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Industrial clusters as an organizational model for the development of Russia petrochemical industry

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Abstract. The article explores the challenges facing Russia petrochemical industry over the past decade and examines the reasons behind its significant lag compared to other industrialized nations. It presents a review of academic research on clusters accompanied by a comparative analysis, generalization, and consolidation of factors influencing the development of the petrochemical industry in Russia. It is argued that advancing the petrochemical industry from production plants to integrated production complexes necessitates a shift towards clustering, which will improve resource utilization efficiency, bolster product competitiveness, and reduce production costs. The article examines and consolidates key cluster concepts, encompassing definitions, characteristics, composition, and constituent elements. It also examines strategic documents guiding the development of the petrochemical sector, assesses the progress made in forming petrochemical clusters in Russia, and draws upon European and Asian experiences and government support tools in the domain of petrochemical clusters. The successful development of petrochemical clusters in Russia is argued to be strongly dependent on state initiatives and support for infrastructure development. Additionally, the presence of research organizations within clusters is crucial for fostering high-tech product innovation and forming an efficient value chain that integrates research and development with specific assets. When establishing petrochemical clusters in Russia, it is essential to consider the unique characteristics of each cluster, including the types of raw materials and resources used, the necessary infrastructure, and the specific support measures and incentives provided by the state.

Keywords: petrochemicals; cluster organization; oil and gas industry; infrastructure; specific assets; public-private partnership

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Introduction. In the coming decades, the petrochemical industry is going to be a promising area for oil utilization globally due to several reasons.

• Due to the green agenda, the energy transition to renewable energy sources, and the growing interest in environmental issues witnessed in both developed and developing countries, the global demand for crude oil will decrease[1] [1, 2]. Despite these trends, the prospect of transitioning to a low-carbon economy in Russia remains vague due to the influence of geopolitical, economic, and social factors, coupled with the fact that the country has major hydrocarbon reserves.

• The oil consumption mix is expected to change towards an increase in the share of petrochemicals. By 2040, the projected growth in petrochemical demand could lead to a 75 % rise in global oil demand, reaching approximately 17 million barrels per day, and the share of petrochemicals may increase from 12.8 % in 2019 to 16.3 % [3, 4].

• The demand for petrochemical products is growing rapidly, particularly due to increased plastic consumption in the fast-developing Asia-Pacific region[2]. Global petrochemical capacity is forecasted to increase by 40 %, from 2,200 million tons per year in 2020 to 3,100 million tons per year in 2030,

[1] Global Energy and Climate Model. URL: https://www.iea.org/reports/global-energy-and-climate-model (accessed 09.04.2024).

[2] Petrochemical industry in Russia: Opportunities for growth. URL: https://www.csr.ru/upload/iblock/d88/9vy10zbpvss8f0h8z31616dij5zab3s6.pdf (accessed 09.04.2024).

mainly in Asia (India and China) due to the rising demand in oil- and gas-producing regions including the CIS, the Middle East, and North Africa [5, 6].

• Petrochemical products yield substantially higher profit margins compared to oil refining, where the margin stands at about 10 %. Processing ethane into basic petrochemical products, for instance, quadruples the value of the product, while LPG processing increases its value by a factor of 1.7[3].

It should be noted that the share of petrochemicals in Russia (2 % of GDP) lags behind industrialized countries, where it can reach up to 10 % [7]. In 2022, petrochemicals accounted for only 1.13 % of Russia's GDP[4], compared to 4.9 % in China[5]. While Russia has a significant number of explored and developed hydrocarbon fields and an abundance of resources, changes in the structure of oil markets and technological factors limit the development of the petrochemical industry. The latter include the following: low quality of produced petrochemicals and low processing rates (71.5 % in Russia compared to 96 % in the USA and 85 % in Europe) [8, 9]; lack of processes focused on improving product quality [10]; lack of up-to-date equipment at oil refineries due to high depreciation rates [11]; lack of oil recycling equipment [12]; limited knowledge intensity in petrochemical production; a lack of resource efficiency technologies in the context of industrial digitalization[6] [13].

Organizational and economic factors also limit the effective development of the petrochemical industry. They include the following: poorly developed infrastructure of the sector; imperfect integration mechanisms among economic entities and the state; high capital intensity and complex organization of modern petrochemical projects [14]; the need for special mechanisms for attracting financial resources and sharing risks [15]; insufficient government management of business coordination and cooperation in the petrochemical sector [16].

Throughout the 20th century, the evolution of Russia's petrochemical chemistry went through a series of distinct organizational stages. The industrial stage of production (1930-1960) witnessed the establishment of so-called combines, or organizational structures facilitating the production of key petrochemical products through sequential technological processes. This stage was characterized by localized production, abundant raw materials, and a local market for products [17].

The subsequent stage saw the emergence of large petrochemical complexes (1960-1980) as forms of territorial and industrial complexes. During this period, the product range broadened, fostering production and technological interconnections among companies and facilities that could be separated by large distances. Collaboration became important, marking a departure from the model within which companies operated individually. Integration became the focal point; i.e. previous stages were supplemented to produce end products. Emphasis was placed on economies of scale as a determinant factor governing production capacities and product mixes [17].

In the planned economy era, the construction of large plants and production complexes was actively pursued, aligning with the objectives of sectoral governance. However, in the contemporary market landscape, the utilization of traditional organizational models imposes constraints on progress in the petrochemical sector for several reasons. Firstly, the majority of industry products are characterized by innovation and, in some instances, specialization, and they are often produced in limited

[3] Khalbashkeev A. Petrochemistry: Results of 2021 and forecasts for the future. URL: https://nprom.online/market/neftehimiya-itogi-2021-g-i-prognozy/ (accessed 09.04.2024).

[4] Petrochemical industry in Russia 2023: Development prospects, consequences of sanctions, major players. URL: https://delprof.ru/press-center/open-analytics/neftekhimicheskaya-otrasl-v-rossii-2023-perspektivy-razvitiya-posledstviya-sanktsiy-krupneyshie-igro/ (accessed 09.04.2024).

[5] Wei Chen. China Issued Policy to Stimulate Petrochemical Industry. URL: https://www.lexology.com/library/detail.aspx?g=dd65fc5e-02dd-4083-a359-c1018dd94ebe#:~:text=In%202022%2C%20the%20gross%20production,approximately%204.9%25%20of%20China's%20GDP (accessed 09.04.2024).

[6] CO_2 as a new raw material – becoming a jack of all trades. URL: https://www.covestro.com/en/sustainability/lighthouse-projects/co2-dreams (accessed 09.04.2024).

quantities. This necessitates intensive research and development (R&D), along with the formulation and implementation of state-led mechanisms to stimulate innovation. Additionally, fostering collaboration mechanisms and industry networking becomes important. Secondly, the high capital intensity of infrastructure, coupled with the imperative to assess infrastructure costs in determining the efficiency of petrochemical production, underscores the necessity of exploring financing sources, with due consideration given to state involvement. Thirdly, an array of risks, encompassing market dynamics among others, necessitates devising mechanisms for risk-sharing between the state and businesses in novel, flexible organizational frameworks.

The national economy's need for the development of the petrochemical sector underscores the state's role in strategic planning, investment, and interaction with private businesses. Therefore, transforming large-scale planned production into cluster forms of organization, which are widely used globally but underdeveloped in Russia, will foster the growth and effective development of the Russian petrochemical industry.

The main goal of this study is to substantiate the use of a cluster form of organization in Russia's petrochemical industry for its successful development. The primary objectives are: identifying the features of the cluster form of industrial organization, including its characteristics, composition, interpretation, and elements; clarifying the definition of an industrial cluster in Russia's petrochemical sector; and analyzing the processes of creating and operating petrochemical clusters in Russia, considering international experience.

Literature review. Industrial clustering traces its roots back to the late 19th century, originating from the works of A.Marshall [18]. Marshall conceptualized clusters as groups of private businesses within a value system of buyers and suppliers, included companies in related technologies and shared factor or product markets. Over time, this model evolved to encompass institutions, such as universities, government agencies, and public-private organizations.

Our analysis showed that conceptual approaches to the definition and interpretation of the term "cluster", formed over more than 100 years, can be summarized as follows:

• American school, which includes concepts emphasizing the territorial forms of enhancing industry competitiveness (A.Marshall [18], M.Porter [19], and M.Enright [20]);

• British school, which includes concepts focusing on value chains and taking into account interconnections between local clusters (T.J.Dunning [21], J.Humphrey, and H.Schmitz [22]);

• Russian school, which includes concepts focusing on the formation of territorial and industrial complexes and the application of systems analysis methods (N.N.Kolosovsky [23] and B.S.Dondokov [24]);

• Scandinavian school, which includes concepts supporting new forms of production organization, integrating training organizations within industrial districts and regional clusters (B.Lundvall [25] and B.Johnson [26]);

• Different concepts based on the dominance of regional goals and ideas, such as regional specialization (A.Smith [27] and D.Riccardo [28]), regional development (W.Laundhart, M.Weber [29], and A.Lösch [30]), and urbanization (S.Rosenfeld [31] etc.).

An analysis of a number of works by Russian researchers[7] [32-34] has shown that there is no single approach to defining the term "cluster". However, common elements of a cluster can be identified, which, according to Russian authors, include a single territory (proximity of objects), government bodies, manufacturing companies, educational institutions, research centers, and infrastructure. Cluster elements are not homogeneous. For example, the location of objects is currently not fundamentally important for the cluster, since the advantages of the cluster are not necessarily associated with locational rent. Also, cluster participants can combine business processes in a common business model of the cluster. Cluster infrastructure, which refers to the

[7] Pomitov S.A. Clusters: Characteristics and models. URL: http://ekportal.ru/page-id-1805.html (accessed 09.04.2024).

assets that ensure the functioning of the cluster and its business processes, includes assets classified as specific within the institutional approach. For petrochemical clusters, such assets are product pipelines.

In order to improve the conceptual toolkit in the field of petrochemical clusters, the definition of a cluster should be supplemented with specific attributes (or elements) and methods of their interaction (or connections between them).

A synthesis of studies [35-37] shows that researchers focus on several factors associated with the emergence of business clusters:

• spatial community (J.Humphrey and H.Schmitz [22]), which is discussed using concepts and tools such as new economic geography, business activity analysis, regional studies, and innovation at the regional level;

• formation conditions (E.Bergman and E.Feser [35]), such as externalities, innovative environment, competition, cooperation, and flexibility of technological development;

• cluster composition by attributes (T.Andersson [36]), among which are geographic concentration, specialization, participant functions, cooperative competition, cluster life cycle, innovative nature, and critical mass;

• the purpose and method of cluster formation (I.Gordon and P.McCann [37]), with a focus on models of agglomeration, industrial complexes, and network interaction.

Factors constituting the first group, which focuses on geography, have limited significance for petrochemical clusters in Russia due to several reasons. They include considerable distances between material assets (hydrocarbon fields) and production facilities (refineries, gas processing plants, etc.), the need to establish an extensive interregional transport infrastructure spanning hundreds of kilometers is imperative, and the necessity to collaborate at the industry level within the domain of research and development.

Some studies [35] are relevant for petrochemical clusters as they consider the influence of the petrochemical industry on related industries involved in the production, sale, and use of petrochemicals. They also consider the innovative development of technologies for producing specialized small-tonnage products[8] and the cooperation and coordination related to knowledge exchange within the cluster.

Some studies [36] center on the composition of clusters and their critical mass as key factors. Notably, petrochemical clusters focus on establishing an effective value-added chain alongside gas (ethane, LPG) and oil (naphtha, straight-run gasoline) industries. Large-tonnage petrochemicals serve as the foundation for small-tonnage products, characterized by diverse items serving various industries and market segments. While large companies may not be inclined to diversify their product offerings due to the associated innovation costs[9,10], small and medium-sized businesses often take on this role. They are typically more technologically agile but may lack the investment resources for R&D.

In another study [37], network interaction within industrial structures emerges as an important cluster feature, particularly in the realm of information, competencies, and knowledge exchange. The connectivity of organizations within a cluster can be categorized as internal (within cluster organizations) and external (between cluster organizations and external entities)[11]. Internal connectivity significantly influences the formation of the value chain, underscoring its critical role in cluster dynamics.

Many clusters are shaped by local factors and resources provided in the region[12]. Many clusters are shaped by local factors and resources provided in the region. Although clusters do not develop

[8] Order of the Government of the Russian Federation N 2834-r "On the Action Plan (Road Map) for the Development of the Production of Small-Scale Chemicals in the Russian Federation until 2030" of December 15, 2017.

[9] Niyakovskaya N. A large role of small-tonnage chemicals: Innovative products and solving large-scale production problems. URL: https://belchemoil.by/news/tehnologii-i-trendy/bolshoj-ves-malotonnazhnoj-himii (accessed 09.04.2024).

[10] Nikishova I. Important small-tonnage products. *Element*[22]. 2020. N 4 (116), p. 8-10.

[11] Kutsenko E. Cluster policy regulations: Current situation and prospects for improvement. Clusters Opening Borders, May 12-13, 2016, St. Petersburg, Russia. 2016. URL: https://cluster.hse.ru/mirror/pubs/share/216093211 (accessed 09.04.2024).

[12] Brenner T. The Evolution of Localised Industrial Clusters: Identifying the Processes of Self-Organisation. *Papers on Economics & Evolution*. 2000. N 11.

automatically, regional factors influence the likelihood of cluster formation. For example, when forming industrial clusters in China, the Chinese Government determined which Chinese regions could produce greater benefits under existing conditions[13].

Our analysis has shown that prerequisites for industrial cluster formation can be divided into several groups:

• Geographic concentration: Clusters include only organizations located in close proximity to one another. Geographic concentration leads to several positive effects, which diminish as the distance between organizations increases. This feature helps distinguish clusters from cluster-like phenomena, such as networks of firms that do not qualify as clusters.

• Natural and environmental factors: These factors include conditions that are specific to a particular geographical area due to its natural and climatic characteristics and environment. They include the availability of natural resources, natural geographical features, the quality of the environment, and other parameters.

• Economic prerequisites: These involve the potential for creating and utilizing a unified value chain, which includes a common scope of activity, availability of skilled labor, cooperation between companies, industrial infrastructure, specialized suppliers, demand levels, potential consumers, developed capital market, and other resource factors. A cluster assumes a high density of connections between organizations within a particular field and with other entities (e.g., buyers, suppliers, including small and medium-sized ones, as well as scientific and educational institutions).

• Political prerequisites: These reflect government regulation, including the active participation of regional or federal authorities in developing and applying incentives for cluster creation.

• Cultural prerequisites: These include the attitudes of local residents and organization employees towards cooperation, partnership, interaction, and adaptability to new developments.

We believe that these factors are of a general kind; they are necessary but not sufficient for cluster formation and do not facilitate its identification. Across diverse industry clusters, these factors serve as a general framework with varying degrees of importance. The importance of a specific factor is contingent upon the cluster's emphasis on earning particular types of economic rent. Analyzing these factors is imperative to evaluate the overall conditions for cluster formation, and it necessitates customization for each specific cluster.

In addition to these prerequisites, several sufficient conditions are crucial for cluster creation: a critical mass of participants, possession of specific assets, and active engagement in innovations demonstrated by cluster participants [17, 38, 39].

The presence of a critical mass depends on the concentration level of economic entities in a particular area. In Russia, the uneven distribution of oil and gas assets across regions is significant. Key hydrocarbon fields are concentrated in the Yamal Autonomous Okrug and the Khanty-Mansi Autonomous Okrug while refining capacities are located closer to sales markets and infrastructure elements such as ports and railway stations.

Asset specificity, as explained by O.Williamson in transaction cost theory [38], indicates that some assets or resources possess unique characteristics that make them less suitable or more expensive for use in other settings or with other partners. This specificity may stem from technological features, cost structure, or other factors limiting their alternative uses. Asset specificity influences organizational decisions regarding production, transactions, and business management. Depending on the degree of specificity of assets, organizations can choose various forms of internal integration or external market transactions. In the Russian oil and gas sector, specific assets include pipelines

[13] China's chemical industry in 2019: A review. URL: https://ect-center.com/blog/chemistry-inchina-2019 (accessed 09.04.2024).

between oil producers and refineries, as well as between refineries and petrochemical production facilities.

The innovative activity of cluster participants involves companies actively seeking development through innovations such as new technologies, organizational changes, and marketing approaches. A high level of innovation activity often requires independence in research and development or collaboration with the scientific and educational community. Conducting R&D by individual cluster participants may be ineffective due to unpredictable demand and small production volumes of finished products[14] [32].

Among Russian researchers studying petrochemical clusters, noteworthy contributions have been made by V.A.Kryukov, A.Yu.Bannikov, E.S.Kutsenko, V.V.Shmat, N.V.Smorodinskaya, and others. They focus their studies on exploring cluster theory, the nuances of regional and innovation-driven clusters, regulatory frameworks in cluster policy, and comparative analyses of Russian and international experiences in clustering.

While general conceptual frameworks for cluster formation have been established, further research is needed concerning petrochemical clusters. Specifically, there is a need to focus on the prerequisites for their formation and their differences from similar forms of collaboration, to study the composition of subjects involved, and to examine the interaction between petrochemical clusters and academic institutions and research centers to foster innovative technologies. Additionally, optimizing logistics and transportation processes within clusters to cut costs and improve efficiency, as well as studying government support mechanisms and fostering collaboration among small and medium-sized enterprises within clusters to enhance their development and competitiveness, warrant further investigation.

Results. Our analysis of the scientific literature reveals that there is no universally accepted definition of a "cluster" or a consensus on its characteristics. However, we can identify a set of essential elements for forming a cluster: geographic proximity of participants, involvement of production companies, participation of research and educational organizations, engagement of public authorities, involvement of auxiliary organizations, technological and organizational linkages among cluster participants, logistics infrastructure accounting for specific assets, a unified strategic direction for all participants, and innovation-driven (knowledge-intensive) activities within the cluster.

The establishment of a petrochemical cluster in Russia is shaped by both conventional prerequisites (geographic, natural and environmental, economic, political, etc.) and specific ones, namely: the presence of a critical mass of participants, specific assets and infrastructure, and state-supported innovative activities of participants [17].

The projected petrochemical clusters in Russia are significantly influenced by previously implemented projects grounded in the concept of forming industrial complexes [17] within a planned economy. Contemporary strategic planning documents emphasize the need for a top-down approach, initiated by the government, for the creation and effective operation of petrochemical clusters[15] [40]. Modern petrochemistry encompasses both large-scale production in developing nations and small-scale production in developed countries. Small-scale petrochemicals necessitate intensive research and development efforts, along with market assessment for specialized products. This entails additional risks, which must be shared between the state and businesses. Notably, small-scale petrochemical production constitutes a unique asset, yielding distinct products.

Considering these factors, the definition of an industrial cluster in the Russian petrochemical industry can be formulated as follows: an industrial cluster is an association of entities engaged in joint activities within the framework of state-business interaction. This includes industrial production companies, research organizations, and educational institutions utilizing specific assets and a unified

[14] Meeting on the strategic development of the petrochemical industry. URL: http://www.kremlin.ru/events/president/news/64529 (accessed 09.04.2024).

[15] Decree of the Government of the Russian Federation N 779 "On Industrial Clusters and Specialized Organizations of Industrial Clusters" of July 31, 2015 (revised 28.09.2023).

infrastructure. Government bodies initiate the organization of the cluster, which aims to produce high-tech, specialized products with high added value.

The formation of an industrial cluster in the petrochemical industry involves the combination of several key elements:

• Shared territory: A fundamental characteristic of a cluster is the geographic proximity of participating entities, which fosters communication and interaction among them. One key characteristic[16] of oil and gas cluster development is that, despite the speed of technological progress and the dynamics of innovation, significant cost reductions and competitive advantages can be achieved through the close integration of interdependent production units and substantial reductions in logistics costs[17]. While early clusters were strictly limited territorially, modern clusters can span multiple cities and even regions [17].

• Research and educational organizations: The presence of educational institutions and scientific centers engaged in petrochemical research, development, and training is vital [17].

• Government bodies: Government entities play a crucial role in creating a favorable investment and legal environment. Their involvement ensures coordination and support for the industry's development [17].

• Manufacturing companies: The participation of manufacturing companies promotes resource sharing, technological collaboration, and innovation exchange. These interactions enhance competitiveness and improve production efficiency [28].

• Interconnection of participants: Network connections and interactions between cluster participants are necessary for knowledge, experience, and resource exchange. These collaborations foster integration and cooperation within the cluster [41-43].

• Developed production infrastructure: A well-established production infrastructure, including transport networks, energy systems, and communication facilities, is essential. Additionally, specific assets necessary for petrochemical industry operations and development are integral components of the production infrastructure [17].

• General focus: Clusters are based on shared strategic goals developed collaboratively by cluster participants. These goals encompass a comprehensive, knowledge-intensive value chain, beginning with hydrocarbon production and ending with the sale of finished goods [17].

To create and effectively develop a petrochemical cluster, state initiation and support measures are required.

To create and effectively develop a petrochemical cluster, state initiation and support measures are required. The creation and activities of petrochemical clusters in Russia are regulated by various regulatory legal documents, including laws, regulations, orders, and other kinds of documents, which are outlined in Table 1.

Table 1

Key documents regulating the creation and activities of petrochemical clusters in Russia

Title	Essence
Federal Law N 488-FZ On Industrial Policy in the Russian Federation" of December 31, 2014[18]	A definition of an industrial cluster is given; measures to stimulate cluster formation are proposed; the connection with the Spatial Development Strategy of the Russian Federation dated February 13, 2019 N 207-r (Article 20)[19] is emphasized
Decree of the Government of the Russian Federation N 779 "On Industrial Clusters and Specialized Organizations of Industrial Clusters" of July 31, 2015	Requirements are established for industrial clusters and specialized organizations within industrial clusters in order to apply federal-level incentive measures in industry

[16] Center for Cluster Development and Project Management of the Republic of Tatarstan. URL: https://innokam.ru/ (accessed 09.04.2024).

[17] Caspian cluster. URL: https://minprom.astrobl.ru/napravleniya-deyatelnosti/kaspiiskii-klaster (accessed 09.04.2024).

[18] Federal Law N 488-FZ On Industrial Policy in the Russian Federation" of December 31, 2014 (revised 12.12.2023).

[19] Decree of the Government of the Russian Federation N 207-r "On the Spatial Development Strategy of the Russian Federation until 2025" of February 13, 2019.

End of Table 1

Title	Essence
Order of the Ministry of Energy of Russia N 939 "On Approval of Methodological Recommendations on the Structure and Mechanisms of the Functioning of Petrochemical Clusters" of December 9, 2015[20]	The document contains fundamental concepts and gives recommendations on the structure and mechanisms of a successful petrochemical cluster
Order N 651/172 "On Approval of the Development Strategy of the Chemical and Petrochemical Sector until 2030" of April 8, 2014 (as amended on January 14, 2016)	The document contains a plan with the goal of establishing six clusters with large pyrolysis capacities in Western Siberia, Volga, Caspian, Eastern Siberia, Northwestern, and Far Eastern regions
Order of the Government of the Russian Federation N 2834-r "On the Action Plan (Road Map) for the Development of the Production of Small-Scale Chemicals in the Russian Federation until 2030" of December 15, 2017	The document is a set of measures to improve the mechanisms of government regulation of small-tonnage petrochemical production in Russia, which include cuts in imports, fostering domestic production of small-tonnage and medium-tonnage petrochemical products, and creating the conditions necessary for the production of small-tonnage petrochemicals capable of competing in the domestic and global markets
Action Plan (Road Map) for the Development of the Russian Petrochemical Sector until 2025[21]	This document shows the key development objectives for the petrochemical industry until 2025, which include the creation of petrochemical clusters in Russia's Arctic and Far East, the development of transport and logistics infrastructure, and the training of highly qualified professionals for the industry

An analysis of legal documents in Russia has revealed that initially, the primary objective of implementing cluster policy was to ensure rapid economic growth and diversification by enhancing the competitiveness of businesses. This encompassed suppliers of equipment, components, production and service providers, as well as research and educational organizations forming territorial production clusters[22]. The underlying assumption was that cluster policy would foster business competitiveness internationally through innovative technologies. However, later priorities shifted towards import substitution, stimulating domestic market demand for end products of the petrochemical industry, and increasing industry revenue contributions to the national budget.

The existing regulatory documents on cluster policy are of a methodological and recommendatory nature. Therefore, further specification is required, owing to the individual nature of clusters and the necessity for a comprehensive project assessment in petrochemical clusters. This approach enables the differentiation of government support measures, considering the unique conditions and prerequisites for the formation and development strategy of each specific cluster.

We have conducted an assessment of the present state and key outcomes of developing petrochemical clusters in Russian conditions, as outlined in strategic planning documents (Table 2).

The data presented in Table 2 yields the following insights:

While the West Siberian cluster is referred to as a petrochemical cluster, it currently does not produce petrochemical products and primarily operates as an oil industry cluster. Some experts even argue that it functions akin to a combine [17]. The Caspian petrochemical cluster does not fulfill the criteria of a petrochemical cluster either. It lacks a general strategic direction and the necessary elements, such as research and educational organizations that contribute to the creation of knowledge-intensive finished products. Moreover, it lacks a fully developed value chain for the production of end products derived from petrochemicals, effectively making it function as a special economic zone (SEZ).

[20] Order of the Ministry of Energy of Russia N 939 "On Approval of Methodological Recommendations on the Structure and Mechanisms of the Functioning of Petrochemical Clusters" of December 9, 2015.

[21] Decree of the Government of the Russian Federation N 1241-r "On Approval of the Action Plan (Road Map) for the Development of the Russian Petrochemical Sector until 2025" of May 16, 2023.

[22] Methodological recommendations for the implementation of cluster policy in the constituent entities of the Russian Federation (approved by the Ministry of Economic Development of the Russian Federation on December 26, 2008, N 20615-ak/d19).

Table 2

Clustering in the petrochemical sector: An analysis of the results

Name	Plans	Results
West Siberian petrochemical cluster	Processing raw materials such as NGL, naphtha, ethane, and LPG sourced from associated gas from oil fields and unstable gas condensate from gas condensate fields in the Khanty-Mansiysk Okrug and the Yamalo-Nenets Autonomous Okrug. Production was scheduled to commence in 2013. The cluster's focus lies on goods suitable for long-distance transportation, catering to the demands of petrochemical production in Russia. Polymer production is the top priority	On March 15, 2021, an agreement to establish the Oil Industry Cluster was signed between the Government of the Tyumen Region and the Oil and Gas Cluster Association. This cluster comprises six large companies, including Gazpromneft-Zapolyarye, Gazpromneft-Yamal, Sibneftemash, GMS Neftemash, SibBurMash, and Teplolux-Tyumen. Additionally, it includes seven medium-sized and six small businesses, along with a higher education institution (Tyumen Industrial University). Organizational support and technological infrastructure are provided by the West Siberian Innovation Center and the Infra-structure Development Agency of the Tyumen Region. The Tyumen regional government provides support to the cluster. The Petrochemical Cluster of the Tyumen Region Association is responsible for supplier selection, contractor management, and general coordination. In 2024, five companies are providing services and manufacturing products (oil services, polystyrene foam, metal structures, electrical equipment, and rolled metal). Another eight companies are producing equipment and components in the field of metal structures and oilfield equipment. Five companies are involved in the production of final products (electronics, oil and gas production, oilfield equipment, drilling rigs, engineering support)
Volga Region cluster	Petrochemical production units in Tatarstan, Bashkiria, Nizhny Novgorod, and Samara. Expanding existing capacities and establishing new facilities. Utilizing raw materials such as naphtha from oil refineries in Tatarstan and Bashkiria, ethane derived from natural gas processing in the Republic of Kazakhstan, and LPG from gas processing plants in Western Siberia. Petrochemical production. RusVinyl and Tolyattikauchuk, part of SIBUR Holding, are prominent PVC producers, producing between 330 and 500 tons annually[23]	The cluster lacks official information, documents, or a representative website, making it challenging to conclusively affirm its successful operation
Caspian cluster	Stavrolen plant, a natural gas conversion facility in the Stavropol Krai with Lukoil as the project initiator. The facility was aimed at processing local raw materials. Ethane and LPG were anticipated to be sourced from a gas processing plant handling associated gas from oil fields on the Caspian shelf, owned by Lukoil	In accordance with the Government of the Russian Federation's Decree No. 1792 dated November 7, 2020 ("On the Creation of a Special Economic Zone (SEZ) and the Caspian Cluster on the Territory of the Astrakhan Region"), the Caspian cluster was integrated with the LOTOS industrial production zone to serve as a node for the International North–South Transport Corridor. The primary activities within the LOTOS special economic zone include shipbuilding, production of components, manufacturing of oil and gas equipment and components, and high-tech industrial production. Within the LOTOS, there are 14 registered residents, but only two are focused on petrochemical production: LNG-Lotos, a project for the construction of an LNG plant, and Golden Industries Group, a project for an integrated natural gas conversion facility[24]

[23] Gordin M.V. Development of specialized industrial parks on the basis of large companies. Forum "Cluster Policy – the basis of innovative development of the national economy", September 11-12, 2014, Samara, Russia.

[24] Decree of the Government of the Russian Federation N 1792 "On the Creation of a Special Economic Zone (SEZ) and the Caspian Cluster on the Territory of the Astrakhan Region" of November 7, 2020.

End of Table 2

Name	Plans	Results
East Siberian cluster	The concept of this cluster, situated in the south of the Krasnoyarsk Territory and Irkutsk, is based on utilizing local raw materials, whose processing is impossible without solving the issue of helium utilization, as this element is abundant in the local deposits, and building gas pipelines for the sale of dry gas	This cluster remains in project
Far Eastern cluster	Located in Primorye, this cluster is intended to be based on the use of raw materials in the south of Yakutia. Helium utilization and storage, the use of resources from fields in Eastern Siberia, and the use of the East Siberia-Pacific Ocean (ESPO) pipeline are the issues that need to be addressed. The final products are expected to be consumed both in the domestic market and internationally. New facilities were planned for commissioning between 2020-2025	This cluster remains in project
North-Western cluster	The cluster was planned to be established on the basis of petrochemical facilities in the Baltic (SIBUR Holding with a potential partner's involvement) and completed by 2017. The cluster was supposed to be located on the coast, which improved sales logistics and naturally oriented it towards exports to the European Union. The launch of production was planned for the period 2017-2020	Currently, a natural gas conversion plant is being designed on the basis of the previously planned cluster, focusing on methanol, ammonia, and urea production. Phased construction is scheduled from 2024 to 2030[25]

Of the six petrochemical clusters outlined in strategic planning documents, only two are fully operational. Notably, the Caspian cluster primarily focuses on shipbuilding and the production of oil and gas equipment and components, rather than petrochemical products.

The challenges encountered in establishing petrochemical clusters in Russia underscore the importance of analyzing international experiences in implementing clusters within the petrochemical domain. Specifically, we examined the Flanders cluster in Belgium[26], the Upper Austria cluster in Austria[27], and the Jurong cluster in Singapore[28]. These clusters were chosen due to their similarity to the Kama industrial cluster. Our analysis encompassed aspects such as cluster composition, model, structure, and necessary infrastructure.

Flanders serves as an industrial hub, hosting approximately 70 % of all Belgian industry, with its chemical cluster being one of the world's largest petrochemical clusters. Global chemical companies such as BASF, Dow Chemical, Exxon Mobil, SABIC, Dupont, Total, Bayer, Sumitomo Chemical, Akzo Nobel, Air Liquide, Evonik, Lindel Group and others are headquartered there.

Jurong accommodates about a hundred leading oil, petrochemical, and chemical corporations. Key investors include BASF, Exxon Mobil, Dupont, Mitsui Chemicals, Shell, Singapore Petroleum, Sumitomo Chemical, and other companies.

[25] Baltic Methanol facility at the Ust-Luga seaport. URL: https://baltmethanol.ru/ (accessed 09.04.2024).

[26] Flanders Cluster Program – Cluster pacts. URL: https://www.interregeurope.eu/good-practices/flanders-cluster-program-cluster-pacts (accessed 09.04.2024).

[27] Cluster und Kooperationen. URL: https://www.biz-up.at/kooperation/unsere cluster (accessed 09.04.2024).

[28] Jurong Island Vision Zero. URL: https://www.tal.sg/wshc/about-us/jurong-island-vision-zero (accessed 09.04.2024).

In Upper Austria, major international companies are involved, including Solvay Vienna, Ticona, Borealis, Eaton, Sony DADC, KTMchemicals, Philips, TCGUNITECH, PipeLife, Delphi, Siemens, ENGEL, PIOVAN, EREMA, ABB, HAIDLMAIR, HASCO, and Meusburger. Cluster participants specialize in raw material production and supply, polymer processing, and tool manufacturing. The share of large businesses in the total number of participants is 17 %, and the share of small and medium-sized companies is 83 %.

High-tech products are created by involving research centers and specialized universities. For example, the Jurong cluster includes business and industrial parks, the Institute of Chemical and Engineering Sciences, the National University of Singapore, and private research centers. The experience of Belgium shows successful collaborations with the largest research centers and universities, including the Universities of Ghent and Antwerp and research centers run by companies including Total Petrochemicals Feluy, Dow Corning, Procter&Gamble, Solvay, Recticel, Agfa-Gevaert, etc. Antwerp hosts technical competence centers of BASF, Evonik-Degussa, and Bayer. The Austrian cluster actively cooperates with the Johannes Kepler University and with institutes of applied sciences. Research centers not only produce new developments but are also responsible for quality control of finished products, i.e., both research and development and engineering functions are performed.

Our analysis has shown that in terms of their model and structure, petrochemical clusters amalgamate transnational corporations with major international investors alongside national small and medium-sized businesses along a cohesive value chain. For example, the state-owned Jurong Town Corporation (JTC Corporation) is the owner of the Jurong cluster's land and infrastructure and the developer and manager of Singapore's industrial complexes and related services. JTC reports to the Ministry of Trade and Industry of Singapore.

Logistics infrastructure and knowledge exchange are fundamental to cluster success, facilitated by well-developed pipeline systems, storage terminals, and distribution platforms. Moreover, an active exchange of experience and knowledge between cluster participants is necessary, including international assistance and consulting, i.e. in the development of networks of various types.

The government provides active research support and uses measures to attract external investors. They take various forms, including flexible taxation standards, R&D subsidies, close interaction with universities, support for technology start-ups, etc.

Cluster initiatives typically receive funding from various sources, which involve a combination of public and private financing. Public financing is provided in the form of subsidies provided by municipal, regional, national, and European authorities, usually in varying proportions. For instance, in the case of the ChemCoast cluster in Germany, infrastructure projects were supported by the governments of Lower Saxony and Schleswig-Holstein, alongside major chemical corporations such as Bayer Material Science and Sasol Germany [44].

In contrast, the effective formation and development of petrochemical clusters in Russia necessitate the creation of transport pipeline infrastructure through Public-Private Partnerships (PPP), accelerate the development and implementation of innovations, expedited innovation cycles, especially in small-scale petrochemicals, and application of tools for state support of petrochemical clusters.

Conclusions. Our analysis of cluster concepts revealed a lack of consensus among Russian and international researchers regarding the definition of a cluster and its elements. Definitions vary based on geographic concentration, type of cluster members, organizational forms, coordination conditions, government participation, and infrastructure availability. This article has broadened the concept of an industrial cluster in the petrochemical sector and identified cluster elements and characteristics.

The study examined prerequisites for the formation of a petrochemical cluster, including innovative activity, specific assets, and logistics infrastructure. Our analysis of Russia's petrochemical clusters showed that out of six planned clusters, only two are operational. However, these two do not focus on petrochemicals but have different objectives. This situation can be attributed to imperfect regulations governing the creation and management of petrochemical clusters in Russia, a vague definition of what a cluster consists of, and a shift in national priorities regarding the economy.

Our study of successful petrochemical clusters around the world underscores the importance of research organizations contributing to high-tech product development, as well as the integration of participants to form an effective value chain, incorporating R&D and specialized infrastructure, and the development of government support tools. It is argued that successful clustering in the petrochemical industry relies on state initiatives and support for logistics infrastructure.

Progress in Russia's petrochemical sector can be facilitated through the adoption of a cluster-based organizational framework, distinguished from other territorial and vertically integrated structures by its strategic orientation, participant-government interaction dynamics, utilization of specific assets, and knowledge-intensive production and products. Initiating the formation of petrochemical clusters in Russia should be a state-driven endeavor, with essential economic support entailing the construction of pipeline infrastructure for both large-scale and small-scale petrochemical production, predominantly facilitated through concession agreements.

The insights garnered from this study hold practical implications. For instance, the identified characteristics and the refined definition of petrochemical clusters can be recommended for informing adjustments to regulatory frameworks, such as the Federal Law N 488-FZ of December 31, 2014 ("On Industrial Policy in the Russian Federation"), the Decree of the Government of the Russian Federation N 779 of July 31, 2015 ("On Industrial Clusters and Specialized Organizations of Industrial Clusters"), as well as updated development strategies and methodological documents on the establishment of petrochemical clusters.

The refined concepts proposed by the authors, the prerequisites for cluster formation, and elements of a cluster discussed in the study are specific to petrochemical clusters in the Russian context. This is due to the historical features of the development of the petrochemical industry in Russia and the relevant regulatory framework (in comparison with the experience of the leading countries in the industry, there is no clear focus typical for petrochemical clusters), and the structure of petrochemical production. It is essential to acknowledge the individuality and uniqueness of each cluster, taking into account factors such as raw materials, resources, necessary infrastructure, government support measures, and government incentives.

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