]. This means that the level of digitalization correlates with the level of equipment cost and digitalization of the organizational processes in the energy sector.

The results of the China energy digital readiness assessment are supported by studies on the implementation of open innovation for the energy efficiency of the industrial sector. Foreign direct investment plays an important role in the implementation of these projects, which, in turn, has a positive effect on the sustainable development of the country [73].

The high level of digitalization of European countries in the context of the energy sector correlates with studies that the ongoing institutional policy of financing R&D and innovation plays an important role, which makes it possible to ensure the efficiency of innovative systems of enterprises [74], also in relation to solar and wind energy projects [75].

Eco-innovations, meanwhile, are a kind of springboard for the transition to renewable energy sources. A study of the countries of the Organization for Economic Cooperation and Development confirms that the economic growth of the country depends on the development of highly qualified human capital to ensure an increasing share of the consumption of renewable energy sources, the introduction of innovations and the digitalization of business processes [76]. Technological innovations as an exogenous element of energy demand ensures the energy efficiency of Malaysia and confirms the level of digitalization of the country's energy sector [77].

At the same time, it should be noted that the open innovation paradigm is confirmed by the need to involve all stakeholders engaged in the implementation of energy efficiency projects in the industrial sector of the economy. Studies show that those companies that use open innovation tools are more likely to use them effectively and get more economic opportunities for successful activities [78]. It is the cooperation of the energy sector that makes it possible to obtain the maximum effect in the implementation of four such components as open innovations, innovative business models, non-productive innovations and openness of achievements. Therefore, the joint design and creation of projects for the introduction of innovations in the energy sector predetermine the relevance of international partnership for the energy transition [79].

The concept of Chesbrough, presented in 2003, is universal and is applicable to various industries, but the practice of its implementation in the energy sector shows the importance of collaboration and innovation management. A good help is the introduction of digital end-to-end technologies [80].

At the same time, the facts show that the regional disproportion of resource intensity does not allow the effective attracttion of talent, the effective introduction of innovation or any guarantees concerning the the qualitative development of the Chinese energy sector [81]. Inconsistency is also observed in the implementation of innovations by large Danish energy companies through the prism of conflicts and competition between various stakeholders. Their policy is aimed at introducing environmentally friendly technologies with open innovation tools, involving the maximum number of participants, information exchange, as well as coordination and control [82]. Open innovation involves collaboration in international, regional, and local enterprise partnerships. The results of studies of partnerships in countries such as the Netherlands, Spain, Germany, and the United Kingdom have demonstrated the effectiveness of the implementation of joint projects to introduce renewable energy sources in the field of solar energy. Another good example of partnership is the energy sector enterprises of Japan, Italy, South Korea, France, USA, which are leading researchers of international cooperation in solar energy projects [83]. When developing their strategy, a significant number of external factors are taken into account, a large amount of information sources is studied. In addition, joint projects in the field of solar energy and wind energy are being implemented. This allows intensive use of a sufficient number of external sources [84–86].

6. Conclusions

6.1. Theoretical and Practical Implication

Within the framework of this study, the relevance and importance of studying the readiness of countries for the digitalization of the energy sector is highlighted. The conducted analytics made it possible to identify the main prerequisites for the digitalization of the energy sector. In addition, highlight 7 stages of digitalization of energy in Russia, indicating the resulting effects and the content component of digitalization. Big Data analytics is one of the digitalization tools. Therefore, the paper presents the possible economic effects from the use of this tool in the energy sector. For the development of the categorical apparatus of the problem under study, the main criteria and approaches to the content of digitalization in the Energy Sector are highlighted, considering Russian and foreign scientists. The work identifies five main areas of digitalization, including end-to-end technologies. In total, 18 tools are highlighted, and their practical application is indicated. At the second stage, in the development of methodological aspects of digitalization in the Energy Sector, several approaches to assessing digitalization are outlined. There were highlighted five groups of indicators, which, in our opinion, will be able to give a real assessment of the country's readiness for digitalization in the energy sector; the corresponding indicators are also highlighted, which are based on data from rating agencies and analytical centers in open information. Based on the comparison method, the article presents several approaches of various countries in order to implement digitalization in their energy administration. In addition, the factors contributing or negative to the development of digitalization in the Energy sector are highlighted.

Modern trends in the transformation of the economy real sector are subject to the principles of implementing Industry 4.0 technologies. The conditions of instability of pandemic processes, globalization processes, and high levels of digital activity predetermined the need to study the energy sector of countries' digital readiness, the results of which can form the basis of a digital development strategy for an enterprise in the sector.

6.2. Limits and Future Research Topics

The presented article outlines the analysis results of the countries' digital readinesss. A high level was noted in the energy sector of the EU countries, Canada and Scandinavian countries and a low level was noted in the countries in the post-Soviet space and in developing countries. The digital divide is associated, first of all, with a large gap in the levels of investment in modernization, innovation, and digitalization of the energy sector enterprise. The energy sector of the first group in terms of digital maturity levels received a lot of government support through the implementation of government programs. For example, in the UK, a digital strategy was introduced in 2017, in Germany in 2017 an initiatives to create smart grids, data storage systems, etc. have been supported.

Of great importance is the work of agencies and associations whose activities are aimed at the development of energy clusters and the introduction of digital communications. Project activities of research institutes allow the development and successful implementation of successful projects related to big-data, digital sensors, digital twins, digital surveys, implementation of smart city tools, etc. In addition, the largest corporate projects related to the introduction of digital platforms are being implemented, and master classes in the field of electric power industry, mobility of digital thinking are being implemented. Start-up incubators are being developed for the efficient operation of enterprises in the value chain of the energy sector.

The presented analytics also made it possible to determine possible results in the energy sector when introducing digitalization into the production processes of an energy company. Thus, further research will focus on detailed consideration and highlighting of internal and external factors that will ensure higher levels of preparedness of countries for digitalization. The study helped us to identify the leading countries in terms of the level of digitalization in the energy industry, which can positively influence countries with a low level of digitalization, as well as the development of mechanisms and tools for digitalization in the industry.

In conclusion, we express the hope that all the scientific approaches we have proposed and the methodological developments that have been made will find a practical application for the development of the energy industry. Prospects for further development of the topic consist of developing methodological tools for the digital development strategy of countries with a low level of digitalization in the energy sector, conducting factorial digital analytics of the contributing factors for the development of the industry and building a forecast for the future.

Author Contributions: Conceptualization, Y.V. and M.K.; methodology, L.S.; validation, Y.V., M.K. and L.S.; formal analysis, S.I.; investigation, L.S.; resources, M.K.; data curation, Y.V.; writing—original draft preparation, Y.V.; writing—review and editing, M.K.; visualization, L.S. and A.K.; supervision, S.I.; project administration, A.K.; funding acquisition, A.K. All authors have read and agreed to the published version of the manuscript.

Funding: The research is partially funded by the Ministry of Science and Higher Education of the Russian Federation under the strategic academic leadership program 'Priority 2030' (Agreement 075-15-2021-1333 dated 30 September 2021).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Tutak, M.; Brodny, J.; Bindzár, P. Assessing the Level of Energy and Climate Sustainability in the European Union Countries in the Context of the European Green Deal Strategy and Agenda 2030. *Energies* **2021**, *14*, 1767. [CrossRef]
2. Mohamued, E.A.; Ahmed, M.; Pypłacz, P.; Liczmańska-Kopcewicz, K.; Khan, M.A. Global Oil Price and Innovation for Sustainability: The Impact of R&D Spending, Oil Price and Oil Price Volatility on GHG Emissions. *Energies* **2021**, *14*, 1757.
3. Global Wind Energy Council. Global Wind Report 2021. Available online: https://gwec.net/global-wind-report-2021/ (accessed on 12 October 2021).
4. The National Energy Administration Released Statistics on the National Power Industry in 2020. National Energy Administration Large, Medium and Small on 20 January. Available online: http://www.nea.gov.cn/2021-01/20/c_139683739.htm (accessed on 10 October 2021).
5. Miglietta, M.M.; Huld, T.; Monforti-Ferrario, F. Local Complementarity of Wind and Solar Energy Resources over Europe: An Assessment Study from a Meteorological Perspective. *J. Appl. Meteorol. Climatol.* **2017**, *56*, 217–234. Available online: https://journals.ametsoc.org/view/journals/apme/56/1/jamc-d-16-0031.1.xml (accessed on 20 March 2022). [CrossRef]
6. Verma, S.K.; Singhal, P.; Chauhan, D.S. A synergistic evaluation on application of solar-thermal energy in water purification: Current scenario and future prospects. *Energy Convers. Manag.* **2019**, *180*, 372–390. [CrossRef]
7. Jia, T.; Dai, Y.; Wang, R. Refining energy sources in winemaking industry by using solar energy as alternatives for fossil fuels: A review and perspective. *Renew. Sustain. Energy Rev.* **2018**, *88*, 278–296. [CrossRef]
8. Adami, V.S.; Júnior, J.A.V.A.; Sellitto, M.A. Regional industrial policy in the wind energy sector: The case of the State of Rio Grande do Sul, Brazil. *Energy Policy* **2017**, *111*, 18–27. [CrossRef]
9. Liu, S.-Y.; Ho, Y.-F. Wind energy applications for Taiwan buildings: What are the challenges and strategies for small wind energy systems exploitation? *Renew. Sustain. Energy Rev.* **2016**, *59*, 39–55. [CrossRef]
10. Novikova, O.; Vladimirov, I.; Bugaeva, T. Expansion of the Fuel and Energy Balance Structure in Russia through the Development of a Closed-Loop Recycling. *Sustainability* **2021**, *13*, 4965. [CrossRef]
11. Rubino, M.; Vitolla, F.; Raimo, N.; Garcia-Sanchez, I.M. Cross-country differences in European firms' digitalization: The role of national culture. *Manag. Decis.* **2020**, *58*, 1563–1583. [CrossRef]
12. Konnikov, E.A.; Osipova, K.V.; Yudina, N.A.; Korsak, E.P. The prevalence of renewable energy in the Russian energy market. In Proceedings of the 2019 International Scientific and Technical Conference Smart Energy Systems, SES 2019, Kazan, Russia, 18–20 September 2019; Volume 124, p. 04018. [CrossRef]
13. Bataev, A.; Potyarkin, V.; Glushkova, A.; Samorukov, D. Assessment of development effectiveness of solar energy in Russia. In *E3S Web Conference*; EPD Sciences: Les Ulis, France, 2020; Volume 221, p. 03002. [CrossRef]
14. Konnikov, E.A.; Konnikova, O.A.; Dubolazova, Y.A.; Mansurov, R.D. Dialectics of the renewable energy market. In Proceedings of the European Conference on Innovation and Entrepreneurship, Rome, Italy, 17–18 September 2020; pp. 952–960. [CrossRef]
15. Putinceva, N.; Ivanova, M.; Liubarskaia, M.; Ghosh, S.K. Implementation of Renewable Energy Sources in the Russian Energy System: Opportunities and Threats. In *ACM International Conference Proceeding Series, Proceedings of the International Scientific Conference—Digital Transformation on Manufacturing, Infrastructure and Service, Saint Petersburg, Russia, 18–19 November 2020*; Association for Computing Machinery: New York, NY, USA, 2020. [CrossRef]
16. Bowen, R.; Morris, W. The digital divide: Implications for agribusiness and entrepreneurship. Lessons from Wales. *J. Rural Stud.* **2019**, *72*, 75–84. [CrossRef]

17. Goedhart, N.S.; Broerse, J.E.W.; Kattouw, R.; Dedding, C. Just having a computer doesn't make sense: The digital divide from the perspective of mothers with a low socio-economic position. *New Media Soc.* **2019**, *21*, 2347–2365. [CrossRef]
18. Robinson, L.; Cotten, S.R.; Ono, H.; Quan-Haase, A.; Mesch, G.; Chen, W.; Schulz, J.; Hale, T.M.; Stern, M.J. Digital inequalities and why they matter. *Inf. Commun. Soc.* **2015**, *18*, 569–582. [CrossRef]
19. Robinson, L.; Ragnedda, M.; Schulz, J. Digital inequalities: Contextualizing problems and solutions. *J. Inf. Commun. Ethics Soc.* **2020**, *18*, 323–327. [CrossRef]
20. Deursen, A.J.A.M.; Van Dijk, J.A.G.M. The digital divide shifts to differences in usage. *New Media Soc.* **2014**, *16*, 507–526. [CrossRef]
21. Kupriyanovsky, V.P.; Sukhomlin, V.A.; Dobrynin, A.P.; Raikov, A.N.; Shkurov, F.V.; Drozhzhinov, V.I.; Fedorova, N.O.; Namiot, D.E. Skills in the digital economy and the challenges of the education system. *Int. J. Open Inf. Technol.* **2017**, *5*, 19–25.
22. Reis, J.; Amorim, M.; Melão, N.; Cohen, Y.; Rodrigues, M. Digitalization: A Literature Review and Research Agenda. In *Lecture Notes on Multidisciplinary Industrial Engineering, Proceedings of the 25th International Joint Conference on Industrial Engineering and Operations Management—IJCIEOM, IJCIEOM 2019 Novi Sad, Serbia, 15–17 July 2019*; Anisic, Z., Lalic, B., Gracanin, D., Eds.; Springer: Cham, Switzerland, 2020.
23. Reis, J.; Amorim, M.; Melão, N.; Cohen, Y.; Costa, J. Counterintelligence Technologies: An Exploratory Case Study of Preliminary Credibility Assessment Screening System in the Afghan National Defense and Security Forces. *Information* **2021**, *12*, 122. [CrossRef]
24. Kohli, R.; Melville, N. Digital innovation: A review and synthesis. *Inf. Syst. J.* **2017**, *29*, 200–223. [CrossRef]
25. Proskuryakova, L.; Kyzyngasheva, E.; Starodubtseva, A. Russian electric power industry under pressure: Post-COVID scenarios and policy implications. *Smart Energy* **2021**, *3*, 100025. [CrossRef]
26. Cong, R.-G.; Shen, S. Relationships among Energy Price Shocks, Stock Market, and the Macroeconomy: Evidence from China Hindawi Publishing Corporation. *Sci. World J.* **2013**, *2013*, 171868. [CrossRef]
27. Konoplyanik, A.A. Challenges and potential solutions for Russia during global gas transformation and "Green Revolution". *Energy Policy* **2022**, *164*, 112870. [CrossRef]
28. Sahbani, S.; Mahmoudi, H.; Hasnaoui, A.; Kchikach, M. Development Prospect of Smart Grid in Morocco. *Procedia Comput. Sci.* **2016**, *83*, 1313–1320. [CrossRef]
29. Freiler, C.; Senn, F.; Hollauf, B.; Schlüsselberger, D. Digitalisierung in der Wasserkraft. 15. Symposium Energieinnovation, 14. Bis 16. Februar 2018, Technische Universität Graz. Available online: https://www.tugraz.at/fileadmin/user_upload/Events/Eninnov2018/files/kf/Session_C2/KF_Freiler.pdf (accessed on 1 October 2021).
30. Employee Job Satisfaction and Engagement—SHRM. Available online: https://www.shrm.org/hr-today/trends-and-forecasting/research-and-surveys/documents/2016-employee-job-satisfaction-and-engagement-report.pdf (accessed on 19 March 2022).
31. Berrada, A.; Loudiyi, K. Gravity Energy Storage. In *Economic Evaluation and Risk Analysis of Gravity Energy Storage*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 51–74. ISBN 9780128167175. [CrossRef]
32. Siemens Energy Sector. Energy Handbook. Edition 7.0. Available online: https://docplayer.com/37515685-Siemens-energy-sector-spravochnik-po-energetike-izdanie-7-0.html (accessed on 19 March 2022). (In Russian).
33. Unlocking Growth in Energy Retail. Building Revenue by Giving Customers What They Want. Available online: https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Energy-and-Resources/gx-eri-unlocking-growth-in-energy-retail-web-final.pdf (accessed on 19 March 2022).
34. Energy Transfer Reports Fourth Quarter 2021 Results. Available online: https://www.businesswire.com/ (accessed on 19 March 2022).
35. Digitalization of the Electricity System and Customer Participation, Description and Recommendations of Technologies, Use Cases and Cybersecurity. Technical Position Paper WG4. European Technology & Innovation Platforms (ETIPs). Available online: https://www.etip-snet.eu/wp-content/uploads/2018/10/ETIP-SNET-Position-Paper-on-Digitalisation-FINAL-1.pdf (accessed on 1 October 2021).
36. Digitalisierung im Energiesektor. Dialogpapier zum Transformationsprozess. Bundesamt für Energie BFE. Available online: https://www.newsd.admin.ch/newsd/message/attachments/55398.pdf (accessed on 1 October 2021).
37. Digitalization & Energy. International Energy Agency. Available online: https://www.iea.org/reports/digitalisation-and-energy (accessed on 1 October 2021).
38. Die Digitalisierung der Energiewende. Agentur für Erneuerbare Energien eV Gefördert Durch Bundesministerium für Wirtschaft und Energie. Available online: https://www.bmwi.de/Redaktion/DE/Publikationen/Studien/digitalisierung-der-energiewende-thema-1.pdf?__blob=publicationFile&v=6 (accessed on 1 October 2021).
39. Digital EVU. Wosteht Die Deutsche Energiewirtschaft? AT Kearney, BDEW Bundesverband der Energie- und Wasserwirtschaft e.V.; IMP3 Rove. Available online: https://www.bdew.de/media/documents/Pub_20190401_Studie-Digital-EVU_WDcoFda.pdf (accessed on 1 October 2021).
40. Abdrakhmanova, G.I.; Bykhovsky, K.B.; Veselitskaya, N.N.; Vishnevskym, K.O.; Gokhberg, L.M. *Report of the Higher School of Economics*; Publishing House of the Higher School of Economics: Rissia, Moscow, 2021; pp. 4–235.
41. Ministry of Energy of the Russian Federation. Available online: https://in.minenergo.gov.ru/energynet/docs/%D0%A6%D0%B8%D1%84%D1%80%D0%BE%D0%B2%D0%B0%D1%8F%20%D1%8D%D0%BD%D0%B5%D1%80%D0%B3%D0%B5%D1%82%D0%B8%D0%BA%D0%B0.pdf (accessed on 1 October 2021).

42. Vankov, Y.; Rumyantsev, A.; Ziganshin, S.; Politova, T.; Minyazev, R.; Zagretdinov, A. Assessment of the Condition of Pipelines Using Convolutional Neural Networks. *Energies* **2020**, *13*, 618. [CrossRef]
43. Prigoreva, E. (Ed.) *Digitalization: Practical Recommendations for Transferring Business to Digital Technologies: Translated from English*ю; Satunin, A., Translator; Alpina Publisher: Moscow, Russia, 2019; p. 251, ISBN 978-5-9614-2849-0.
44. Kholkin, D.V.; Chausov, I.S. Digital Transition in the energy of Russia: In Search of Meaning. *Energy Policy* **2018**, *5*, 7–16.
45. Obukhova, A.; Merzlyakova, E.; Ershova, I.; Karakulina, K. Introduction of digital technologies in the enterprise. In Proceedings of the 1st International Conference on Business Technology for a Sustainable Environmental System, Almaty, Kazakhstan, 19–20 March 2020; Volume 159, p. 04004. [CrossRef]
46. Veile, J.W.; Schmidt, M.-C.; Voigt, K.-I. Toward a new era of cooperation: How industrial digital platforms transform business models in Industry 4.0. *J. Bus. Res.* **2022**, *143*, 387–405. [CrossRef]
47. Rosenthal, S. Information sources, perceived personal experience, and climate change beliefs. *J. Environ. Psychol.* **2022**, *81*, 101796. [CrossRef]
48. Abd El-Aziz, R.M. Renewable power source energy consumption by hybrid machine learning model. *Alex. Eng. J.* **2022**, *61*, 9447–9455. [CrossRef]
49. Bonan, J.; Cattaneo, C.; D'Adda, G.; Tavoni, M. Can social information programs be more effective? The role of environmental identity for energy conservation. *J. Environ. Econ. Manag.* **2021**, *108*, 102467. [CrossRef]
50. O'Dwyer, E.; Pan, I.; Charlesworth, R.; Butler, S.; Shah, N. Integration of an energy management tool and digital twin for coordination and control of multi-vector smart energy systems. *Sustain. Cities Soc.* **2020**, *62*, 102412. [CrossRef]
51. Ma, S.; Li, Y.; Du, L.; Wu, J.; Zhou, Y.; Zhang, Y.; Xu, T. Programmable intrusion detection for distributed energy resources in cyber–physical networked microgrids. *Appl. Energy Part B* **2021**, *306*, 118056. [CrossRef]
52. Gawusu, S.; Zhang, X.; Ahmed, A.; Jamatutu, S.A.; Miensah, E.D.; Amadu, A.A.; Osei, F.A.J. Renewable energy sources from the perspective of blockchain integration: From theory to application. *Sustain. Energy Technol. Assess. Part B* **2022**, *52*, 102108. [CrossRef]
53. Wang, T.; Hua, H.; Wei, Z.; Cao, J. Challenges of blockchain in new generation energy systems and future outlooks. *Int. J. Electr. Power Energy Syst.* **2022**, *135*, 107499. [CrossRef]
54. Gourisetti, S.N.G.; Cali, Ü.; Choo, K.-K.R.; Escobar, E.; Gorog, C.; Lee, A.; Lima, C.; Mylrea, M.; Pasetti, M.; Rahimi, F.; et al. Standardization of the Distributed Ledger Technology cybersecurity stack for power and energy applications. *Sustain. Energy Grids Netw.* **2021**, *28*, 100553. [CrossRef]
55. Leng, J.; Ruan, G.; Jiang, P.; Xu, K.; Liu, Q.; Zhou, X.; Liu, C. Blockchain-empowered sustainable manufacturing and product lifecycle management in industry 4.0: A survey. *Renew. Sustain. Energy Rev.* **2020**, *132*, 110112. [CrossRef]
56. Despotovic, M.; Koch, D.; Leiber, S.; Döller, M.; Sakeena, M.; Zeppelzauer, M. Prediction and analysis of heating energy demand for detached houses by computer vision. *Energy Build.* **2019**, *193*, 29–35. [CrossRef]
57. Lauriola, I.; Lavelli, A.; Aiolli, F. An introduction to Deep Learning in Natural Language Processing: Models, techniques, and tools. *Neurocomputing* **2021**, *470*, 443–456. [CrossRef]
58. Yağanoğlu, M. Real time wearable speech recognition system for deaf persons. *Comput. Electr. Eng.* **2021**, *91*, 107026. [CrossRef]
59. Cheng-Dong, L.I.; Zhang, G.Q.; Wang, H.-D.; Ren, W.-N. Properties and Data-driven Design of Perceptual Reasoning Method Based Linguistic Dynamic Systems. *Acta Autom. Sin.* **2014**, *40*, 2221–2232. [CrossRef]
60. Anthopoulos, L.; Kazantzi, V. Urban energy efficiency assessment models from an AI and big data perspective: Tools for policy makers. *Sustain. Cities Soc.* **2022**, *76*, 103492. [CrossRef]
61. Kuznetsov, D.A.; Kormin, T.G.; Moseichuk, E.I.; Vasiliev, A.N. *Industry 5.0, Its Differences and Points of Contact with Industry 4.0. Science Is an Effective Tool for Understanding the World: Proceedings of an International Scientific and Practical Conference*; LLC "Center for Professional Management" Academy of Business: Saratov, Russia, 2018; pp. 46–51.
62. Karanina, E.V.; Bortnikov, M.A.; Kochetkov, M.N. Assessment of indicators for determining the efficiency and degree of readiness of countries for the digital transition in the electric power industry. *Bull. Acad.* **2020**, *3*, 100–110.
63. Wang, N.; Zhai, Y.; Yang, Y.; Yang, X.; Zhu, Z. Electrostatic assembly of superwetting porous nanofibrous membrane toward oil-in-water microemulsion separation. *Chem. Eng. J.* **2018**, *354*, 463–472. [CrossRef]
64. Švecová, L.; Ostapenko, G.; Veber, J.; Valeeva, Y. The Implementation Challenges of Zero Carbon and Zero Waste Approaches. *E3S Web Conf.* **2019**, *124*, 04025. [CrossRef]
65. Mohapatra, B.; Tripathy, S.; Singhal, D.; Saha, R. Significance of digital technology in manufacturing sectors: Examination of key factors during COVID-19. *Res. Transp. Econ.* **2021**, 101134. [CrossRef]
66. You, Y.; Yi, L. A Corpus-based empirical study on energy enterprises digital transformation. *Energy Rep.* **2021**, *7* (Suppl. 7), 198–209. [CrossRef]
67. Xu, Q.; Zhong, M.; Li, X. How does digitalization affect energy? International evidence. *Energy Econ.* **2022**, *107*, 105879. [CrossRef]
68. Liu, L.; Yang, K.; Fujii, H.; Liu, J. Artificial intelligence and energy intensity in China's industrial sector: Effect and transmission channel. *Econ. Anal. Policy* **2021**, *70*, 276–293. [CrossRef]
69. Maroufkhani, P.; Desouza, K.C.; Perrons, R.K.; Iranmanesh, M. Digital transformation in the resource and energy sectors: A systematic review. *Resour. Policy* **2022**, *76*, 102622. [CrossRef]
70. Tutak, M.; Brodny, J. Business Digital Maturity in Europe and Its Implication for Open Innovation. *J. Open Innov. Technol. Mark. Complex.* **2022**, *8*, 27. [CrossRef]

71. Deckert, A.; Dembski, F.; Ulmer, F.; Ruddat, M.; Wössner, U. Chapter 9—Digital tools in stakeholder participation for the German Energy Transition. Can digital tools improve participation and its outcome? In *The Role of Public Participation in Energy Transitions*; Academic Press: Cambridge, MA, USA, 2020; pp. 161–177. ISBN 9780128195154. [CrossRef]
72. Shabalov, M.; Zhukovskiy, Y.; Buldysko, A.; Gil, B.; Starshaia, V. The influence of technological changes in energy efficiency on the infrastructure deterioration in the energy sector. *Energy Rep.* **2021**, *7*, 2664–2680. [CrossRef]
73. Zhang, R.; Fu, Y. Technological progress effects on energy efficiency from the perspective of technological innovation and technology introduction: An empirical study of Guangdong, China. *Energy Rep.* **2022**, *8*, 425–437. [CrossRef]
74. Calvo-Gallardo, E.; Arranz, N.; de Arroyabe, J.C.F. Innovation systems' response to changes in the institutional impulse: Analysis of the evolution of the European energy innovation system from FP7 to H2020. *J. Clean. Prod.* **2022**, *340*, 130810. [CrossRef]
75. Fernandez, A.D.J.; Watson, J. Mexico's renewable energy innovation system: Geothermal and solar photovoltaics case study. *Environ. Innov. Soc. Transit.* **2022**, *43*, 200–219. [CrossRef]
76. Huang, Y.; Ahmad, M.; Ali, S.; Kirikkaleli, D. Does eco-innovation promote cleaner energy? Analyzing the role of energy price and human capital. *Energy Part D* **2022**, *239*, 122268. [CrossRef]
77. Sohag, K.; Begum, R.; Abdullah, S.M.S.; Jaafar, M. Dynamics of energy use, technological innovation, economic growth and trade openness in Malaysia. *Energy* **2015**, *90 Pt 2*, 1497–1507. [CrossRef]
78. Greco, M.; Locatelli, G.; Lisi, S. Open innovation in the power & energy sector: Bringing together government policies, companies' interests, and academic essence. *Energy Policy* **2017**, *104*, 316–324. [CrossRef]
79. Dall-Orsoletta, A.; Romero, F.; Ferreira, P. Open and collaborative innovation for the energy transition: An exploratory study. *Technol. Soc.* **2022**, *69*, 101955. [CrossRef]
80. Aziz, E.; Mustapha, H.; Jamila, E.A. A bibliometric study of the recent advances in open innovation concept. *Procedia Comput. Sci.* **2020**, *175*, 683–688. [CrossRef]
81. Hao, X.; Deng, F. The marginal and double threshold effects of regional innovation on energy consumption structure: Evidence from resource-based regions in China. *Energy Policy* **2019**, *131*, 144–154. [CrossRef]
82. Sovacool, B.K.; Jeppesen, J.; Bandsholm, J.; Asmussen, J.; Balachandran, R.; Vestergaard, S.; Andersen, T.H.; Sørensen, T.K.; Bjørn-Thygesen, F. Navigating the "paradox of openness" in energy and transport innovation: Insights from eight corporate clean technology research and development case studies. *Energy Policy* **2017**, *105*, 236–245. [CrossRef]
83. De Paulo, A.F.; Porto, G. Solar energy technologies and open innovation: A study based on bibliometric and social network analysis. *Energy Policy* **2017**, *108*, 228–238. [CrossRef]
84. Lacerda, J.S.; van den Bergh, J.C.J.M. Effectiveness of an 'open innovation' approach in renewable energy: Empirical evidence from a survey on solar and wind power. *Renew. Sustain. Energy Rev.* **2020**, *118*, 109505. [CrossRef]
85. Kulachinskaya, A.; Akhmetova, I.G.; Kulkova, V.Y.; Ilyashenko, S.B. The Challenge of the Energy Sector of Russia during the 2020 COVID-19 Pandemic through the Example of the Republic of Tatarstan: Discussion on the Change of Open Innovation in the Energy Sector. *J. Open Innov. Technol. Mark. Complex.* **2020**, *6*, 60. [CrossRef]
86. Renna, P. Peak Electricity Demand Control of Manufacturing Systems by Gale-Shapley Algorithm with Discussion on Open Innovation Engineering. *J. Open Innov. Technol. Mark. Complex.* **2020**, *6*, 29. [CrossRef]