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The Role of Digitalization in the Global Energy Transition[1, 2]

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Abstract

In the context of the COVID-19 pandemic, digitalization has become a popular topic in both practical and theoretical terms. In many areas, for example, education and communications, information and communication technologies began to play a leading role, especially during the period of limited mobility. However, in some other areas that also came under close scrutiny during the pandemic, such as the field of energy transition, digitalization has not yet fully unlocked its potential. Moreover, the digitalization of energy transition has not been researched enough.

The purpose of this article is to fill this gap. The authors investigate the current stage of digitalization of the energy sector and the role of information and communication technologies in the traditional energy complex and in clean energy and identify and analyze the key groups of technologies that will have a decisive impact on the energy transition in the near future. The authors also examine the process of digitalization in the Russian energy sector in order to determine whether it is giving an impetus to the energy transition of Russia.

Key words: energy transition, renewable energy sources (RES), digitalization, Internet of energy (IoE), Internet of things (IoT), big data, blockchain

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Introduction

The Paris Agreement and the United Nations Sustainable Development Goals (SDGs) require fundamental changes in the global energy sector, namely the reduction of greenhouse gas emissions through an energy transition. The use of fossil fuels, mainly for energy, accounts for al-

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most 85% of all global greenhouse gas emissions [Global Carbon Project, 2020]. Because the energy sector is of great geopolitical, economic, social and environmental importance [IRENA, 2019a; Kivimaa, Sivonen, 2021; Sovacool, Hess, Cantoni, 2021], the impact and consequences of energy transition go far beyond this sector and are relevant to global governance in general.

In general terms, the energy transition is defined as a change in the structure of the primary energy supply, which consists of a gradual transition from one state of the energy system to another [Smil, 2010]. There have been several such transformations already. The first energy transition was associated with the replacement of biomass with coal; the second, with an increase in the share of oil in the primary energy supply; and the third, with an increase in the share of natural gas [Smil, 2018]. The modern – fourth – energy transition is characterized by the replacement of fossil fuels with renewable energy sources (RES)[3] excluding large hydroelectric power plants (HPPs). Its fundamental difference from the three previous transitions is that it is based not only on increasing economic efficiency and providing access to new resources, but also on the fight against climate change, which is actually the new driver of this transition [Mitrova, Melnikov, 2019].

The fourth energy transition has already begun and is progressing at a rapid pace, especially in the electric power sector. Modern RES, excluding hydroelectric power plants, accounted for 7.4% of total global final energy consumption in 2018 and 11.7% of global electric power production in 2019 [REN21, 2020]. For comparison, a decade earlier, in 2008, the values of these indicators were respectively 2.8% and 3.0% [REN21, 2010].

The energy transition cannot be reduced to a simple replacement of fossil fuels with RES. In addition to the direct construction of a new generation based on RES, the energy transition requires a radical transformation of individual energy sectors, for example, electrification of transport and heating/cooling, the development of new green energy transport, such as green hydrogen, and the massive use of energy storage devices. Energy transition faces various technical obstacles, such as the difficulty of integrating large shares of RES with variable generation into the network. This category of RES includes the most widespread and rapidly developing solar and wind generation. Another important barrier to the energy transition is the fundamental sophistication of the energy system associated with the introduction of RES. Thus, the spread of RES leads to the emergence of a large number of low-power generators (solar panels on the roofs of households) and prosumers – market participants who are both producers and consumers of energy. Electrification of transport and heating aimed at transferring these sectors to RES contributes to the emergence of a large volume of new loads – electric vehicles, heat pumps, and so on. All this makes centralized energy systems less and less efficient. It is possible to reduce the listed barriers and establish management of the rapidly growing complex energy systems through the introduction of new digital technologies.

In one of the studies by the International Renewable Energy Agency, digitalization, along with electrification and decentralization, is ranked among the three most important innovation trends that are changing the energy paradigm, making the global energy sector more friendly to renewable energy, allowing its participants to change rules and roles, and opening doors to new players [IRENA, 2019c]. Even the concept of "three d" has appeared in renewable energy – decarbonization, decentralization and digitalization [IRENA, 2017]. Moreover, digitalization facilitates electrification and decentralization in the energy sector [IRENA, 2018]. In developing countries, digitalization of the energy sector will help to significantly accelerate electrification, similar to what happened in telephony, when mobile communications began to develop immediately in countries with undeveloped fixed telephony.

[3] Renewable energy sources without traditional biomass, such as firewood.

Digitalization has recently attracted great attention due to the fact that during a pandemic it is important to distinguish between digitization and digitalization. Digitization is usually understood as the transfer of data from analog to digital form, and digitalization or digital transformation is usually understood as the use of digitized data for making decisions in order to improve the performance, safety and sustainability of power systems [Verma et al., 2020].

In 2020, many organizations in almost all countries had to largely switch to remote operation, which is impossible without information and communication technologies. The rapid development of telecommuting in a constrained environment, as well as the replacement of face-to-face meetings and events with teleconferencing, has shown that in a number of activities (including, for example, education), the potential for digitalization is much greater than expected [Dutta, Lanvin, 2020]. And quite logically, the potential for digitalization in other industries, including the energy sector, is no less great and not fully unleashed.

The possibilities of using digital technologies to reduce energy transition barriers have not been sufficiently studied in the world scientific literature [Loock, 2020], although in the modern world digital technologies can become the basis of energy systems management. The study of these possibilities is the purpose of this work. The article is divided into three parts. In the first, the basic characteristics of energy digitalization are considered. The second part is devoted to identifying and analyzing key digital technologies of the energy transition, to identify their potential and the barriers that hinder their development. The third part examines Russia's energy digitalization efforts and analyzes how these efforts are contributing to the energy transition. In this article, answers are offered to the following questions. What digital technologies are most conducive to the energy transition? What exactly is their contribution? Are these technologies developing in the Russian energy sector?

Basic Characteristics of the Energy Sector Digitalization

Historically, the energy sector has been one of the pioneers of digital adoption. In the 1970s, digital technologies were used in the power industry to improve the efficiency of grid management. Oil and gas companies have long used digital technologies in exploration and in pipeline management. The industrial sector, especially heavy industry, has been using digital technologies for decades to improve quality and output while reducing energy consumption [IEA, 2017]. At the same time, it should be noted that in the coal, as well as in the oil and gas industries, it is heavy equipment and not the digital environment that predominates, and the level of digital integration in these industries has so far been relatively low compared to other industries [Verma et al., 2020].

It is believed that digitalization opens up significantly more opportunities for clean energy technologies than for the traditional energy complex. Thus, in a study by P. Verma et al. [2020], in part 18 on the digitalization opportunities for various supply-side actors in the energy sector, only one point was devoted to the coal and oil and gas industries, while the remaining four points are mainly devoted to clean energy technologies. Fossil fuel industries can continue to implement sensors, automate processes and perform remote monitoring, while the renewable energy sector can dramatically increase its efficiency and ability to integrate into the power system. Decentralization of the electric power industry, primarily with the use of RES, creates risks for the traditional business models of electric utilities. With the help of digital technologies, the management of systems consisting mainly of renewable energy and storage facilities will make it possible to respond in a timely manner to fluctuations in the volume of electricity generation. Numerous consumers of energy will also be able to become energy producers without threatening to destabilize the grid. The digitalization of clean energy, encompassing not only renewable energy but also various related technologies such as electric transport, energy storage and decentralized grids, will create new business models and change the roles of different actors in the power system.

According to A. Booth, N. Patel and M. Smith [2020], traditional energy companies have failed to create tangible commercial value through the introduction of digital technologies due to the inertia of their development, which is difficult to overcome. In particular, traditional energy is dominated by physical assets, investment is huge and profit creation is complex. That is why proposals regarding investment in new technologies are faced with strict selection and the need to prove their feasibility. In addition, engineers play a key role in oil and gas and power companies, and many of the top managers of such companies are former engineers. Consequently, conventional energy companies tend to favour large and complex projects that lack flexibility and resist quick solutions. These characteristics hinder the adoption of digital technologies, which precisely requires high speed decisions, flexibility and willingness to take risks.

Booth, Patel and Smith [Ibid.] also noted that, in traditional energy, the introduction of digital technologies existed more at the level of discussion than in reality. Another study noted that the oil and gas sector has not exploited many of the opportunities associated with data and digital technologies. In addition, many oil and gas companies find it difficult to translate digital performance into improved financial performance and business development [Smart, 2017].

Digitalization can be viewed as a threat to the existing energy system and, in particular, to traditional energy. The large-scale and global digitalization of the energy sector will undoubtedly bring fundamental changes to it. At the same time, the introduction of digital technologies offers tremendous opportunities to overcome the barriers that the energy sector currently faces. In particular, digitalization will enhance energy security, expand universal access to energy and reduce the negative impact of energy on the environment. In addition, since digitalization generally improves efficiency, reductions in energy costs can be expected. Thus, according to the IEA [2017], digitalization can reduce the cost of electricity generation by producers by $80 billion per year in 2016–40, which will be about 5% of the annual gross electricity production costs. This can happen by reducing operating costs and maintenance costs of generating facilities, increasing the efficiency of generating facilities and networks, reducing the number of accidents and idle hours, and extending the life of equipment.

Digital Technologies of Energy Transition

Traditional power systems are not designed to integrate large portions of variable generation or distributed generation. The existing network infrastructure is in most cases too old, inefficient, outdated and unreliable and does not provide sufficient protection against unexpected changes in the amount of electricity generated by power plants [Jha et al., 2017]. The use of digital technologies makes it possible to optimize the functioning of RES facilities in energy systems and, as a result, increases the efficiency and reliability of energy systems with large shares of RES. The International Renewable Energy Agency (IRENA) identified the following key groups of digital technologies promoting the adoption of renewable energy [2019b]:

- Internet of things (IoT),
- artificial intelligence and big data,
- blockchain.

The transformation of energy systems to the Internet of energy (IoE), which is also being discussed, will provide opportunities for the use of all three groups of digital technologies distinguished by IRENA. It is believed [Zhang, 2021] that the term "Internet of energy" was first proposed in the book *The Third Industrial Revolution* by the famous American researcher

J. Rifkin [2013], with the following characteristics: primary energy is being transformed into renewable energy; distributed generation systems and small energy storage systems are interconnected, and the modes of their access to the network are gradually diversifying; different energy sources in different places can be linked using Internet technology; and the Internet of energy supports the development of electrification. Thus, the development of the IoE will facilitate electrification and a gradual transition to renewable sources. At the same time, it should be emphasized that the IoE is still a developing concept, and its very definition causes a lot of controversy.

In the work of Y. Wu et al. [2021], there are two key groups of digital technologies that contribute to the development of the IoE: the IoT and blockchain. At the same time, it is noted that the IoT contributes to the development of such innovative information and communication technologies as artificial intelligence, big data and cloud technologies. Thus, herein, the IoT, artificial intelligence and big data are actually combined into one technology group.

Some authors focus on power supply platformization, which also applies to these three groups of digital technologies. Energy platforms use the digital environment to connect energy consumers and energy suppliers, promoting decentralization and the exchange of energy from distributed sources [Kloppenburg, Boekelo, 2019]. Sharing platforms and the sharing economy have already developed in many industries such as rental housing, cars, and equipment, but their development in the energy sector is just beginning. However, there are already numerous successful projects and business models. For example, the Dutch platform Powerpeers allows households to choose the prosumers from whom they will buy their electricity. Similar services are provided by the German platform SonnenCommunity, but its members are exclusively prosumers with lithium batteries. The American platform SunShare Community Solar allows households that are unable or unwilling to install their own solar panels on the roofs of their homes to acquire shares in solar power plants and thereby reduce their electricity bills [Kloppenburg, Boekelo, 2019].

Next, the features of each of the listed groups of technologies are considered, as well as their potential and limitations.

The Internet of Things

The recent explosive growth in the number of mobile devices used, various communication media, and interest in cloud technologies and big data analytics have raised the question of the interaction between many devices. To solve assigned tasks, objects can automatically exchange information, process it, and create new connections with each other through wireless and wired connections. The IoT refers to this technology. It is estimated that the number of connected IoT devices grew from 8.4 billion in 2017 to 20 billion in 2020 [IEA, 2017].

The IoT offers tremendous opportunities for the energy sector, especially in the renewable energy sector. A smart system based on IoT technology is able to integrate all devices on both the demand side (for example, electrical appliances and electric vehicles) and the supply side (such as solar and wind farms) to manage demand and improve the efficiency of power supply systems.

Currently, the use of IoT technology is possible at various stages of the electricity life cycle, starting at the production planning stage. Various technologies are being tested already, such as tracking the movement of clouds or wind characteristics and using the data obtained to predict the generation of electricity by renewable energy facilities. Also, automated monitoring at each facility allows for more accurate forecasts and the more efficient operation of facilities. The IoT can significantly improve the ability of networks to provide balancing, aggregation and load dispatch services, as well as to automate the operation of electric substations. This could potentially lead to the creation of fully autonomous energy grids that can independently cope with the unexpected reduction in the generation of renewable energy facilities. As a consequence, it would increase the resilience and stability of the networks. Another equally important application of the technology could be its use for the automated management of energy demand through communication between electrical appliances. The use of technologies of varying complexity, for example, to control room temperature or the energy consumption of an entire building, will significantly save overall energy consumption and reduce loads where energy may not be used at the moment (for example, when there are no people in the premises).

However, the massive expansion of the IoT in the energy sector has not yet begun. Moreover, it can be associated with a number of challenges. In particular, a problem of data security and privacy could occur, as well as the data exchange security. Another issue is the compatibility of different encryption protocols and methods and how quickly they can be brought together.

Artificial Intelligence and Big Data

Artificial intelligence can be understood as technology that uses data, especially in large volumes (big data) for developing models, often using machine learning algorithms that can perform the function of informing, or automating, decision-making [Boza, Evgeniou, 2021]. As the power distribution system is constantly becoming more complex, it is difficult to control it manually. Artificial intelligence helps to make decisions automatically with thousands of households in the power system with installed micro-generating RES and energy storage facilities.

In the field of renewable energy, artificial intelligence is still used mainly for weather forecasts and the projection of the volume of renewable energy produced by facilities with variable generation, as well as for the renewable energy facilities service. However, it can be applied at all stages of the electricity life cycle. In the future, as the share of renewables increases, it is expected that artificial intelligence will become a key technology in forecasting and – most importantly – decision-making processes. Artificial intelligence will allow the automation of operations that are now performed in the manual mode. Thus, even more automation will occur along the entire chain of energy unit creation, from production to distribution and consumption.

In the power generation phase, artificial intelligence is paramount in planning solar and wind power generation. The most accurate forecasting for the short term makes it possible to minimize excess electricity generation and reduce the need for reserve capacities and, consequently, the costs of their maintenance [Zhou et al., 2016]. During the transmission and distribution phases, artificial intelligence maintains the stability of the uninterrupted operation of the network, providing more accurate forecasts of supply and demand. Due to the expected increase in decentralized energy distribution, it is important to manage possible fluctuations and peak loads in the power system. Artificial intelligence algorithms optimize the generation and consumption of electricity and make decisions to moderate the network traffic, and in the future they will also be able to take into account electricity prices in specific areas. Artificial intelligence technologies can also detect possible errors in the system, which makes it possible to respond more effectively to critical situations and thus increase the security of the entire network infrastructure [IRENA, 2019b].

Artificial intelligence technologies can significantly improve consumer energy efficiency. By analyzing the consumer energy behaviour and comparing it, for example, with the temperature in the room, artificial intelligence can predict the required temperature and make recommendations for the use of both the entire heating/cooling system and specific devices. Artificial intelligence improves the efficiency of energy storage management. For example, artificial intelligence algorithms can make decisions about turning on/off storage facilities during peak loads, as well as predict the working lifespan of storage facilities and, in general, manage the sale and purchase of electricity.

The use of artificial intelligence technologies can significantly increase the economic efficiency of renewable energy. For example, one study found that a 25% improvement in forecast accuracy lowers the cost of solar power generation by $0.33/MWh and $0.5/MWh at 9% and 18% solar penetration rates, respectively [Martinez-Anido et al., 2016].

The development of artificial intelligence technologies in the energy sector is faced with such risks and obstacles as the problem of data quality, a shortage of qualified experts, the risk of data leakage, including personal data, issues of legal protection [Ahmad et al., 2021], risks of cyberattacks, and the need for significant initial investment in improving data management systems [Boza, Evgeniou, 2021]. However, the potential benefit from the development of artificial intelligence technologies in the energy sector justifies the search for solutions to these problems.

Blockchain

In recent years, blockchain technology (distributed ledger) has been actively developing and could have a significant impact, among other things, on the energy transition process. Blockchain is able to facilitate the creation of platforms that work without intermediaries for the distributed networks of the IoE [Cao, 2019], as well as support microgrids. This will contribute to automation and transparency in energy distribution. The use of blockchain can also reduce transaction costs and improve transaction security [IRENA, 2019b]. Thus, it is possible to reduce the likelihood of fraud or data leakage in the face of increasing risks of cyberattacks.

In the development of blockchain technology, three stages can be distinguished [Ahl et al., 2020]: cryptocurrencies, smart contracts and decentralized autonomous organizations (DAOs). The technology is currently in the second stage of development. Smart contracts are algorithms that automatically move digital assets according to predefined rules [Buterin, 2014]. The third stage of development implies long-term smart contracts that will manage assets and code the charters of organizations [Ibid.].

In the energy sector, smart contracts operate on the “if… then…” principle and ensure the automatic fulfilment of obligations under the terms of a contract concluded between electricity producers and consumers. When electrical networks need energy, transactions are automatically initiated with predefined conditions. When generation exceeds consumption, the electricity surplus is sent to storage facilities.

As noted above, RES development leads to the decentralization of the energy sector, as well as to an increase in the number of small energy producers. Smart contracts facilitate the transition from centralized to decentralized energy distribution and provide all network participants with the ability to transact directly with any other participants without intermediaries [IRENA, 2019b]. In the decentralized model, more incentives are created for the widespread introduction of distributed RES, since all members of the network have the opportunity to sell the generated energy. Blockchain technology will introduce automated electricity trading through pre-negotiated smart contracts between households, businesses and suppliers.

Despite the obviously potentially large role of blockchain in the energy transition [Wu, Tran, 2018], the implementation of blockchain technology in the energy sector is still limited and involves many issues, some of which are highlighted in the work of A. Ahl et al. [2020], including the need to access high capacity servers as well as an uninterrupted and reliable Internet connection. Another problem is the lack of a regulatory framework for resolving blockchain-generated conflicts. The procedure for resolving disputes due to the cancellation of a transaction is not yet defined. The very use of blockchain in the energy sector is widespread only in developed countries, where the necessary infrastructure already exists (distributed electrical networks). In developing countries (for example, in China), where centralized energy supply systems are widespread, blockchain technologies are facing challenges [Wang, Su, 2020].

Over the past few years, blockchain in the renewable energy sector has attracted significant attention from governments as well as private companies. About 200 companies with investments of $466 million are working on the application of blockchain in the energy sector. More than 70 projects are developing at the global level [IRENA, 2019b].

Digital Transformation of the Russian Energy Sector

Russian authorities regard the digital transformation of the energy sector as a serious technological challenge, taking into account Russia's high dependence on imports of high-tech equipment [Mitrova, Melnikov, 2019]. The first step in the development of the agenda for the Russian energy sector's digitalization at the state level was the creation of the EnergyNet working group and the approval of the EnergyNet roadmap of the National Technological Initiative (NTI) in 2016. The goal of Energynet NTI is to achieve the leadership of Russian companies in the global energy markets of the future, in particular, in such segments as distribution networks, intelligent distributed energy, and consumer services. In 2017, by the government order No 1632-r of 28 July [Government of the RF, 2017], the programme "Digital Economy in the Russian Federation" was approved (the order was canceled in 2019 after the release of the Presidential Decree No 204 of 5 July 2018), which affected energy digitalization issues. Taking into account the programme's priorities, a departmental project "Digital Energy" was formed, focused mainly on ensuring the safety of the energy infrastructure, as well as on the digitalization of the electric power industry, the oil and gas sector, and the coal industry. By the Decree of the President of the Russian Federation No 204 of 7 May 2018 "On National Goals and Strategic Objectives of the Development of the Russian Federation for the Period up to 2024," the Government of the Russian Federation was tasked with introducing digital technologies and platform solutions, as well as intelligent control systems in the energy industry [President of the RF, 2018].

In 2020, the Energy Strategy of the Russian Federation up to 2035 was approved [Ministry of Energy of the RF, 2020]. It also focuses on aspects of the energy sector digitalization. In particular, it provides for the improvement of the mechanisms of state support for the implementation of end-to-end digital technologies, including platform solutions, the formation of a management system, coordination and monitoring of the digital transformation of the fuel and energy complex, ensuring the digitalization of public administration, and control and supervision activities in the energy sector.

It should be noted that Russia lags behind many countries in the digitalization of its economy as a whole. According to the Network Readiness Index (NRI), in 2020, Russia was ranked 48th out of 134 in digital economy readiness and 49th in technological readiness. This index characterizes a country's level of development of information and communication technologies. It was developed by the World Economic Forum and the international business school INSEAD in 2002, and since 2019, it has been issued by the Portulans Institute and the World Information Technology and Services Alliance. Sweden, Denmark, Singapore, the Netherlands and Switzerland are among the five leaders of the index in 2020 [Dutta, Lanvin, 2020].

Digitalization in the electric power sector is going faster than in other energy sectors such as heating/cooling and energy for transport. Today, many facilities already use automation, telecontrol and telemechanization systems, and a two-way exchange of information.

PJSC Rosseti has developed the concept "Digital Transformation 2030" [Rosseti, 2018]. Eighty-four digital substations, functioning without the constant presence of personnel, were put into operation, 38 digital areas of electrical networks, 22 digital network control centers, and more than two million smart meters were installed as a result of digital transformation during 2017–20. The digitalization of regional network organizations at the moment is mainly limited to the installation of smart metering devices.

The digital transformation of energy supply companies is focused on modernization of the current billing systems, systems of interaction with consumers, the introduction of personal accounts, and self-service portals. The installation of smart metering devices is the first stage in the application of IoT technologies. Artificial intelligence technologies are not yet used in energy sales activities but could be widely used in tracking the dynamics of production and consumption, data analysis and current trends. The use of blockchain technologies is another trend that is currently being implemented only in pilot projects but would make it possible to increase the efficiency and clarity of electricity trading and accounting.

Implementation of digital technologies in the oil and gas industry, as well as the search for new technological solutions, is driven by the need to reduce costs and improve efficiency in an increasingly competitive environment. In 2008, the Salym group of fields became the first group to be equipped with a completely remote monitoring system. At the beginning of 2019, digital solutions had already been applied at more than 40 Russian fields [Kozlova, Pigarev, 2020].

Digital transformation is now part of the strategies of all major Russian oil and gas companies. And although digital solutions are spreading slowly in this industry, at the moment there are many pilot projects and successful cases.

PJSC Gazprom Neft approved a digital transformation strategy in September 2019. Through the use of new technologies, by 2030, Gazprom Neft plans to halve the time to obtain the first oil from fields, increase the speed of implementation of large oil and natural gas extraction projects by 40%, and cut production management costs by 10% [Gazprom Neft, 2019].

Within the Rosneft-2022 strategy, in 2019, Rosneft developed 24 concepts, 18 prototypes and conducted 28 approbations of digital solutions, some of which were put into commercial operation. Technologies of digital fields, digital twins, and artificial intelligence technologies were introduced for predicting equipment failure and for conducting supply and inventory management of material base; additionally, a prototype of a software package for processing and interpreting geophysical well surveys, a drone monitoring system, and a digital worker were developed [Rosneft, 2021].

The digitalization strategy of PJSC Tatneft is part of its group development strategy up to 2030 [Tatneft, 2018]. PJSC Tatneft, like other oil and gas companies, is focused on the implementation of big data technologies, the IoT, and digital twins. Elements of digital field technology have been successfully tested at the Romashkinskoye field, which resulted in the reduction of production costs by up to 30%. The company also managed to produce an additional 200 thousand tons of oil and increase the flow rate of previously low-profit wells up to 10 times. By the end of 2021, the company planned to introduce models at all oil facilities and to start taking decisions on the basis of models.

The Digital Lukoil 4.0 programme includes the company's work in four main directions: digital twins, digital personnel, robotization and the digital ecosystem. The concept of intelligent fields is also being introduced [Klubkov, Mosojan, 2020]. By the end of 2019, 45 integrated field models were built, with additional hydrocarbon production exceeding seven million barrels of oil equivalent. Digital technologies are also being implemented in oil refining. For example, a predictive analytics system for the state of dynamic equipment was introduced at the Perm Oil Refinery. At the refinery in Burgas, a system for monitoring and forecasting equipment condition is in operation. The Volgograd Refinery has a video analytics system integrated into an automated process control system.

Thus, a gradual introduction of digital technologies is taking place in the oil industry. Most stakeholders have developed digital strategies and are gradually implementing technologies – digital fields, cloud technologies, big data, artificial intelligence and remote monitoring. But this whole process has a very indirect relationship to the energy transition. It is rather similar to ordinary industrial automation aimed at reducing costs and increasing the efficiency of business processes. The concept of digital energy, including energy transition, implies a new business model formation and a new structure of interaction between the main subjects and new services. The application of digital technologies in the Russian oil and gas sector does not fundamentally change industrial processes, but only automates them. Since the application of technologies in the industry is just beginning, there is no information about the obtained, even preliminary, effects. The companies have only preliminary values of the planned effects based on the completion of all strategy stages.

It should be noted that the digitalization of the RES sector is not included in the list of state tasks for the energy industry's digitalization in Russia. However, the introduction of digital technologies is taking place in this sector as well. The most common practice today is to implement remote management. The first such project was completed in September 2019 by the System Operator and the Hevel company. The use of digital solutions at the Buribayevskaya SPP (installed capacity is 20 MW) made it possible to provide remote control of active and reactive power, as well as to service the solar power plant without personnel constantly on duty. After the success of the remote control project at Buribayevskaya SPP, similar systems were implemented at other solar generation facilities (for example, at Maiminskaya SPP and Staromaryevskaya SPP). Another digital solution is the use of unpiloted aerial vehicles by Hevel for the inspection of solar power plants. Kochubeevskaya and Adygeiskaya wind farms, as well as three solar power plants in the Volgograd region, are already connected to the Internet and digital services. The Ushakovskaya wind farm in the Kaliningrad region is integrated into the first digital region of the electric grid in Russia. Also, most SPPs and WPPs in Russia are equipped with automated control systems and automated measuring and information systems for electric power fiscal accounting, which could become the basis for deeper digital transformations in the future. Artificial intelligence and blockchain technologies in the RES sector in Russia are not yet used, with the exception of isolated cases, such as Sber's blockchain platform for renewable energy certificates trading.

The RES sector's digitalization is proceeding at a slow pace. The introduction of digital technologies in this area is at the pilot project stage and, as in the case of traditional generation, resembles an automation process. Digital solutions mainly help to optimize work and ensure dispatching. The current process of green energy digitalization is not an incentive for RES development in Russia. And even the implementation of digital technologies at a deeper level will not lead to an increase in RES capacities. The restructuring of the entire energy system and the creation of new infrastructure, including digital, could become a tool for RES development. But the main condition is the application of state support mechanisms. At the moment, at the level of state strategic documents, the digital development of the RES sector is not a priority. Thus, the interest of all players in the Russian energy sector, as well as the renewal of the entire energy system from a technological and organizational point of view, could become a driver for the development of green generation and, as a result, microgeneration, distributed generation and energy storage markets in Russia.

In general, the process of energy sector digitalization in Russia is at an initial stage. At the moment, a legislative basis has been created for the introduction of digital technologies and a number of pilot projects are being implemented. However, the application of technologies is not associated with the structural changes in the industry, which implies the energy transition. Energy digitalization in Russia looks more like an automation process. This initial stage could become the basis for further industry digitalization, but this requires, first of all, the will of all participants in the Russian energy system.

Conclusion

Digital technologies were introduced in the traditional energy sector about half a century ago, but their role in the development of the coal, oil, and gas industries is quite modest and is mainly limited to the usual automation of operations and increasing efficiency. This is largely due to the predominance of engineering thinking in these spheres, as well as to the general inertia in traditional energy development. Clean energy, on the other hand, offers much more room for innovation, new business models and quick decisions, which opens up wide horizons for digital adoption. Digital technologies, in turn, create opportunities to manage the challenges of a clean energy transition, such as the difficulty of integrating large volumes of variable generation into the grid and managing distributed grids.

The introduction of RES and the energy transition are driving electrification and leading to a significant increase in the complexity of electric power systems in which new players are emerging, including prosumers, and a large number of different electrical appliances, devices, and sources of electricity generation, as well as new business models, are appearing. It is becoming more and more difficult to control such systems in manual mode, and at some point this could become an obstacle to the energy transition.

This research identified three groups of key digital technologies that are able to overcome barriers to the clean energy development in the coming years – the IoT, artificial intelligence and big data, and blockchain. The possibility and importance of organizing interaction and integration of all these groups of technologies within the framework of digital platforms and the IoE was also noted.

The IoT is able to integrate electrical devices as well as power plants, which will make it possible to control them in an automatic mode. The IoT can significantly improve the ability of networks to provide balancing, aggregation and load dispatch services, as well as to automate the operation of substations. Artificial intelligence in the field of renewable energy is still used mainly to predict the production of solar and wind power plants. However, in the future, its algorithms can be included in decision-making processes. For example, artificial intelligence algorithms can make decisions about turning on/off certain objects. Artificial intelligence technologies can also detect possible errors in processes, which will increase the safety of power systems. Blockchain, in particular through short-term and long-term smart contracts, will allow various participants of the power system to carry out transactions without intermediaries, and that will facilitate the transition from centralized to decentralized energy distribution.

Russia lags significantly behind other countries in the digitalization of the economy in general, as well as in the digitalization of the energy sector in particular, although since 2016, the digitalization of the fuel and energy complex has been one of the state's priorities. Digital transformation has already become part of the strategies of all large Russian oil and gas corporations, as well as many other companies in the energy sector (for example, grid organizations), but so far it has mainly been limited to conventional industrial automation in order to reduce costs and increase the efficiency of business processes. Many promising digital technologies (for example, blockchain) have hardly been developed in the Russian energy sector yet. In general, the digitalization of energy so far does not contribute to the energy transition in Russia, mainly due to the limited ambitions of Russia in the renewable energy development and related industries, such as energy storage, electric transport and others.

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