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MODELING FLEXIBLE VALUE CHAINS WITHIN THE FRAMEWORK OF CLEAN COAL TECHNOLOGIES

The study characterizes resilience of value chains in the Russian coal industry and is the first step toward modeling feasible value chain adaptation under the pressure of sanctions and other challenges. The authorial approach to the analysis of coal value chains includes identification of basic types of value chains in the coal industry, assessment of their current resilience and modeling feasible upgrading directions to enhance the long-term resilience of the value chains. The proposed approach to modeling flexible coal value chains sticks follows a certain algorithm, namely: review of typical value chains in the coal industry; assessment of their current resilience and development trends; finding of feasible directions of upgrading the value chains on the ground of enhanced flexibility and robustness and using clean coal technologies; description of new effective value chains in the coal industry using advanced clean technologies.

Keywords: *coal industry, value chains, value chain model, typical coal value chains, coal value chain resilience, value chain modeling, value chain upgrade*
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Introduction

One of the sensitive issues to be urgently addressed in the short run is stabilizing and adapting the Russian coal industry to the worsening conditions of coal mining, strengthening environmental standards and new sanctions being endlessly imposed on Russia.

In this regard, the authors have earlier referred to the concept of resilience to evaluate adaptability of the coal sector and to find methods capable to mitigate adverse factors.

The present-day situation both chops the demand for coal and breaks value chains (VC) in the coal industry and related branches. As a consequence, the adverse impact seizes the allied industries, the risks amass, and the integrated evaluation of the aftereffects is impossible without the VC analysis. Thus, in modern reality, the VC concept becomes increasingly often a framework for developing growth strategies for regions and industrial branches via finding the best options of their upgrading [1–4].

The authors, as other researchers in Russia and abroad, understand upgrading as the rise of a business company, an industry or a country in the global value chains. Kondratiev V. B. [5, 6] distinguished between four kinds of the upgrade: improvement of technology and production; improvement (upgrade) of a product; finding lower competition niches; transition between the value chains. Smorodinskaya N. V. et al [7] discussed feasibilities of rapid upgrade of a company's specialization to find new niches in different VC in the conditions of essential shifts in the global industrial landscape.

Available information and research methodology

The value chain analysis on a corporate, sectorial and transnational scale rests upon the concept proposed by M. Porter [8]. Sturgeon gave a most generalized definition of VC [9]. According to Sturgeon, value chains are the full sets of activities required to drive a product from an idea, through all stages of production and up to the end user. Kaplinsky R. [10] defined VC as a set of activities performed by the process participants—suppliers of products or services, starting from design and finishing with disposal after use. Park et al [11] associated VC with the distributed production at different places all over the world under coordination administered by a lead-company.

In this manner, despite some difference in definitions, the VC analysis can be assumed as a single concept including separate approaches which differ by the scale of a subject of the research, i.e., a company, an industry, a group of industries, countries or regions of the world. Each approach identifies the key links of chains, describes them and shows their connections. Frederick S., Jones L. et al, and Smorodinskaya N. V., Katukov D. D. emphasize that the modern VC analysis and mapping uses a reference model of a value chain composed of four basic components: supplies; added value; governance model; enabling environment [12–14]. This enables a researcher to reveal the critical sources of risks and competitive advantages of a test subject. **Figure 1** illustrates interaction between key elements of the VC reference model.

This article uses the concept of a value chain and takes the integrated value chain model as a framework for studying and modeling the existing and future value chains in the Russian coal industry, with selecting potentially promising value chains on the ground of their resilience.

The novelty of the authorial approach to the analysis of value chains in the coal industry consists in identifying the basic types of VC in the coal sector in Russia, evaluating their current resilience and attempting modeling their upgrading by way of improvement of their long-term resilience. Modeling of flexible coal chains follows the algorithm below:

1. Review of typical VC in the Russian coal industry;
2. Assessment of their current resilience and development trends;
3. Finding feasible directions of the value chain upgrading by means of enhancing robustness and flexibility of VC using clean coal technologies;
4. Description of new potential VC based on advanced clean coal technologies in the Russian coal industry.

Typical value chains and their current resilience in the Russian coal industry

The source data for the research are the official information available from the Central Dispatching Department of the Fuel and Energy Complex (CDD FEK), Rosinformugol JSC and from the Federal Service for State Statistics of Russia (Rosstat) on overall coal production in Russia and per coal mining companies in 2011–2021. The scope of the analyses encompassed 169 companies in operation over the period from 2011 to 2021. The information on communication between the companies and with the allied industrial sectors was obtained from the database of the electronic document management system SBIS and from

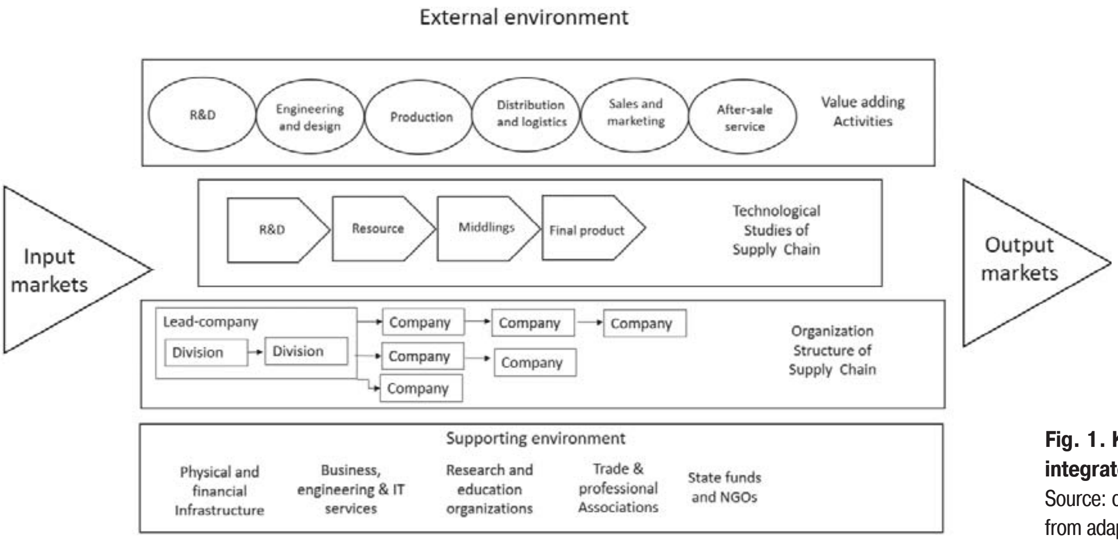

Fig. 1. Key elements of the integrated value chain model
Source: compiled by the authors from adaptation of [12–14]

Table 1. Sizes and stability maintenance strategies of independent coal mining companies

Size of companies	Number of companies	Percent of total number	Stability maintenance strategy		
			Bankruptcy procedure	Governmental support	Informal networking
Big	7	9	2	1	4
Average	8	10	2		4
Small	64	81	30	10	17
Total	79		34	12	25
Percent of companies adopting the strategy			43%	15%	32%
Source: authorial estimates from the evidence of Central Dispatching Department of the Fuel and Energy Complex (CDD FEK) and SBIS databases					

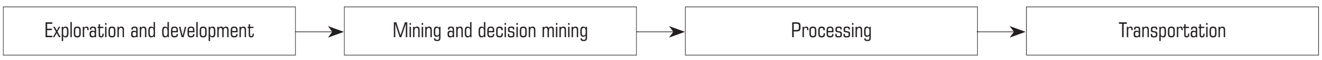

Fig. 2. Framework of typical market VC in coal sector
Source: authorial compilation from the evidence of Central Dispatching Department of the Fuel and Energy Complex (CDD FEK) and SBIS databases

interviewing expert practitioners in the coal mining industry. On this basis, the authors identified three basic types of coal VC efficient in Russia in 2011 up to 2021. The type design of VC used two key criteria: the value chain framework and governance. Then, choosing the procedure of Lagravinese, 2015; Faggian et al. 2018 and E. Giannakis et al 2020 [15–17] and using the gross coal production profile, we evaluated resilience of VC in two time periods: from 2011 to 2017 and from 2018 to 2021 which were the two waves of economic crisis. The first wave was connected with falling energy prices in 2014; the second wave took place because of VC fracture and decline in energy demand during the COVID-19 pandemic in 2019–2020. Each wave had limits represented by the year of the highest output on the eve of the crisis, the year of drop in production during the crisis and by the year of performance restoration after the crisis.

The review of the Central Dispatching Department of the Fuel and Energy Complex (CDD FEK) and SBIS databases and SBIS databases reveals three basic types of VC fully formed in the Russian coal sector, namely, the market value chains, the captive value chains and the hierarchy value chains, as per the methodology of Gereffi, 2005 [18].

The market VC represents a group of independent diversified companies having low expenses connected with finding a new business partner for any part. Such companies may be both small and big. The authorial selection of such VC contains 79 companies, including small-size companies defined as companies with annual coal production up to 500 Mt (**Table 1**).

Produced coal mostly goes to the internal market. Companies often have no a pronounced specialization. Consumers are often big coal companies which buy coal products to balance their own sales. Even when coming on the external markets, consumers are small, change frequently, and the share of companies on both sides of the market is insignificant. The companies within the market value chains seldom produce premium grade coal; for this reason, their main source of competitive capacity is saving of expenditures connected, first of all, with safety and wages. Often, to reduce expenses, companies choose outsourcing of some auxiliary activities (engineering, stripping, maintenance and transportation services).

The organizational framework of the market VC appears as a production chain of an individual company (**Fig. 2**).

The companies included in the market VC are extremely unstable. The lifespan of such companies is 5 years while the average investment life cycle in the coal sector is 15 years. **Table 2** describes the resilience dynamics of 8 companies included in the market VC and operated within

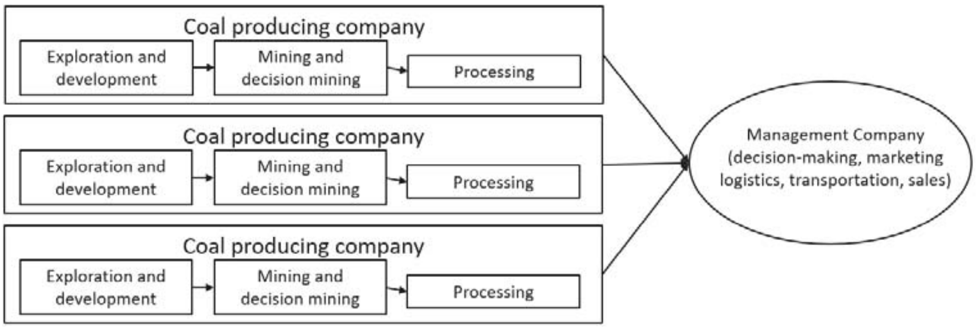

Fig. 3. Typical captive value chain in coal industry
Source: authorial compilation from the evidence of Central Dispatching Department of the Fuel and Energy Complex (CDD FEK) and SBIS databases

Table 2. Resilience of VC generated by independent coal companies

No.	Company	Resilience level	
		2011–2017	2018–2021
1	Kaichak 1 Open Pit Mine, LLC	4	1
2	Kan Open Pit Mine, JSC	4	1
3	Arktikugol Trust	3	2
4	Ugolnaya Mine, JSC	4	1
5	Oktyabrinsky Open Pit Mine, JSC	3	1
6	Rover, LLC	4	0
7	Shitkino Open Pit Mine, LLC	2	0
8	Zyryansky Open Pit Coal Mine, JSC	4	0

Source: authorial compilation from the evidence of Central Dispatching Department of the Fuel and Energy Complex (CDD FEK) and SBIS databases

Table 3. Resilience and business strategy of coal companies forming captive VC

No.	Company	Resilience level		Strategy*	Size**
		2011–2017	2018–2021		
1	Sibanthracite Group	0	2	1	3&2&1
2	Far-Eastern Generating Company	2	1	0	3
3	Russian Coal	1	2	1	3&2
4	TopProm Holding	2	1	0	2&1
5	YUKAS-Holding	3	3	0	2&1
6	SDS Ugol Holding	2	1	1	3
7	East Mining Company (EMCO)	0	4	1	3
8	KARAKAN INVEST	3	4	0	3

*Strategy: 0—VC core preservation; 1—acquisition of new coal assets to establish control over market; 2—establishment of new holdings with participation of governmental institutions.
**Size: 1—small companies; 2—average-size companies; 3—big companies.
Source: authorial estimates from the evidence of Central Dispatching Department of the Fuel and Energy Complex (CDD FEK) and SBIS databases

the whole test period. Figure 0 means that a company has either started or closed up business in the test period, which disables relevant calculation of company's resilience level.

When an individual company generating a market VC leaves the market, it has a weak influence on the current condition. Sometimes, for escaping the safety compliance, companies can informally unite for a short time and temporarily enter VC of another type. These temporal VC often lack a formal center of governance. In case of a crisis, companies prefer to leave the market. For this reason, the market VC have smudgy outlines in time and space.

Table 4. Resilience and business strategies of coal companies in hierarchy VC

No.	Company (specialization)*	Resilience level		Strategy**
		2011–2017	2018–2021	
1	EVRAZ (1)	3	1	2
2	Mechel (1)	4	3	0
3	Severstal (1)	2	1	2
4	Magnitogorsk Iron and Steel Works (1)	0	4	1
5	SUEK (2)	4	3	0
6	EN+ GROUP (2)	4	3	0
7	Inter RAO UES (2)	0	1	1
8	Siberian Cement Holding Company (3)	3	3	0

*Specialization: 1—metallurgy and coke chemistry; 2—coal-fired power generation; 3—cement.
**Strategy: 0—VC core preservation; 1—acquisition of coal assets to establish control over domestic market; 2—rejection of coal assets as non-core assets.
Source: authorial estimates from the evidence of Central Dispatching Department of the Fuel and Energy Complex (CDD FEK) and SBIS databases

The second group of value chains in the coal industry is the captive value chains. These are small diversified coal companies transactionally dependent on larger buyers [18]—sales and governance centers represented by big management or production companies (**Fig. 3**). The relationships between the companies in the captive value chains are formalized (based on property relations) and form diversified holding structures.

The captive value chains orient at both local and global coal markets, readily change consumers and use the domestic market as the mechanism of the business stabilization. The source of resilience is reduction in expenditures: logistics and transportation cost avoidance; flexibility is ensured by ingoing/outgoing from VC of small companies. The structure of the captive VC is more robust as against the market VC but is yet unstable.

The audit of the Russian coal industry reveals 18 diversified holdings based on the captive VC and independent of the certain industry consumers. **Table 3** gives information on 8 companies.

The studies show that companies in the captive VC adhered to two types of resilience strategies in 2011–2021. The first type strategy is acquisition of new asset to establish control over market, especially the domestic market. This trend was particularly pronounced in the first wave of crisis. The second type strategy is preservation of VC core composed of the money-winner companies producing premium quality coal. This trend was typical of the second wave of crisis.

The higher long-term resilience is a feature of the hierarchy value chains represented by the closed vertically integrated and product-oriented structures (**Table 4**).

Stability of the hierarchy VC ensues from tough dependence on specific consumers (metallurgical, power-generating or cement companies) which ensure a relatively stable demand for coal. It is important that such VC set severe entry constraints, which allows controlling all key links of VC, starting from extraction to end use of a mineral, as well as maintaining and promptly distributing revenues. Apart from minor exceptions, all links of such VC are the parts of a single company (**Fig. 4**).

Despite the generally higher resilience, the hierarchy VC demonstrated the lower level resilience in the second wave of crisis as against the first wave. In many ways, this is connected with the weaker flexibility of the hierarchy VC. These VC better withstand crisis but recover more difficultly afterwards.

It is also important that the resilience strategies in the hierarchy VC depend on the specialization. For instance, the companies within the metallurgical and cement holdings reduced their expenses in the time of the second wave of crisis by getting rid of their coal assesses as the non-core assets. In case that EU continue supporting sanctions on the Russian coal, this trend will intensify. Funneled out of the holdings, the companies will either undergo closure, or will join the unstable market and captive VC. To the authors' opinion, upgrade is the only way of enhancing resilience of coal companies in such situation.

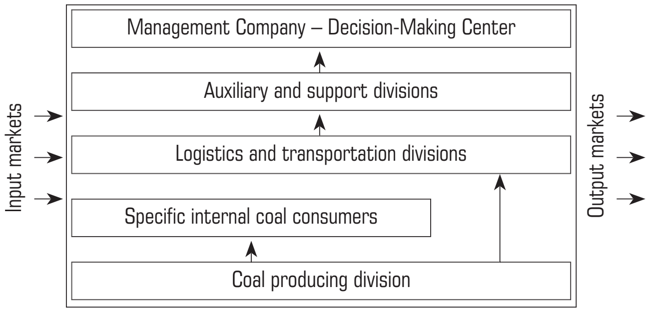

Fig. 4. Typical hierarchy VC in coal industry

Source: authorial estimates from the evidence of Central Dispatching Department of the Fuel and Energy Complex (CDD FEK) and SBIS databases

Possible ways of upgrading coal value chains

The analysis of the strong points and vulnerabilities of VC in the Russian coal sector enabled the authors to identify the most promising ways of upgrading VC on the basis of the commodity and technology integration:

- Elongation of VC by introduction of clean technologies for coal dressing and use;
- Creation of parallel VC by means of waste management;
- Building of branched VC (transformation of VC into a production network).

Efficiency of the VC upgrading in many ways depends on feasibility of using clean technologies in coal dressing and waste management, in scaling up of production and entrance to noncompetitive markets, and in localization of new segments of VC in the receiving regions. Such technologies should be a framework for the long-term technological integration and long-term resilience of coal companies. The authors revealed such technologies by implementing patent analysis and by interviewing expert practitioners. The revealed promising technologies were used to delineate the range of the available process flows in coal processing to become the basis for creation of new VC.

The patent analytics allows the cross analysis of the development strategies, products and engineering capabilities of regional coal companies, the research projects implemented by universities and research institutions in the regions to find the avenues of synergy and integrated technological advance, as well as the analysis of inter-regional relations and activities within the innovation and production clusters, which can optimize creation of new VC.

For instance, elongation and localization of coal VC is achievable using highly profitable, flexible and clean technologies of dry coal preparation, and ultra-supercritical (USC) technologies in coal-fired power generation. Such approaches can elongate the existing VC, stabilize the domestic demand for coal and reduce emission of CO_2. For example, the first USC coal-fired power plant at the cost of USD 3.4 billion, started in the United Arab Emirates—the Hassyan PP—will increase its capacity up to 2400 MW by 2023. The USC technology enables the plant to operate at higher steam temperatures and pressures than traditional thermal power plants have, which increases the power generation efficiency; moreover, the project includes carbon trapping, which greatly reduces emission of CO_2 [19]. Furthermore, this approach fosters localization of high-tech production in mining regions and ensures energy security (resilience) and economic security owing to differentiation of energy sources and products.

An illustration of the second and third ways of upgrading VC may be the low temperature pyrolysis technologies. They enable separation of coal into gas fuel and carbon residue, essential reduction of CO_2 emissions owing to the clean energy source (gas fuel) as well as production of semicoke and smokeless clean and high-calorific fuel. Moreover, the process is free from generation of ash and slag waste [20]. With such VC, alongside with the environmental effect, business enjoys scaling-up (trigeneration—production of three useful products from coal). Furthermore, VC extends with deeper conversion of coal and becomes more flexible. The simultaneous production of three and more products allows easier adaptation to fluctuating demand and price, and to reducing reserves. Such production is expedient to situate nearby coal mining areas, which favors diversification of the mono-specialization of the extractive regions and enhances their resilience.

A promising trend of VC upgrading, to the experts' opinion, is the use of coproduced methane and methane-oxidizing bacteria in production of protein to feed fish, domestic birds and cattle, and production of ferments, lipoids, sterols, antioxidants, pigments and polysaccharides [21]. Closed mines can use recovered methane as a clean energy source. Such approach improves safety, ecology and energy supply in the region. There exist methods to utilize methane from uncontrollable sources, including recovery of methane from a methane–air mixture, preliminary treatment of methane and, then, decomposition into hydrogen and acetylene. Hydrogen is used in fuel cells which supply the process of methane disposal, itself, and also external consumers. Such experience is available in Australia, Germany, Belgium, Poland, France and in some other countries.

Another promising trend in production networking may be land improvement above the closed mines via carbon farming or green belting using special technologies to increase absorption of carbon dioxide and to issue carbon units. The latter are meant to be purchased by not-carbon-neutral producers to compensate greenhouse gas emissions. The carbon farm testing on different terrain sites shows that one hectare of such land can absorb up to 7 tons of carbon [22].

It is important that VC upgrading by means of advanced high-tech inter-industry production networking within the framework of operating surface and underground coal mines can effectively reduce social, ecological and economic risks of coal mine closure.

Conclusions

Despite the ascending paradigm of zero carbon power generation, it is possible to preserve the coal industry thanks to a differentiated approach to the VC upgrading on the ground of introduction of new adaptable technologies with regard to specifics of mining companies. Such VC can be built in operating coal mines. Later on, diverse eco-friendly production can be arranged on the basis of the operating VC.

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