Toward industry 4.0 in energy sector

Elena Goosen¹, Sergey Nikitenko², Elena Kagan¹ and Evgeniya Pakhomova²

¹Kemerovo State University, 6 Krasnaya street, Kemerovo, 650000, Russia
²Federal Research Center of Coal and Coal Chemistry, Siberian Branch of the Russian Academy of Sciences, 18 Sovetskiy Ave., Kemerovo, 650000, Russia

E-mail: nsm.nis@mail.ru

Abstract. The article attempts to identify the profound changes occurring in the global and Russian energy sectors under the conditions of Industry 4.0. The features of the implementation of the global innovative Industry 4.0 project in the global energy sector are studied; a change in the technological basis, an upgrade of value chains and a change in business models are shown. The state and prospects of the Russian fuel and energy complex transition to a new Industry 4.0 development paradigm are analyzed. The main models and barriers to the formation of new value chains in the Russian fuel and energy complex are identified. The main niche in the Russian energy complex is highlighted, in which its development on the principles of the Industry 4.0 paradigm is possible and most likely.

1. Introduction

The fuel and energy complex plays a crucial role in ensuring the growth rate and resilience of the Russian economy. At the end of 2018, Russia was in first place in the world in terms of oil production, in the second place in gas production, in the fourth place in electricity generation and in the sixth place in coal production. In 2019, the fuel and energy complex provided about 22% of GDP, almost 60% of exports and 40% of budget revenue. According to the latest forecast for the development of the energy sector until 2040, presented by British Petroleum, Russia will remain the leading player in the global energy market in the coming years, and Russian exports will provide more than 5% of the global demand for primary energy by 2040 [1]. Despite the difficult economic environment and the negative attitude towards coal and coal generation amid the struggle to reduce CO2 emissions into the atmosphere, coal will remain an important source of electricity for a long time; Russia will remain its most important producer and exporter, having a real opportunity to expand Russia's presence on the world coal market, strengthen its position and increase its share due to such high-quality competitive advantages as high calorie content, low content of sulfur, nitrogen and ash. Over a 20-year period, Russia's share in international coal trade has increased more than 3.5 times and has amounted to 14% [1].

Recently, the Russian economy and its energy sector have faced a new challenge known as the transition of the world economy to a new development paradigm; this is the industrial revolution, which is called Industry 4.0. It is heavily dependent on manufacturing and high-tech sectors but experts are sure that it is the technologies of Industry 4.0 that will become the basis for the development of the extractive sectors, including the coal industry. It is safe to say that the future lies with those companies that can take advantage of Industry 4.0 [2, 3].

A sufficient amount of work has already appeared analyzing the features of digital technologies in the processing and enrichment industry [4-7]. However, the term Industry 4.0 itself and the set of...
digital and production technologies describing it vary greatly from article to article [8-10]. This is largely due to the fact that the new paradigm of industrial production (Industry 4.0) is still taking shape. In addition, it is now clear that in different industries it will go in different ways and at different speeds [8, 11]. Most likely, in its final form, it will rely on a kind of mixture of related production and digital technologies that have serious industry and company differences, while having high inter-industry interoperability [12-13].

There are already attempts to predict how Industry 4.0 will look in the mining industries. The authors make predictions about the introduction of unmanned dump trucks and drones in quarries, the introduction of the SX-EW method in copper processing or new filtering technologies. Most of the Industry 4.0 research in the extractive industries focuses on the discussion of new machines and new main processes [14-15]. Already now we can conclude that, unlike previous industrial revolutions, Industry 4.0 does not rely on a single technology. In these conditions, it makes sense to discuss not only the technologies themselves (digital and production), but also the specific points of growth of these technologies and their possible impact on business processes. One approach that can answer these questions is the “value-chain analysis” (VCA) concept.

The purpose of this article is to identify Industry 4.0 growth points in the domestic coal industry and the forecast of possible changes in the business models of energy companies using the concept of value chains.

2. Subject and methods of research
To analyze the current and emerging paradigms of development of the global energy sector, data from world energy statistics posted on the websites of IAE (International Energy Agency) and BP was used. The information on the state of the Russian fuel and energy complex was obtained from the official websites of the Federal State Statistics Service of the Russian Federation and Ministry of Energy of the Russian Federation. To assess the degree of readiness of Russian oil and gas and coal enterprises, the authors of the article analyzed the official documents of companies (reports, development strategies), official websites and public speeches of top managers over the period 2017 to 2019. As a theoretical basis, the work uses the concept of value chains (Value-chain analysis VCA).

3. Industry 4.0 and the upgrade of value chains in the energy sector
The industrial revolution in the energy sector is under the pressure of three main groups of factors: the exhaustion of energy sources that were traditional for the previous stage of development, rapid changes in the energy market and the emergence of new technological development possibilities, including digital and manufacturing technologies (figure 1).

![Figure 1. Driving forces of Industry 4.0.](image-url)
In the history of mankind, the industrial revolution has always relied on a change in the basic source and key technology (see figure 2).

![Figure 2. World industrial revolutions and world energy transitions [16].](image)

Industry 1.0 relied on coal and a steam engine; electricity and oil lay at the core of Industry 2.0; Industry 3.0 is associated with active gas development and automation. Industry 4.0, unlike previous revolutions, is not accompanied by a transition to a new energy source, when the fuel balance was achieved by reducing the extraction of one resource and the growth of another; overcoming resource limitations is due to the amplification of reducing energy intensity and the creation of hybrid resources with predetermined properties. In the fuel balance, there is not so much replacement of one resource by another, but diversification that is the equalization of the shares of coal, oil, gas and non-mineral alternative sources of primary energy. The most important requirements for them are the predetermined consumer properties and on time flexible deliveries. This allows concluding even now that in the near future a whole range of hybrid interchangeable resources with predetermined properties will become the leading energy resource.

In addition to changing the basic energy carrier, all previous industrial revolutions were accompanied by a change in key technology that determined the nature and structure of markets, especially supply chains.

In modern foreign and domestic studies, the fourth industrial revolution is mainly considered through the prism of using information and digital technologies in industrial processes. Among them, the most important are Cyber-Physical System (CPS), Internet of Things (IoT) in industry (the usage of digital counterparts, scanners and sensors), Big Data and Business Intelligence, Augmented Reality (AR) technology, Cloud Storage technologies, Autonomous Work, Information Security (secure data, access authentication system and full control of operation networks), Additive Manufacturing, Digital
Modeling and Horizontal and Vertical System Integration (internal and external organizational interaction of the enterprise) [17].

However, it would be wrong to reduce the fourth industrial revolution to digital technology alone. Changes are occurring swiftly; along with digital technologies they are connected, firstly, with breakthrough industry production technologies, which no less than digital ones change the production processes, structure and organization of company management. Secondly, the changes are the result of occurrence of platform solutions, which are based on new products and the way they are promoted and consumed, which means a radical restructuring of the markets and the mechanisms of interaction of the main participants on them. Thirdly, there are changes in the relationship of companies with the external environment, involving the erosion of borders enterprises, industries and sectors. There is also a transformation of part of the external environment of companies into the internal one, which opens up new opportunities for interaction between business, the state and society. The authors of the article define the concept of “Industry 4.0” as a profound change in the economic structure: an interconnected change in technology, organizations, markets and society, which comprehensively affects all sectors and aspects of human life.

The distinguishing feature of Industry 4.0 is that it is difficult to define a particular technology for it. Digitalization, the Internet of Things, advanced robotics, artificial intelligence, machine learning, block chain and the creation of new materials have led to serious technological and structural changes. Automation, sensors, and Internet connection create great potential for increasing efficiency and lowering costs in the energy sector. According to the World Economic Forum, digitalization of the oil and gas industry alone could bring additional revenue of $ 1.6 trillion by 2026 [18]. It is true that digitalization largely determines the nature of the changes in the transition to Industry 4.0. But just as in the situation with energy resources, it is impossible to define one leading technology here. The key here is a mix of production and digital interoperable technologies, while for each individual industry this mixture has distinctive properties.

Finally, new technologies modify markets and impose new requirements on key players, as well as on the rules for their interaction between themselves and companies from related industries. As a result, the nature and structure of the energy market is changing. In the framework of the modern industrial revolution, the producer market has been replaced by the consumer market; the number of consumers has grown rapidly; energy prices have become extremely volatile. The structure of companies is gradually changing. This is especially noticeable when comparing the traditional value chain in the energy sector and the new hybrid cluster formations that arise as a result of upgrading value chains as they transit to Industry 4.0 (figure 3).

In its most general form, the added value chain can be represented as “the whole cycle of the organization, production, and delivery of products from inception to use and recycling which provides a tool for mapping these crucial domains of private and public policy. But, more than that, by focusing on the dynamic shifting of producer rents through the chain, on the processes whereby key actors provide governance to production that occurs on a global basis, value-chain analysis provides important insights into ... challenges confronting both private and public actors” [19].

In most extractive industries, including the coal industry, until recently, AVCs were fairly simple (figure 3a). Most of the economic profit was generated due to the resource component (the quality of coal and the conditions of its bedding), and the management process was reduced to the establishment of highly integrated vertical companies that would create barriers for the competitors to enter the sector and supplement the natural rent with the monopoly one. Now in the energy sector global vertically integrated companies (VICs), whose competitiveness is largely determined by the ability to build upward, supply chains, are being replaced by national and regional companies included in horizontal networks (clusters), whose competitiveness is largely determined by flexibility and ability to cooperate and adapt to flexible market conditions. Large energy companies are increasingly cooperating with companies in high-tech industries. So only during 2017 did BP acquire Beyond Limits, a start-up based on artificial intelligence and cognitive computing that adapts NASA’s upstream technologies for deep space exploration to the sector. Chevron is actively developing
graphics processors for visualizing seismic data and creating three-dimensional field models. The main goal is to determine the most suitable places for drilling. Shell is developing machine learning algorithms for seismic exploration to automatically detect and classify geological structures onshore and offshore oil and gas fields. This shows that it’s not just a deep transformation of the energy sector, but the barriers between sectors and the borders between suppliers, producers and consumers that are being destroyed. These global changes make it possible to talk about a complete paradigm shift in the development of the energy sector and related industries [20]. They almost completely put an end to the old approach to the extraction and use of energy resources, the essence of which was “the consistent development of new” mineral reserves, with “the main emphasis on the discovery and development of primarily large and giant deposits”, and require active inclusion in the process of developing a new conceptual approach. In recent decades, there has been a shift in direct control over global oil and gas resources from “super majors” (the largest transnational non-state oil and gas and coal companies) to national and regional companies [21-22]. All this has affected the value chains in the energy sector, which are gradually turning into integrated value chains (figure 3b).

4. Discussion. Readiness of the Russian energy companies to introduce elements of Industry 4.0 based on digital technology

Until recently, the largest companies in the Russian energy sector have had a vertically integrated structure, which was especially evident in the oil and gas sector. According to the Ministry of Energy of the Russian Federation, 290 organizations carry out oil and gas condensate production in Russia, of which 100 organizations are part of 11 vertically integrated companies (VICs), mainly oil producers, and two are mainly gas and condensate producers. The number of independent mining companies outside the VIC structure is 187. Three companies operate in Russia under production sharing agreements (PSA).
Table 1. Modern concepts of digital business models.

| Key function | Platform model | “Smart field” model | Cyber-physical system |
|--------------|----------------|---------------------|----------------------|
|              | Upgrade (modification) of existing value chains | Based on full product lifecycle management | Based on the design and management of the entire value chain and the external environment of the company |
| Key digital business processes | Automatically tracks prices, markets, and consumer requests; Replaces intermediaries - optimizes the process of concluding transactions and conducting payments | Flexible serial automated production - transformer; Lean, automated, supply chain driven by the Internet of things; Integration with research, service, logistics and sales | A single complex of computing resources and physical processes, covering both individual enterprises and complexes of enterprises implementing sequential redistribution in value chains; Formation of a digital eco-system, including business and other interested parties |
| Key digital technologies | Big data, cloud storage, distributed registries | Industrial Internet of Things, robots, including drones, digital doubles, smart materials, 3D printing | Formatted of a new development paradigm based on the principles of Industry 4.0 |
| Removed restrictions | Expanding the boundaries of demand constraints | Expanding resource limits | Formation of a new development paradigm based on the principles of Industry 4.0 |

In the structure of oil and condensate production, VICs account for 80.3%; independent companies produce 16.4% of hydrocarbons, and PSA companies accounts for 3.4% of the production. The share of state-owned companies (Rosneft PJSC and Gazprom Neft PJSC, excluding unconsolidated assets) amounts to 42%, which is by 0.3% more than the previous year [22].

Over the past years, oil and gas companies have experienced severe resource constraints. Mega large fields with readily available resources are gradually exhausting themselves; over the past 10 years, independent oil companies operating with small and medium fields and the so-called hard-to-recover reserves have shown stable positive growth dynamics in oil production in Russia. They formally do not enter the structure of VICs. The average growth rate of oil production by independent companies over the past 10 years has been 8.2%, and the growth in production over the previous year was 2.1 million tons.

Changing the structure of the mineral resource base, the growth of hard-to-recover oil and gas reserves necessitate the development of new technological and organizational solutions. The search, exploration and production processes are significantly more expensive in connection with the development of deposits in remote and infrastructure-undeveloped places, the shelf of the Arctic seas, which requires the adaptation of known technologies to unconventional hydrocarbon production conditions. In the 1990’s, there was a demand in the industry for innovative process control tools to ensure the economic efficiency of oil and gas production in these difficult conditions. Therefore, the digitalization of the oil and gas industry is mainly related to the development of the “smart field” business model related to the development of forms of automation and management of the process of extraction, transportation and hydrocarbons processing [22].

One of the first digital projects in the oil and gas industry was the “smart well” project, implemented in 1997 at the Snorre Field in the North Sea by the Norwegian company Saga Petroleum. Later, the term was expanded to “smart field”, which allowed it to be applied to larger objects. The so-called “smart” technologies have been developed and disseminated throughout the AVC in the oil and gas industry. The effectiveness of these digital technologies is achieved by increasing the level of
control and automation of the production process, as well as minimizing labor. However, the latter is controversial because most likely there is a change in the structure of employees, and often towards downgrading [22].

Currently, the terms “intellectual field” (i-field), “field of the future” and “digital oil field of the future” (DOFF) are widely used. The purpose of creating “intelligent” deposits is the ability to ensure transparency and accessibility of the necessary production, geological, economic and other parameters and indicators of the enterprise [21].

In addition, the development of digital systems has allowed the formation in the oil and gas industry of a new element of the AVC – “administrative” or “managerial”. Thus, following high technology, the organizational structure of companies is being transformed, and the centralization process is intensifying. Subsidiary production units of large oil and gas companies are limited or completely deprived of their freedom of decision-making, since data processing and the formation of a development strategy take place in the head unit (holding) [22].

But, despite the existing positive aspects of the digitalization of the oil and gas industry, its level of Industry 4.0 formation lags far behind the world [23].

Somewhat different, the processes of Industry 4.0 are developing in the Russian coal industry. This is due to the fact that the domestic coal industry is much less monopolized than the oil and gas sector. This is because of the fact that they were privatized, and the enterprises incorporated in them became part of the energy, metallurgical, chemical and construction holdings as one of the lower branches. Due to this, such large monopolists as Gazprom and Rosneft did not survive in the coal industry; the AVCs turned out to be shorter and more branched. However, in the coal industry, most of the companies are still united in vertically integrated holdings, working mainly for export [24].

Another important factor, determining the features of the formation of Industry 4.0 and the creation AVCs in the industry, is more stringent demand constraints in the world market compared to the oil and gas sector. The fall in coal prices in 2011 and the decarbonization policy, pursued in developed countries, led to the fact that digital platform solutions in the field of logistics and sales began to actively develop in the coal industry. This made it possible to increase the efficiency of coal mining, reduce operating costs, and optimize other indicators of industry enterprises. Separate elements of Industry 4.0 and digitalization are also present in coal mining and processing technologies. There has appeared robotic or remotely controlled equipment, remote centralized control rooms, high-precision positioning of drilling rigs or excavators, portable devices for monitoring personnel health status, three-dimensional design and management enterprise models, predictive methods for analyzing geological data and everything related to the production process. However, they are mainly of a demonstration or experimental nature. The consequence of the energy transition and digitalization of the industry has been the growing role of medium and small independent coal mining companies focused on local markets [25].

The transition to digital technologies has created the conditions for cooperation between these companies within the framework of cooperative AVCs with the involvement of scientific and educational organizations and the state. The importance of intersectoral cooperation in the energy sector has grown. Coal producers and consumers are forced to adapt to the extreme volatility of markets and diversify their business, including the incorporation of small coal companies operating in local markets in their orbit of influence [16].

With the digitalization of logistics and the transport sector, the AVCs of large metallurgical and especially energy holdings have begun to change. Management and profit centers in these AVCs have begun to move to engineering, logistics and transport companies. AVCs themselves have become more flexible and decentralized. Even in developing countries, where with the support of the state vertically integrated coal companies with centralized AVCs maintained for especially long, new forms of competition have started to develop gradually; this sector has started to more and more join the “network economy”. At the same time, unlike the oil and gas sector, which is developing towards the creation of a “smart field” business model, the Russian coal mining companies are mainly going along
the path of creating platform solutions in the field of logistics. In this regard, the experience of SUEK, the largest Russian and world coal-mining holding company, is very indicative [26].

However, in general, the digitalization level of the Russian coal industry is still far behind the digitalization level of the coal industries of foreign countries such as the USA, the UK, Japan, the Czech Republic and Germany. The processes of digitalization and transformation of the industry are point-like in nature, have little impact on the areas of logistics and transport and have little effect on downstream costs.

5. Conclusion
The intensification of the global energy complex necessitates the search for a new paradigm for the development of the Russian fuel and energy complex with a focus on new approaches to the development of the raw material base and energy transition to environmentally friendly, mixed and renewable energy sources, sustainable development through the use of integrated geotechnologies and the formation of new added value chains.

The Industry 4.0 concept of industrial development opens up new opportunities for enterprises of the fuel and energy complex of Russia to significantly increase labor productivity, ensure safety, and rational subsoil use. Thanks to digitalization technologies, the “Internet of Things”, artificial intelligence and elements of robotization of the main and auxiliary technological processes, significant potential is being formed to reduce costs and increase the competitiveness of the Russian fuel and energy complex in the global energy market.

Acknowledgements
This article was prepared with the support of Russian Science Foundation (No. 17-78-20218, the project “Spatial specialization and holistic development of resource-type regions”).

References
[1] BP Outlook 2019 www.bp.com/en/global/corporate/energy-economics/energy-outlook.html
[2] Klaus Schwab 2016 World Economic Forum (Geneva, Switzerland) p 184
[3] Paul H 2016 Industrie 4.0. Annäherung an ein Konzept (Dortmund: Gelsenkirchen: IAT)
[4] Jämsä-Jounela S-L 2007 Future Trends in Process Automation. Annual Reviews in Control 31(2) 211–220
[5] Groenveld D and Rozou M 2016 Advanced Process Control for Grinding Circuits
[6] Ofstie D and Kargutkar B Proc. 54th Annual Conference of Metallurgists hosting America’s Conference on Aluminiun Alloys (Canada: Canadian Institute of Mining Metallurgy and Petroleum)
[7] Van Duin S, Meers L and Gibson G 2013 Proc. of 30th International Symposium on Automation and Robotics in construction and Mining (ISARC 2013) (Montreal, Quebec, Canada)
[8] Bassi L 2017 IEEE 3rd International Forum on Research and Technologies for Society and Industry – Innovation to Shape the Future for Society and Industry (RTSI) (Piscataway, NJ: IEEE) pp 1–6
[9] Chiarello F et al 2018 Computers in Industry 100 244–257
[10] Centre for the Fourth Industrial Revolution Network for Global Technology Governance. Web Economic Forum 2019 p 24
[11] Stanway G et al 2015 The Australasian Institute of Mining and Metallurgy ed Iron Ore Conference (Perth) pp 631–645
[12] Goosen E V, Nikitenko S M et al 2019 Eurasian Mining 2 36-40
[13] Nikitenko S M, Goosen E V et al 2017 Fundamental Research 2017 no 10 part 2 375–380
[14] Lumley L 2012 The Australasian Institute of Mining and Metallurgy ed Project Evaluation Conference pp 203–224
[15] Stanway G et al 2015 The Australasian Institute of Mining and Metallurgy ed Iron Ore Conference (Perth) pp 631–645
[16] Plakitkin Yu A and Plakitkina L S 2017 Ugol 2017 10(1099)
[17] Camarinha-Matos L M, Fornasiero R and Afsarmanesh H 2017 Collaboration in a Data-Rich World. PRO-VE 2017. IFIP Advances in Information and Communication Technology 506 3-17
[18] Capturing Value from Disruption Technology and Innovation in an Era of Energy Transformation. PwC global power & utilities. PwC 2016 p 36
[19] Kaplinsky R 2004 Journal Problems of Economic Transition vol 474 iss 2 74-115
[20] The Industry’s Future: The Destruction of Barriers. PwC Series of Development Prospects PwC 2018 p 16
[21] Kontorovich A E 2016 Science First-hand 1(67) 6-17
[22] Kontorovich A E, Eder L V and Filimonova I V 2017 IOP Conference Series: EES 84 012010
[23] Competing in the Digital Age. Strategic Challenges for the Russian Federation 2018 http://documents.worldbank.org
[24] Nikitenko S M and Goosen E V 2017 ECO vol 9 (519) 104–124
[25] Pestun V 2019 Jet Info 5-6
[26] Capturing Value from Disruption Technology and Innovation in an Era of Energy Transformation. PwC global power & utilities. PwC 2016 p 36