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战略决策和风险管理

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CONTENTS / 目录

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Moscow as an example of a methodological approach to a comprehensive assessment of the environmental safety of heat supply

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Abstract

The letter of the Ministry of Energy of the Russian Federation No. MU-4343/09, dated 15 April 2020, defines recommendations for the content of heat supply systems for cities in accordance with Decree of the Government of the Russian Federation No. 154, dated 22 February 2012. It is necessary to assess the environmental safety on urban heat supply. The authors propose a methodological approach to the development of the 'Environmental safety of heat supply' part, taking into account the regulatory framework of pollutant emissions that defined by regulatory legal acts in Russia. The article highlights the issues of creating a database of pollution sources, conducting an inventory of emissions, using automated algorithms to calculate the dispersion of pollutants, and creating a geo-information layer of pollutants for the electronic model of a heat supply system.

Keywords: ecology, heat supply scheme, atmospheric air protection, automation, dispersion of pollutants.

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以莫斯科为例综合评估供热环境安全的方法论

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简介

2020年4月15日俄罗斯能源部第MU-4343/09号“关于批准居民点和城市区域供热计划 ”的信函，根据2012年2月22日俄罗斯联邦政府第154号“关于供热计划的要求、制定和批准程序 ”的决议，确定了居民点供热计划内容的建议。作者特别指出，有必要对居民区供热的环境安全进行评估。作者提出了制定 “供热环境安全 ”部分的方法论，包括考虑俄罗斯联邦环境安全和环境保护领域的规范性法案所规定的污染物排放规范性法律条例。 文章重点介绍了建立污染源数据库、编制污染物排放清单、使用自动算法计算扩散量以及在供热计划电子模型中形成污染物扩散地理信息层等问题。

关键词: 生态、供热计划、空气保护、自动化、污染物扩散。

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Osokin N.A., Maximov A.G., Kurov A.A., Zolotova I.Yu. (2025). 以莫斯科为例综合评估供热环境安全的方法论。战略决策和风险管理, 16(1): 10–19. DOI: 10.17747/2618-947X-2025-1-10-19。(俄文)

Introduction

The quality of atmospheric air plays a key role in ensuring environmental safety and public health and is regulated in the Russian Federation by regulatory legal acts that establish the basic requirements for environmental protection, control of emissions of pollutants (hereinafter referred to as PP) and ensuring the sanitary and epidemiological well-being of the population. The Constitution of the Russian Federation (hereinafter referred to as the Constitution) defines the rights of citizens to a favourable environment and reliable information about its condition, as well as the obligation to preserve nature and take good care of natural resources. The relevant provisions of the Constitution are reflected in the regulations governing not only the sphere of environmental protection, but also practically all sectors of the Russian Federation, including heat supply. Table 1 shows the regulatory legal framework for ensuring the quality of atmospheric air as part of federal laws in the sphere of environmental protection and energy, reflecting the articles of the Constitution.

In accordance with Part 1 of Article 3 of the Federal Law of the Russian Federation dated 27.07.2010 N 190-FZ 'On Heat Supply', one of the principles of the organisation of relations in the sphere of heat supply is to ensure the environmental safety of heat supply. According to Article 10 of the Decree of the Government of the Russian Federation dated 22.02.2012 N 154 'On Requirements to Heat Supply Schemes, the Procedure of Their Development and Approval'[1] (hereinafter – Decree 154), the heat supply scheme of settlements, municipal districts, city districts, cities of federal importance is subject to annual updating[2]. In accordance with Articles 2 and 23 of the Decree of the Government of the Russian Federation No. 154, when developing and updating heat supply systems for populated areas with a population of 100,000 people, one of the mandatory components of the heat supply system is the 'Electronic model of the heat supply system of a settlement, a municipal district, a city of federal importance'.

According to the Letter of the Ministry of Energy of the Russian Federation dated 15.04.2020 No. MU-4343/09 'On

Table 1
Regulatory framework for ensuring air quality: Federal laws in connection with Articles 42 and 58 of the Constitution of the Russian Federation

Federal law	Articles of the Constitution in the field of atmospheric air protection	
	Art. 42: Everyone has the right to a favourable environment and reliable information about its condition	Art. 58: Everyone is obliged to preserve nature and the environment and to treat natural resources with care
Federal Law No. 7-FZ of 10.01.2002 'On Environmental Protection'.	Establishes requirements for the provision of environmental information (Art. 4.3) Establishes the procedure for the creation of a federal state information system on the state of the environment (Art. 4.4) and a unified system of state environmental monitoring (Art. 63.1)	Defines the objects of environmental protection subject to state control (Art. 4, 69) Defines the standards in the field of environmental protection (Art. 19-31)
Federal Law No. 96-FZ of 04.05.1999 'On Protection of Atmospheric Air'.	Sets out requirements for the provision of information on changes in atmospheric conditions (Art. 19, 23, 29)	Establishes requirements and standards for the quality of atmospheric air (Articles 11-19) Ensures control of impacts on atmospheric air (Article 21) Establishes the procedure for monitoring and controlling emissions of pollutants (Articles 23-26)
Federal Law No. 52-FZ of 30.03.1999 'On sanitary and epidemiological protection of the population'.	Establishes the procedure for ensuring the sanitary and epidemiological well-being of the population (Art. 2)	Establishes sanitary and epidemiological requirements for atmospheric air (Art. 20)
The Federal Law 'On Electric Power Industry' No. 35-FZ of 26.03.2003.	Establishes requirements for the provision of information on accidents in the electricity industry (Art. 28.5)	Establishes the principle of ensuring the environmental safety of the electricity industry (Art. 6)
Federal Law No. 190-FZ of 27.07.2010 'On Heat Supply'.	Establishes requirements for the provision of information on the activities of heat supply organisations (Art. 23.7)	Establishes the principle of ensuring the environmental safety of heat supply (Art. 3) Determines the development of heat supply systems taking into account the minimum harmful impact on the environment (Art. 23)

Sources: prepared by the authors on the basis of the Federal Laws 'On Environmental Protection" of 10.01.2002 No. 7-FZ, "On Atmospheric Air Protection' of 04.05.1999 No. 96-FZ, 'On Sanitary and Epidemiological Welfare of the Population' of 30.03.1999 No. 52-FZ, 'On Electric Power Industry' of 26.03.2003 No. 35-FZ, 'On Heat Supply' of 27.07.2010 No. 190-FZ.

[1] Decree of the Government of the Russian Federation dated 22.02.2012 N 154 'On requirements to heat supply systems, the procedure of their development and approval'. https://base.garant.ru/70144110/?ysclid=m82x2l2m82131373086.

[2] Except for the approval of the Master Plan in accordance with the procedure established by the legislation on urban development activities, changes in the period for which the Master Plan is approved, or in the event that the period of validity of the heat supply scheme (updated heat supply scheme) is less than 5 years. In such cases, a draft of a new heat supply scheme shall be prepared.

Approval of Heat Supply Schemes for Settlements, Urban Districts'[3] (hereinafter referred to as the Letter of RF Ministry of Energy), when developing and updating heat supply schemes it is recommended to include a section describing the current state of environmental impact 'Environmental safety of heat supply':

- an electronic map of the territory of a populated area showing the current location of all heat supply facilities;
- description of background or summary calculations of pollutant concentrations;
- description of the characteristics and quantities of fuels burned in heat supply installations;
- description of the technical characteristics of boiler units;
- description of gross and maximum single emissions of pollutants into the atmosphere from thermal energy sources;
- description of the results of calculations of the annual average concentrations of pollutants in the ground layer of atmospheric air from heat supply plants;
- description of the results of calculations of the maximum one-time concentrations of pollutants in the ground layer of atmospheric air from heat supply installations;
- description of the volume (mass) of the formation and emplacement of waste from fuel combustion;
- presentation of calculated data on the dispersion of pollutants from heat supply installations on a map of the settlement.

The letter from the Russian Ministry of Energy also lists pollutants for which it is recommended to provide a description of the gross and maximum one-time emissions into the atmosphere from thermal energy sources: sulphur dioxide, carbon monoxide, nitrogen oxides, benzo(a)pyrene, fuel oil ash calculated as vanadium, and solid particles. These pollutants are included in the list of pollutants, in respect of which state regulatory measures are applied in the field of environmental protection, and are presented in the Order of the Government of the Russian Federation dated 20.10.2023 No 2909-r[4].

Standards for maximum allowable concentrations (hereinafter referred to as MAC) of pollutants in the atmospheric air of urban and rural settlements are approved and presented in SanPiN 1.2.3685-21[5]. Standards for approximate safe reference levels of impact (hereinafter referred to as SRLI) have been approved for a number of substances. Table 2 presents the standards for MAC of pollutants in the atmospheric air, determined by the Ministry of Energy of Russia.

According to Paragraph 70 of SanPiN 2.1.3684-21, the hygienic standards for the content of pollutants in the air 1.0 MAC (SRLI) in residential areas and 0.8 MAC (SRLI) in the areas of health resorts, sanatoriums, rest homes, boarding houses, tourist centres, organised recreation of the population, beaches, parks, sports bases, long-term medical and preventive institutions and rehabilitation centres must not be exceeded[6].

In the Russian Federation, state monitoring of air quality is carried out at federal monitoring stations of the

Table 2
MAC standards for pollutants in the air of urban and rural settlements

Pollutant	MAC one-time (mg/m^3)	MAC d/a (mg/m^3)	MAC a/a (mg/m^3)	SRLI (mg/m^3)
Nitrogen dioxide NO_2	0.2	0.1	0.04	—
Nitrogen oxide NO	0.4	—	0.06	—
Sulfur dioxide SO_2	0.5	0.05	—	—
Carbon oxide CO	5.0	3.0	3.0	—
Benz(a)pyrene $C_{20}H_{12}$	—	0.000001	0.000001	—
Fuel oil ash	—	0.002	—	—
Inorganic dust with SiO_2 content of 20–70%	0.3	0.1	—	—
Coal ash	—	—	—	0.3

Source: prepared by the authors based on the analysis of SanPiN 1.2.3685-21.

[3] Letter of the Ministry of Energy of the Russian Federation dated 15.04.2020 No. МЮ-4343/09 'On Approval of Heat Supply Schemes for Settlements and Urban Districts'. https://www.garant.ru/products/ipo/prime/doc/73896578/?ysclid=m82qcoua2x611919392.

[4] Decree of the Government of the Russian Federation dated 20.10.2023 N 2909-r 'On Approval of the List of Pollutants for Which State Regulatory Measures are Applied in the Field of Environmental Protection and on Recognition of Invalidity of Certain Decisions of the Government of the Russian Federation'. http://publication.pravo.gov.ru/document/0001202310230035?ysclid=m82qzlofoa566641787.

[5] Resolution of the Chief State Sanitary Doctor of the Russian Federation dated 28.01.2021 No. 2 'On Approval of Sanitary Rules and Regulations SanPiN 1.2.3685-21 'Hygienic standards and requirements for ensuring safety and (or) harmlessness of environmental factors for humans'. http://publication.pravo.gov.ru/Document/View/0001202102030022?ysclid=m82qgi3yaj304980243.

[6] Resolution of the Chief State Sanitary Doctor of the Russian Federation dated 28.01.2021 No. 3 'On Approval of Sanitary Rules and Regulations SanPiN 2.1.3684-21 "Sanitary and epidemiological requirements for maintenance of the territories of urban and rural settlements, water bodies, drinking water and drinking water supply, atmospheric air, soils, residential premises, operation of industrial, public premises, organisation and implementation of sanitary and anti-epidemic (preventive) measures"'. . http://publication.pravo.gov.ru/Document/View/0001202102050027?ysclid=m82qkbxy2o246511165.

Roshydromet network (641 stations in 222 cities in 2023)[7]. In a number of cities, for example, pollution levels are also monitored at regional level:

– State Budgetary Institution ‘MosEcoMonitoring’ in Moscow (56 automatic stations)[8];
– SPb State Budgetary Institution ‘Mineral’ in St. Petersburg (25 automatic stations)[9];
– Krai State Budgetary Institution Center for the Implementation of Environmental Manage-ment and Environmental Protection in the Krasnoyarsk Territory (17 automatic stations)[10].

Requirements for monitoring the state of the environment are approved by Order of the Ministry of Natural Resources of Russia dated 30 July 2020 No 524[11].

Emissions of pollutants into the atmosphere from stationary sources are regulated by the state in accordance with Article 3 of the Decree of the Government of the Russian Federation dated 09.12.2020 No. 2055[12]. Heat supply installations shall comply with the following standards:

– maximum permissible emissions (standards for permissible emissions);
– technological emission standards;
– maximum permissible standards for harmful physical impacts on atmospheric air;
– technical emission standards.

Table 3
Number of heat supply sources in the Russian Federation in 2022 by capacity

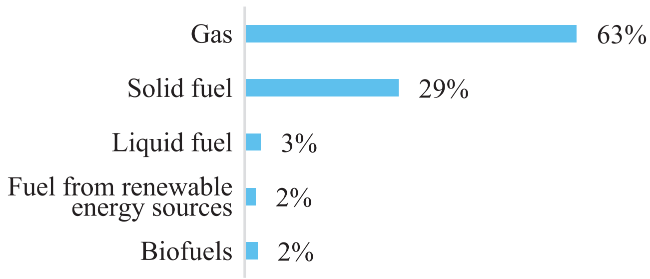
Heat supply source	Power	Number
Combined heat and power plants	< 25 thousand. kW	225
	> 25 thousand. kW	170
Boiler houses	< 3 Gcal·h	56876
	3–20 Gcal·h	13319
	20–100 Gcal·h	2453
	> 100 Gcal·h	598
Electric boilers, other	—	1180

Source: prepared by the authors on the basis of the report of the RF Ministry of Energy for 2022. https://minenergo.gov.ru/press-center/presentations/doklad-o-sostoyanii-teploenergetiki-i-tsentralizovannogo-teplosnabzheniya-v-rf-2022-?docs-group=file-295051.

According to the report of the Ministry of Energy of Russia ‘On the state of thermal power engineering and centralised heat supply in the Russian Federation in 2022’ (hereinafter referred to as the ‘Report of the Ministry of Energy of Russia for 2022’), in 2022 there will be 395 combined heat and power plants and about 74.4 thousand boiler houses in the Russian Federation (Table 3)[13].

Heat supply sources in the Russian Federation use the following types of fuel: gas, solid fuel (coal, peat, pellets, etc.), liquid fuel, fuel from renewable energy sources and biofuel. The fuel structure of heat supply sources in the Russian Federation in 2022 is shown in Fig. 1.

Fig. 1. Fuel structure of heat supply sources in 2022 (%)



Source: prepared by the authors on the basis of the RF Ministry of Energy's report for 2022. https://minenergo.gov.ru/press-center/presentations/doklad-o-sostoyanii-teploenergetiki-i-tsentralizovannogo-teplosnabzheniya-v-rf-2022-?docs-group=file-295051.

According to the Information and Technical Handbook on Best Available Technologies ITS 38-2024 [Information and Technical Handbook, 2024], the main types of pollutants emitted into the atmosphere during the combustion of organic fuels in thermal power plants (hereinafter referred to as TPPs) are: sulphur dioxide, nitrogen oxides, carbon monoxide and solid fuel ash, and the greenhouse gas carbon dioxide CO_2. Other pollutants are also formed: benz(a)pyrene, soot, solid particles of unburned fuel.

The government has therefore established norms and standards aimed at minimising the negative impact of heat supply sources on the environment.

1. Literature review

Issues of the environmental safety of heat supply have been addressed repeatedly in the scientific literature.

A study by the National Research University ‘MPEI’ [Chekhranova, Gasho, 2020] analysed the operation of the Krasnoyarsk thermal power complex. The authors studied the possible effects of minimising the impact of the heat supply

[7] Review of the state and pollution of the environment in the Russian Federation for 2023. Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet). Moscow, 2024. https://www.meteorf.gov.ru/product/infomaterials/90/.
[8] https://mosecom.mos.ru/.
[9] https://mineral.kpoos.gov.spb.ru/.
[10] http://krasecology.ru/About/Index.
[11] Order of the Ministry of Natural Resources of Russia of 30 July 2020 N 524 ‘On Approval of Requirements for Monitoring the Condition of the Environment and Its Pollution’. http://publication.pravo.gov.ru/Document/View/0001202012140051?ysclid=m82qm4ko3s896194726.
[12] Decree of the Government of the Russian Federation dated 09.12.2020 N 2055 ‘On Maximum Permissible Emissions, Temporary Permissible Emissions, Maximum Permissible Standards for Harmful Physical Effects on Atmospheric Air and Permits for Emissions of Pollutants into Atmospheric Air’. http://government.ru/docs/all/131484/.
[13] Information and analytical report ‘On the state of thermal power engineering and central heat supply in the Russian Federation in 2022’, Ministry of Energy of the Russian Federation, 2023. https://minenergo.gov.ru/press-center/presentations/doklad-o-sostoyanii-teploenergetiki-i-tsentralizovannogo-teplosnabzheniya-v-rf-2022-?docs-group=file-295051.

system on the atmospheric air by increasing the supply of thermal energy from thermal power plants by redistributing the thermal load from boiler houses to thermal power plants with subsequent decommissioning or preservation of boiler houses. This practice is justified by the higher stacks of thermal power plants and the lower specific fuel consumption in the production of thermal energy, which has a positive effect on the volume and dispersion of emissions of pollutants from heat supply sources.

The work [Gasho et al., 2019] investigated the degree of influence of motor transport, production of thermal and electric energy at power plants and boiler houses on the ecological and climatic systems of Moscow. The authors found that the energy saving policy implemented in Moscow in terms of reduction of thermal energy losses led to an annual decrease in gas consumption at thermal energy sources by 7% in 2018, and a decrease in gross emissions of pollutants into the atmosphere of the city by 3.3 thousand tons/year.

The aforementioned works evaluated the effectiveness of specific measures aimed at reducing emissions of pollutants and minimising their concentration in the atmospheric air. It should be noted that currently there is no approved methodological approach to the issue of conducting a comprehensive assessment of the environmental safety of heat supply in cities, taking into account the requirements and methods defined by Orders of the Ministry of Natural Resources of Russia No. 273[14] (hereinafter referred to as Methodology No. 273) and No. 813[15] (hereinafter referred to as Methodology No. 813).

2. Research objective

On the territory of the Russian Federation there is a procedure of verification of computer programs for calculation of dispersion of emissions of pollutants in atmospheric air (except for emissions of radioactive substances) for compliance with Methodology No. 273 in accordance with Order No. 779 of the Ministry of Natural Resources of Russia dated 20.11.2009[16]. Within the framework of this work, the authors also proposed an analysis of existing calculation programmes and assessed the possibility of their integration to solve the complex problem of forming the ‘Environmental safety of heat supply’ section in heat supply schemes. The developed approach will be relevant for cities included in the experiment on quotas of pollutant emissions into the atmosphere within the framework of the federal project ‘Clean Air’ in accordance with the Resolution of the Government of the Russian Federation dated 07.07.2022 No. 1852-r[17].

The assessment of the environmental safety of the city’s heat supply should be carried out in stages, taking into account the current requirements of legal acts and based on the principle of minimising manual data processing and calculations:

1) creation of a database of emission sources and monitoring posts;
2) entering data into certified calculation software (e.g., Integral, ECOcenter, Logus, ERA);
3) calculation of emissions and dispersion of pollutants taking into account external conditions (including meteorological conditions) using certified calculation software;
4) Creation of an electronic model of the impact of thermal power plants on atmospheric air using geoinformation software (hereinafter referred to as GeoPO);
5) Processing of the results of calculations of the dispersion of pollutants;
6) Creation of the project of the section ‘Environmental safety of heat supply’ for the heat supply scheme.

The first stage of the creation of a database of pollutant emission sources and air pollution monitoring stations includes the creation of registers of heat supply organisations, heat supply installations, heat generating installations and chimneys.

The second stage involves the transfer of data from the database to certified software that meets the requirements of the regulatory documents of the RF Ministry of Natural Resources. The certified software reflects the key attributes of all information objects, including fuel consumption, gas-air mixture characteristics and emission source parameters (height, pipe mouth diameter, presence of multi-barrel pipes).

The third step is to fill in the data and specify the parameters for the calculation:

– indicating meteorological characteristics and coefficients that determine the conditions for the dispersion of pollutant emissions into the atmosphere (based on data from a long-term observation period);
– indicating background concentrations of pollutants at background monitoring sites;
– selecting substances for calculation and background consideration
– indicating calculation areas with the introduction of calculation points;
– determining the dimensions of the calculated grid of the territory;
– forming layers (industrial, residential, safety, sanitary) with landfills.

The fourth stage involves the development of an electronic calculation model based on GeoPO. In this case, it is necessary to ensure the unloading of spatial data layers:

[14] Order of the Ministry of Natural Resources of Russia dated 06.06.2017 No. 273 ‘On Approval of Methods for Calculating the Dispersion of Emissions of Noxious (Polluting) Substances in Atmospheric Air’. http://publication.pravo.gov.ru/Document/View/0001201708110012?ysclid=m82qujzx7t214321841.

[15] Order of the Ministry of Natural Resources of Russia of 29 November 2019 No. 813 ‘On Approval of the Rules for Conducting Consolidated Calculations of Atmospheric Air Pollution, Including Their Updating’. http://publication.pravo.gov.ru/Document/View/0001201912260018?ysclid=m82qv8wd32613657367.

[16] Decision of the Ministry of Natural Resources of Russia of 20.11.2019 N 779 ‘On Approval of the Procedure for Conducting an Examination of an Electronic Computer Program for Calculating the Dispersion of Emissions of Pollutants in Atmospheric Air (Except for Emissions of Radioactive Substances)'. http://publication.pravo.gov.ru/Document/View/0001201912260037?ysclid=m82qw70jnt555713095.

[17] Order of the Government of the Russian Federation dated 07.07.2022 N 1852-r ‘On Approval of the List of Municipalities and Municipal Districts with High and Very High Levels of Air Pollution, in Addition to the Territories of the Experiment on Pollutant Emission Quotas’. http://publication.pravo.gov.ru/Document/View/0001202207080032?ysclid=m82qxylj1o596954812.

objects, chimneys, monitoring stations, calculation points, isolines of dispersion fields for each pollutant. In addition, sanitary protection zones (hereinafter referred to as SPZ), residential areas and specially protected natural areas (hereinafter referred to as SPNA) can be applied.

The fifth stage involves analysing the results of the calculations, including:

- presentation of the calculation results in the form of maps - diagrams of a populated area with isolines of the results of the calculation of the dispersion of pollutants;
- determination of the contribution of thermal energy sources to the concentration of pollutants at calculation points;
- determination of the thermal energy sources with the largest contribution to the concentration of pollutants in the ground;
- determination of pollutants exceeding the hygienic standards for the quality of atmospheric air by more than 0.8 MAC at points located within the boundaries of specially protected natural areas, and by more than 1 MAC at other calculation points.

In the sixth stage, a textual description of the results is produced, with conclusions structured in several sections: by heat supply organisations and facilities, by territorial division of the settlement, by pollutants, by monitoring stations and calculation points.

To validate the proposed approach, the efficiency is assessed, including the time and labour costs required to implement the stages of the proposed approach. In order to assess the efficiency of the decisions made at each stage, an experiment was conducted by comparing the time resources spent on implementation with and without the use of automation algorithms. The results of the experiment are described in the next section of this article.

3. Practical significance

The proposed approach was implemented using the example of the Moscow heat supply scheme for the two most relevant periods (updated for 2024 and 2025) to analyse the existing impact of thermal power plants on the air basin and climate of the city.

A total of 325 heat supply facilities included in the Moscow Heat Supply Scheme as of 01/01/2022 and 01/01/2023 were reviewed, including 687 emission sources (chimneys), 1278 pollution sources (boilers). To create the database, forms were sent to heat supply organisations for completion. Then the initial data were verified on the basis of the developed rules of format-logical control: establishment of confidence intervals for the parameters of pollution sources (height, pipe diameter, etc.), logical rules for calculated indicators (e.g. checking the gross values of pollutant and greenhouse gas emissions by the volume of fuel used and thermal energy supplied).

The initial data was loaded and processed using the PostgreSQL database management system (used in software products included in the Unified Register of Russian Programs for Electronic Computers and Databases, and is also part of the basic services of the Unified Digital Service of GosTech).

Based on the results obtained, a register of pollutant emission sources was compiled, which was used to calculate pollutant concentrations (Fig. 2).

The second stage of data collection involved transferring the data from the database to the certified ‘Integral’ calculation software.

The coding was introduced to ensure the information link of all sources along the following chain: organisation, object, chimney. For example, the chimney of TPP-23 of PAO Mosenergo was coded as OT312_T0003, where OT is the heat supply object, 312 is the serial number of the heat supply object in the register, T0003 is the serial number of the chimney.

The algorithm for the automatic input of data from the database into the certified software ‘Integral’ was developed in the Python programming language. In this way, the original database is independent of the certified software used to calculate the dispersion of pollutants. This approach makes it possible to minimise the number of errors when entering source data into the certified software and to reduce the time spent on updating and correcting data. It should be noted that certified software does not cover the full list of tasks specified in the recommendations of the Russian Ministry of Energy’s letter, including the calculation of greenhouse gas emissions, management of production and consumption waste, and water discharges.

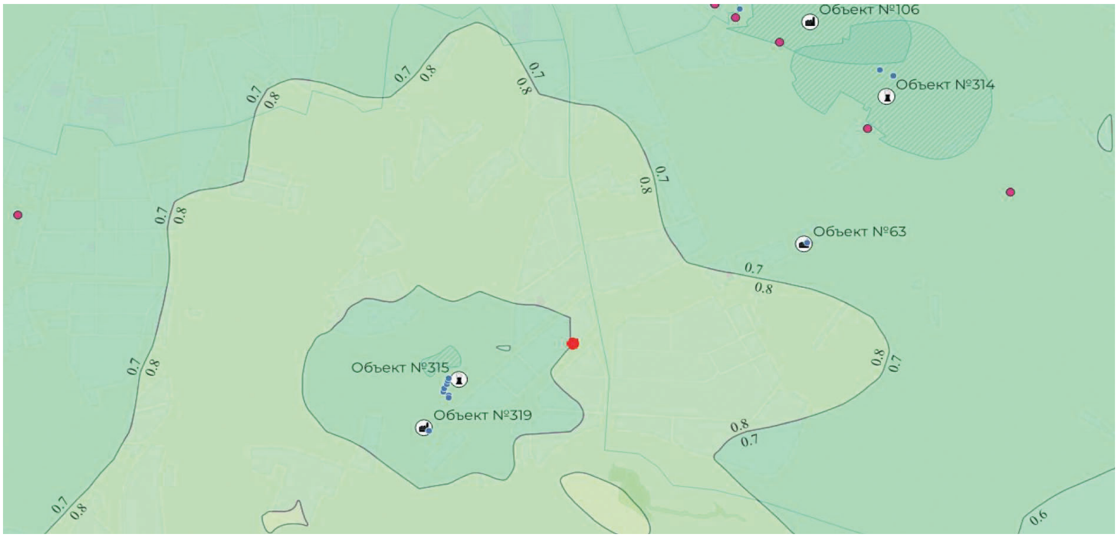
At this stage, time savings of up to 100 hours have been achieved by eliminating manual data transfer and the need for repeated checks.

In the third stage, preliminary and refined calculation of maximum one-time concentrations of pollutants and calculation of dispersion of pollutant emissions were carried out in the Integral software and calculation complex. One of the stages of the automated calculation was the introduction of meteorological characteristics and coefficients determining the conditions for the dispersion of pollutant emissions into the atmosphere. A short meteorological characteristic for Moscow was used as a source of data on meteorological conditions based on the observations of the meteorological station of the Federal Observatory of the Roshydromet network (FSBI Central UGMS).

Preliminary and refined calculations of ground-level concentrations have been made for the following pollutants and combinations of pollutant effects when present together in ambient air (summation effect):

- nitrogen dioxide (0301);
- nitrogen oxides (0304);
- carbon monoxide (0337);
- benz(a)pyrene (0703);
- sulphur dioxide (0330);
- fuel oil ash (for vanadium - 2904);
- nitrogen dioxide and sulphur dioxide (6204);
- all substances (combined result).

Fig. 2. Visualisation of a geo-information model showing heat supply facilities, pollutant emission sources, sanitary protection zones, residential areas, dispersion fields (isolines) and the results of the calculation of ground concentrations at control points



Source: compiled by the authors.

The results of the preliminary calculations were compared with the data from the monitoring stations of the federal network of Roshydromet to identify discrepancies, with the aim of adjusting the initial data for carrying out updated calculations of pollutant concentrations in accordance with Methodology No. 813.

At the next stage, an electronic model of the impact of thermal power plants on atmospheric air was created using GeoPO with open source code, on the basis of which it is possible to develop domestic software included in the Unified Register of Electronic Computers and Databases. The following layers were created in the geo-information model:

– calculation points: near thermal power plants, federal monitoring stations of the Federal State Budgetary Institution 'Central UGMS', regional monitoring stations of the State Budgetary Institution 'MosEcoMonitoring', on the border of protected zones, on the border of the sanitary protection zone;
– zones: industrial, residential, safety and health protection zones;
– pollutant emission sources;
– sources of heat supply;
– results of pollutant dispersion calculations in the form of isolines.

The developed model was formed as an independent single geoinformation file, which allows interactive visualisation of the spatial distribution of pollutants in the atmosphere. To create the model, an algorithm was used that included processing and transfer of the generated results from the Integral software and calculation complex to GeoPO. This model can also be integrated into an electronic model of a heat supply system, including for the formation of electronic models of heat supply systems (ZuluThermo, CityCom, etc.). An example of a visual representation of the modelling results is shown in Fig. 2.

By automating this stage of the process, time savings of up to 50 hours per iteration of the data visualisation and presentation process have been identified.

The stage of processing the results of the dispersion calculations involved the following types of work:

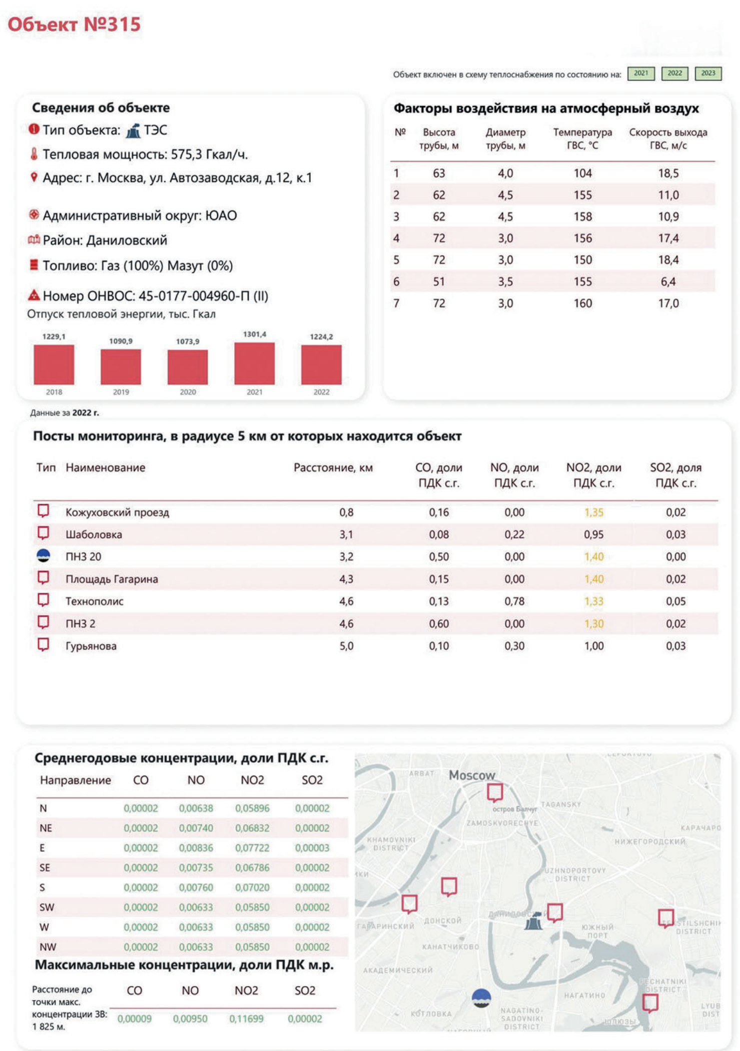
– development of an algorithm to automatically process the results of pollutant dispersion calculations;
– entering the results into the database;
– creation of passports for heat supply facilities with information on each facility, including its characteristics, technical parameters and the nearest air monitoring stations (Fig. 3);
– monitoring station passports containing information on the location of the stations, the pollutants monitored and their concentrations in the air (Fig. 4).

The draft text of the section 'Ecological safety of heat supply' of the heat supply scheme can be created using the Report Designer of Cycle-On LLC - Thermo Carb-On, which enables the generation of a textual description of the calculation results in relation to the database. Using Moscow as an example, the final section contains 325 facility passports, 68 monitoring station passports, analyses for 12 administrative districts, including analyses for facilities outside Moscow, analyses for 4 substances and summation groups for which emissions from heat supply facilities are formed, and for 143 reference points.

By automating the processing of dispersion calculation results and text generation, it is expected that up to 80 hours of data processing and text generation time will be saved.

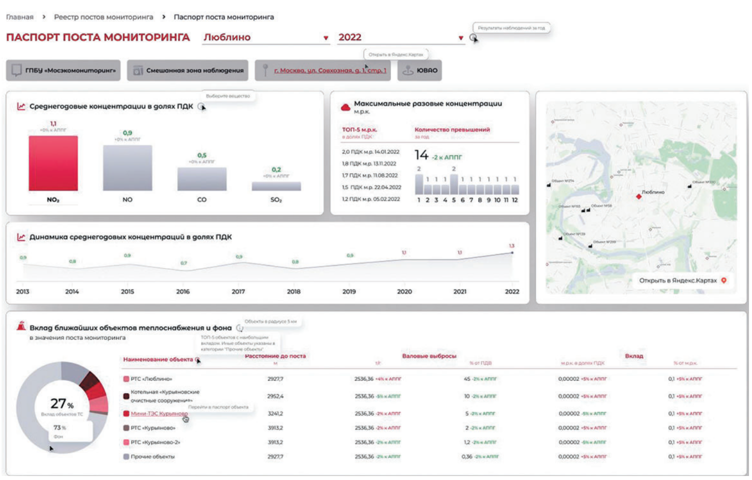
Table 4 presents tools for automating processes to reduce the labour costs of conducting a comprehensive assessment of the environmental safety of heat supply, using Moscow as an example.

Fig. 3. Facility certificate



Source: compiled by the authors.

Fig. 4. Example of a surveillance pass



Source: compiled by the authors.

Table 4
Effects of automating the stages of complex environmental assessment on the example of Moscow

Stages		Impacts	
№	**Stage name**	**Time saving (hours per 1 iteration)**	**Description of the impact**
1	Collecting and systematising the data received	100	The need for manual data entry and aggregation is eliminated, data format errors and technical errors are minimised
2	Automating the input of information from the database into the Integral calculation software	40	The need for manual data entry when transferring to certified software is eliminated
4	Creating an electronic model of the impact of thermal power plants on atmospheric air	50	The need to manually consolidate dispersion calculation results into a single geoinformation model (a layer for each substance and each calculation grid) is eliminated
5	Processing the results of calculations of pollutant dispersion	20	The need for manual processing of results, aggregation of results is eliminated
6	Formation of the project of the section ‘Environmental safety of heat supply’.	60	The labor costs for writing a text description of calculation results and the costs of processing the description when updating data and calculations are minimised

Source: compiled by the authors.

Conclusions

At present, there is no approved methodological approach for implementing the recommendations of the Russian Ministry of Energy on making a comprehensive assessment of the environmental safety of heat supply systems for populated areas.

Within the framework of this article an approach to the formation of the section ‘Ecological safety of heat supply’ of heat supply schemes is proposed, taking into account the recommendations of the Ministry of Energy of Russia, including the use of automated algorithms. Testing of the approach on the example of the Moscow heat supply system allowed to create a scalable toolkit for assessment of ecological safety of heat supply in cities.

The proposed methodological approach can be used in the development of heat supply schemes in cities that are obliged to develop and update an electronic model of the heat supply scheme. The approach can also be used in the work of state and municipal authorities in connection with the preparation of the order for the development and updating of heat supply schemes, and in carrying out procedures for their coordination and approval. The proposed approach is particularly relevant for cities included in the experiment on quotas for emissions of pollutants into the atmosphere within the framework of the federal project 'Clean Air'.

As a further development of this study, it is also possible to develop automated software products that allow the formation of the 'Environmental safety of heat supply' section, including through integration with certified computer calculation programs that calculate the dispersion of pollutants according to Method No. 273.

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Integration of coal mining and metallurgy sectors: Transforming partnership models for sustainable development

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Abstract

The article examines the characteristics of traditional partnerships and those created to achieve sustainable development goals.
Although perceived as a positive contribution to solving sustainable development problems, numerous studies demonstrate the ineffectiveness of such partnerships. This presents researchers and practitioners with the critical challenge of understanding how to improve partnership effectiveness.
An empirical analysis of partnerships in the coal mining and metallurgical sector was carried out. Five types of relationship clusters were identified: partnerships focused on economic benefits; partnerships focused on scientific and technical cooperation; partnerships focused on joint value creation; partnerships focused on new opportunities; and partnerships focused on relationships. It was concluded that in the coal mining and metallurgy sectors, partnerships for economic benefits and partnerships for scientific and technical cooperation predominate. In this context, it is necessary to develop a mechanism aimed at improving common technologies and economic indicators in order to ensure the effectiveness of the partnerships created to pursue sustainable development goals.
The article aims to develop and analyse new models of interaction between the coal mining and metallurgy sectors, with a view to improving environmental and economic sustainability.
Keywords: sustainable development, metallurgical industry, coal mining industry, interfirm relationships, partnership models, partnership management strategy.

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整合煤炭和金属部门：转变伙伴关系模式促进可持续发展

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简介

文章讨论了传统伙伴关系和为实现可持续发展目标而建立的伙伴关系的特点。
尽管伙伴关系被视为对解决可持续发展问题的积极贡献，但有许多研究证明这种伙伴关系并不有效。这对研究人员和从业人员了解如何提高伙伴关系的有效性提出了重要挑
战。
对煤矿和冶金行业的公司伙伴关系进行了实证分析。确定了五类关系集群：追求经济效益的伙伴关系；以科技合作为目的的伙伴关系；以共同创造价值为目的的伙伴关系；以新机遇为重点的伙伴关系；以关系为重点的伙伴关系。结论是，煤矿和冶金部门主要是追求经济效益的伙伴关系和以科技合作为目的的伙伴关系。在这方面，为了使为实现可持续发展目标而建立的伙伴关系发挥效力，有必要建立一个旨在提高联合技术效力和改善经济效益的机制。
文章旨在开发和分析煤炭开采和冶金行业之间互动的新模式，以改善环境和经济的可持续性。
关键词: 可持续发展、冶金工业、煤矿工业、企业间关系、伙伴关系模式、伙伴关系管理战略。

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Introduction

The successful implementation of the Sustainable Development Goals (SDGs) can only be achieved through the formation of partnerships between businesses, public organisations and the public sector [Prescott, Stibbe, 2015; Clarke, MacDonald, 2019; MacDonald et al., 2019]. Only through partnerships will it be possible to achieve a 'safe space for human action' [Rockstrom et al., 2009], as new forms of collaboration will allow more effective solutions to be developed to achieve sustainable development goals [Biermann et al., 2009; Keohane, Victor, 2011; Zelli, 2011]. Research in the field of partnership formation argues that such partnerships are characterised by a polycentric governance architecture [Cole, 2015] and are multilateral.

Despite the emergence of many multi-stakeholder partnerships, academic research finds little evidence of their positive impact on achieving the Sustainable Development Goals. This poses an important challenge for researchers and practitioners to understand and improve the effectiveness of partnerships, especially as their popularity grows.

The focus of this study is on the effectiveness of partnerships to reduce the carbon footprint in the metals industry. Existing works mainly focus on individual aspects, such as the use of hydrogen or coal processing, without addressing the comprehensive approach to the transformation of partnership models and their impact on sustainable development.

Life cycle assessment and emission modelling methods were used to analyse environmental aspects, which made it possible to identify the most promising technologies in terms of sustainable development.

1. Theoretical review of the literature

1.1. Characteristics of traditional partnerships and partnerships for the achievement of sustainable development goals

Historically, partnerships emerged as business partnerships for mutual economic benefit. Approaches to forming partnerships have been determined by their effectiveness, the achievement of intended results, the activity of the participants in the interaction, the emphasis on long-term cooperation and the multidimensional nature of the relationships within the framework of value creation.

A win-win approach and emphasis on long-term cooperation means that when mutually beneficial relationships are established and developed, the partners add value to each other and the gain of one party becomes the gain of the other (win-win). If there is no mutual benefit in the relationship, then the gain of one party is the loss of the other.

The activity of the participants in the relationship is realised through trust in each other and the quality of the relationship, which is reflected in the frequency of interaction between the parties.

The multidimensionality of relationships is determined by a variety of factors and levels of relationship management: at the level of the organisation as a whole, at the level of the organisation's divisions, at the individual level of individual employees. At the same time, the factors of interaction include factors of the external environment of relationships and the atmosphere of interaction (Fig. 1).

The external environment of interaction reflects the level of competition between partners, their interdependence, trust, commitment to relationships and interaction with stakeholders.

The atmosphere of interaction[1] is both the result of the development of the relationship and a factor in further cooperation. It is determined by the balance of power of the partners in the relationship, mutual understanding, the level of cooperation between the partners, including the exchange of knowledge, cooperation in the field of R&D, the implementation of standards, etc.

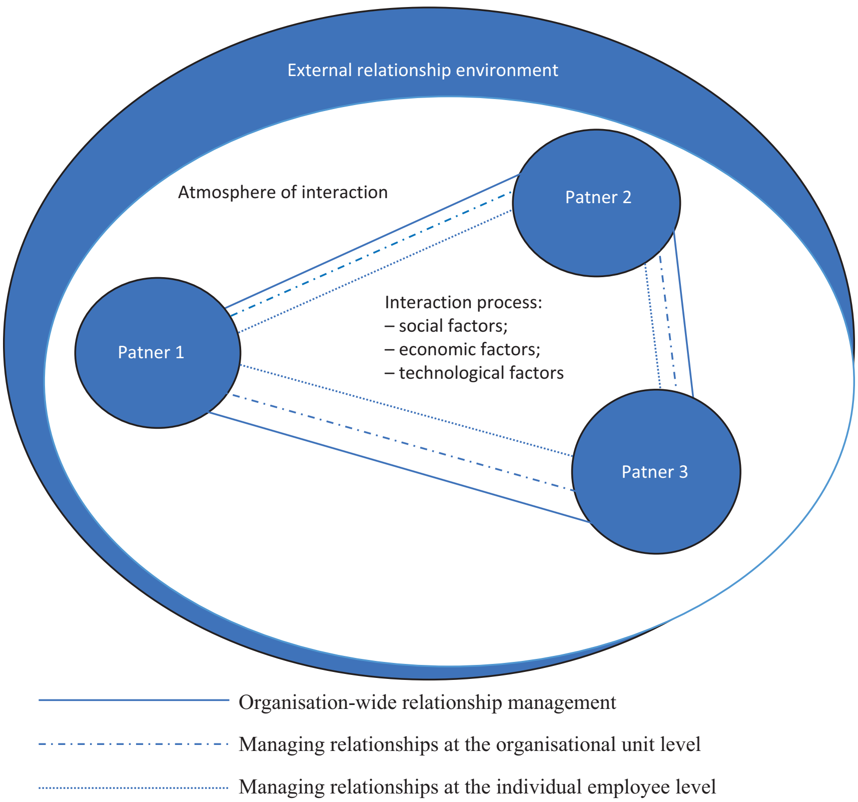
Mutual understanding is defined as the willingness of partners to understand each other's situation and to help each other achieve common goals. An important condition for mutual understanding is the willingness to share knowledge and information in order to reduce the risks of interaction.

In addition, existing studies highlight two other characteristics of relationships - trust and commitment to the relationship. Trust is formed on the basis of shared values and interpersonal communication, and commitment to the relationship is expressed as the willingness of partners to invest in the development of the relationship, thereby reducing the risk of opportunistic behaviour on the part of the partner.

Factors of inter-firm interaction are important: technological, social and economic.

Social factors are expressed in the level of satisfaction with relationships, the level of conflict between group members, and the compatibility of the main goals of interaction [Gummesson, 1999]. Economic factors reflect the level of costs incurred by participants in maintaining relationships, as well as the positive impact of relationships on the performance of partners. Technological relationship factors are related to the compatibility and complementarity of technologies used by relationship partners and to joint innovation.

Fig. 1. Characteristics of traditional partnerships



Source: compiled by the authors.

[1] The term 'interaction atmosphere' was introduced by researchers in the IMP group.

Table 1
Comparative characteristics of traditional partnerships and those created to achieve sustainable development goals

Relationship component	Traditional partnerships	Partnerships created to achieve the Sustainable Development Goals
Purpose of the interaction	Achieving high economic results, increasing competitiveness	Achieving sustainable development goals
Participants in the partnership	Commercial companies	Commercial companies
Factors of interaction	State companies	Government companies
Atmosphere of the interaction	Economic, technological, social	Public organisations
Activity of interaction participants	Trust and commitment to relationships	Regulators

Source: compiled by the authors.

Thus, studying the process of relationship development allows us to take into account the diversity of factors and aspects of joint activities and is the basis of the strategy for managing the development of relationships.

1.2. Partnerships to achieve the Sustainable Development Goals

Partnerships to achieve sustainable development goals were first described in [Murphy, Bendell, 1997] and subsequently studied in detail in [Biermann et al., 2009; Rockstrom et al., 2009; Pattberg, Widerberg, 2016] and others.

For example, research [Eweje, 2007] argues that partnerships created to achieve sustainable development goals are characterised by more intense interactions, but are more focused on formal reporting within the existing institutional structure. As a result, there is an increasing gap between expectations and results achieved, which calls into question the effectiveness of such partnerships [Pattberg, Widerberg, 2016].

The ineffectiveness of creating such partnerships is also noted in [Glasbergen, 2007, p. 14]: partnerships mainly deal with limited governance of SDG issues, and thus the partnership paradigm is a fragmented way of achieving sustainable development.

In addition, a number of authors criticise the concept of sustainable development itself [Redclift, 2005], noting that sustainable development is a compromise between development and sustainability: between those who prioritise economic development and those who seek to improve social and environmental conditions [Kates et al., 2005]. The works [Hahn et al., 2014; Prescott, Stibbe, 2015] show that most of these partnerships have only indirect economic benefits, which reduces the interest of the participants in the partnership.

The nature of the quality of relationships in such partnerships has also been criticised. For example, the authors [Bendell et al., 2010] argue that the paradigm of such partnerships is moving away from a methodology towards an ideology of ‘partnershipism’, defined as ‘the orthodox view that partnerships, when well managed, always lead to net positive outcomes for participants, communities and society as a whole’ [Bendell et al., 2010, p. 352]. This view suggests that partnerships are a matter of operational objectives and reflects unrealistic expectations of partnerships.

For example, partners may receive or perceive only indirect benefits from coalition building, at least in the short term. Moreover, partnerships may even threaten their own interests, as power relations change when the issue is resolved [Zammit, 2003; Utting, Zammit, 2009].

A comparative analysis of traditional and sustainable development partnerships is presented in Table 1.

Studies by various authors suggest measures to

Table 2
Value analysis of relationships between companies in the coal mining and metallurgy sectors

Components of value	For coal mining companies	For companies in the metallurgical sector
Strategic component	Coking coal sales	Providing a key component for smelting iron and steel
Economic component	Reducing the cost of transporting and storing raw materials Optimising logistics Improving financial performance	Efficient allocation of resources Reducing production costs Improving financial indicators
Social component	Creating a system of shared values through collaborative innovation Improving environmental performance Reducing carbon emissions	

Source: compiled by the authors.

improve the effectiveness of such partnerships. For example, the Marine Stewardship Council standard suggests defining common goals, principles, roles, responsibilities and outcomes for achieving goals, as well as providing partnership participants with worksheets for achieving interaction goals [Foley, 2013].

Works [Turcotte, Pasquero, 2001; Clarke, Fuller, 2010] indicate that since participants can only receive indirect economic results from the interaction, it is necessary to form a mechanism for the exchange of knowledge, innovations that contribute to the achievement of sustainable development goals and assistance in solving the problems of participants [Koschmann et al., 2012]. Researchers [Albani, Henderson, 2014] believe that participants in such partnerships should adapt their vision of the concept of efficiency to achieve sustainable development goals. In [Elkjaer, Simpson, 2011] the creation of an effective mechanism for managing such partnerships is proposed.

Partnerships formed to achieve the SDGs therefore need to be transformed, both to increase their effectiveness and to improve the quality of relationships. However, the SDGs themselves and the context of the sector may be important to the effectiveness of forming partnerships for the SDGs.

Next, we will consider forming partnerships between companies in the coal mining and metallurgical sectors to reduce their carbon footprint.

2. Models for integrating the coal mining and metallurgical sectors

Partnerships between coal mining and metallurgical companies play an important role in the development of the industry, ensuring a reliable supply of raw materials and increasing production efficiency.

D. Wilson and S. Jantariya's model describes three components of relationships in partnerships:

– strategic component - optimal allocation of resources, development of key competencies, achievement of strategic goals;
– economic component - increasing competitiveness, reducing costs, improving the quality of goods and services, ensuring access to resources, markets, technologies;
– social component - creating trust and commitment to relationships, creating a system of shared values [Wilson, Jantrania, 1994].

Coal mining enterprises supply metallurgical enterprises with coking coal, which is a key component in the process of smelting iron and steel. An analysis of the value of the relationship between enterprises in the coal mining and metallurgical sectors is presented in Table 2.

At the same time, it is necessary to develop strategic models of interaction between market participants in order to ensure stability of supply and adaptation to economic and environmental changes [Islamov, 2010].

Partnership models are a range of different forms of collaboration between companies aimed at improving operational efficiency, optimising production processes and ensuring long-term sustainability. The interaction of companies within the framework of such models helps to reduce costs, implement innovative solutions and reduce the negative impact on the environment. In today's environment, the development of partnerships is particularly important as it allows companies to adapt to dynamic changes in the market environment and increased competition.

The development of the mining and metallurgical industry has historically been accompanied by the formation of various forms of inter-company cooperation aimed at increasing production efficiency and rationalising the use of resources. As early as the beginning of the 20th century, companies recognised the need for cooperation, which led to the creation of the first strategic alliances. These associations allowed participants to share infrastructure, improve technological processes and reduce operating costs. In the second half of the 20th century, globalisation processes and increased competitive pressures became important factors contributing to the expansion of such forms of cooperation. As a result, companies began to actively diversify their assets and develop new markets, using partnership strategies as a tool to strengthen their position.

The classification of partnership models is based on a number of key criteria, including the level of integration, the strategic objectives of the cooperation and the nature of the interaction between the participants. The following main models can be distinguished:

- Vertical integration involves the unification of successive stages of the production process within a single corporate structure, from the extraction of raw materials to the release of the final product. This form of interaction helps to reduce costs by 15-20% through the comprehensive optimisation of technological operations and logistical processes [Porter, 1985]. However, this format requires significant financial investment and complex management, making it more suitable for large companies with sustainable resource capabilities.
- Horizontal integration involves the merger of companies operating at the same stage of the production chain, which allows the expansion of sales markets and the strengthening of competitive positions. This approach helps to reduce the level of competition and increase the market power of the merged enterprises, but is associated with the risk of violating antitrust laws [Teece, 1986].
- Cluster cooperation involves the formation of network structures of firms that share technological resources and production capacities. For example, cluster interaction models implemented in China in 2021 led to a significant reduction in carbon dioxide emissions and increased environmental sustainability of the industry [Zhang et al., 2021].
- Strategic alliances are agreements between companies aimed at achieving common goals, such as developing innovative products or exploring new markets. These alliances can be temporary or long-term and allow companies to minimise operational risks by taking advantage of complementary resources [Dyer, Singh, 1998].

At present, strategic alliances have taken on more complex and diverse forms due to differences in the objectives of interaction, the degree of technological integration and the degree of interdependence of the parties. One of the most common areas of cooperation are alliances focused on joint research and development (R&D) aimed at developing innovative methods of coal mining and improving metallurgical technologies. In addition, alliances focused on optimising logistics processes, improving supply chains and implementing unified resource management strategies have become widespread, which can significantly improve companies' operational efficiency.

It is difficult to overestimate the importance of strategic alliances for the sustainable development of the mining and metallurgical sector. They help to increase the adaptability of companies to dynamically changing economic and technological conditions, reduce risks and strengthen market positions. Innovative partnership projects make it possible to modernise production processes, which increases the competitiveness of alliance participants on a global scale. Moreover, cooperation in this format contributes to the optimisation of natural resources management and the reduction of negative environmental impacts, which is a key factor in the context of the modern course towards sustainable industrial development [Dunikov, 2017].

At the same time, the effectiveness of such forms of interaction will depend on the strategy for managing the relationships of the alliance participants.

3. Partnerships between coal and metal companies: an empirical analysis

The typology of relationship management strategies was first developed by W. Campbell, who identified three types of management strategies:

– a cooperative type of strategy, which involves focusing on long-term relationships, achieving alignment of objectives, building mutual trust and creating a mechanism for ongoing investment in relationship development;
- competitive type of strategy - focused on the competitive selection of partners (e.g. by price or speed of delivery) with the aim of increasing efficiency indicators;
- team type strategy - exerting pressure on the network partners of the strongest participant to achieve the required supply parameters [Campbell, 1985].

In this study, we surveyed 173 participants in coal mining and metals alliances to identify clusters of companies that characterise established partnerships between companies in these sectors.

The k-means method described in [Trachuk, Linder, 2018] was used for the analysis.

Binary values of the component characteristics were used to analyse the strategies used:

- typology of relationship management strategies according to the groups identified:
  – cooperative type (if yes - 1, if no - 0);
  – competitive type (if yes - 1, no - 0);
  – team type (if yes - 1, no - 0);
- quality of relationships:
  – trust between partners (if yes - 1, if no - 0);
  – satisfaction with relationships (if yes - 1, no - 0);

Table 3
Characteristics of clusters by type of partnerships established between companies in the coal mining and metallurgic sectors

Clusters by type of partnership established	Number of companies in the cluster	Main characteristics	Dominant type of relationship management strategy
Cluster 1: Partnerships for economic benefit	54	Dominance of a large customer or supplier. The main objective is to increase economic efficiency: to increase profits and reduce costs as a result of the relationship.	Competitive
Cluster 2: Innovative and technical cooperation partnerships	38	The main objective is innovative partnership, knowledge exchange, technical and technological cooperation to improve the level of technologies used. Regular improvement of technical and research skills of employees	Competitive
Cluster 3: Partnerships to co-create value	29	The main objective is to create joint value for the consumer and increase market share. Coordinating marketing and product strategies	Cooperative
Cluster 4: Opportunity-driven partnerships	24	The main objective is to create new opportunities for the company, such as entering new markets, achieving sustainable development goals and providing preferential investment opportunities.	Team
Cluster 5: Relationship-based partnerships	28	The main objective is to achieve better results in the area of supplier and consumer relations.	Cooperative

Source: compiled by the authors.

  – knowledge sharing and joint problem solving (if yes - 1, no - 0);
  – alignment of objectives (if yes - 1, no - 0);
  – presence of sustainable development objectives (if yes - 1, no - 0);
  – joint creation of innovations (if yes - 1, no - 0);
  – commitment to relationships (if yes - 1, no - 0);
  – effectiveness of communication (if yes - 1, no - 0);
- economic characteristics of the relationship:
  – optimal allocation of resources (if yes - 1, no - 0);
  – increase in profit as a result of investing in relationships (if yes - 1, no - 0);
  – cost reduction as a result of relationship building (if yes - 1, no - 0).

The hierarchical cluster analysis model was used to determine the clusters. The formula used to determine the distances between clusters was:

$$d_{ij} = \sum x_{ik} - x_{jk} \text{right}|, \quad (1)$$

where d – distance between characteristics, x_i – highlighted relationship characteristics, k – number of companies surveyed.

The result of the analysis was the identification of five clusters based on the type of partnership structure and the strategy implemented to manage them (Table 3).

It can be concluded that most companies aim to gain economic benefits from their relations with partners. In second place are the objectives of S&T cooperation, which is explained by the companies' desire to also achieve efficiency indicators through the introduction of new technologies, both in new products and services and in their own business processes. For example, the partnership between ArcelorMittal and Nippon Steel led to an 8% increase in the efficiency of production processes through the introduction of advanced technological solutions [Zhang et al., 2021].

The remaining three clusters - partnerships for joint value creation, partnerships for new opportunities and partnerships for relationships - have roughly the same distribution of companies and are aimed at developing long-term relationships to open up new opportunities, such as entering foreign markets through partnering, creating joint value for customers to increase market share and stable relationships with multiple suppliers and customers.

Thus, in the coal mining and metallurgy sector, partnerships aimed at economic benefits and partnerships aimed at scientific and technological cooperation predominate. In this regard, in order to achieve the effectiveness of the partnerships created to achieve the SDGs, it is necessary to develop mechanisms aimed at increasing the effectiveness of the implementation of joint technologies and economic efficiency.

4. Achieving technological and economic efficiency of partnerships in the coal and metallurgical industries

4.1. Technological integration of the coal and metallurgical sectors

Modern technologies allow coal mining and processing processes to be optimised, which in turn improves the quality of the final metallurgical product. For example, the use of thermocoke, obtained from lignite and thermal coal, opens up new opportunities for metallurgical plants. Thermocoke has high strength and chemical purity, making it an excellent alternative to traditional coke and providing more stable conditions for metallurgical processes [Teece, 1986].

Hydrogen is also becoming increasingly important in the steel industry, especially as part of the transition to cleaner technologies. Its use as a reducing agent in place of carbon allows a significant reduction in carbon dioxide emissions. Hydrogen can be used in the direct reduction of iron ore, opening up new horizons for sustainable steelmaking. In combination with thermocoke, it can help steelmakers achieve higher standards of environmental safety and efficiency, an important step towards reducing the industry's carbon footprint.

The integration of the coal and steel sectors not only reduces the cost of transporting and storing raw materials, but also opens up new opportunities for more efficient resource management. This interaction makes it possible to optimise logistics processes, which in turn leads to a significant reduction in time and financial costs. Joint efforts in research and development can become a catalyst for the creation of innovative technologies that will not only improve the environmental performance of both industries, but also help to reduce carbon emissions, which is extremely important in the context of global climate change. In addition, such technologies can minimise negative environmental impacts, promote sustainable development and preserve natural resources for future generations. The integration of these sectors is therefore a strategic step towards a more sustainable and environmentally friendly future.

Hydrogen iron production, which is being actively developed in a number of countries, promises to revolutionise the industry by providing cleaner and more efficient steelmaking processes.

Plasma arc furnaces are also an innovative solution for the metallurgical industry. These furnaces allow high temperatures to be achieved and provide more precise control over the melting and alloying of metals. The use of plasma technologies can lead to a reduction in energy costs and an improvement in the quality of the final product, making them attractive for implementation in modern production.

The combination of thermocoke, hydrogen technologies and plasma arc furnaces opens up new horizons for the sustainable development of metallurgy, reducing the negative impact on the environment and increasing the efficiency of production processes.

Partial coal gasification plants are characterised by significantly lower costs compared to full gasification plants. This advantage is due to a simpler process diagram, fewer stages and reduced gas cleaning requirements. According to the author of the paper [Islamov, 2017], the use of such units is particularly promising for coals with a high content of volatile substances, as this allows the most efficient extraction of thermal coke at minimal cost.

One of the key benefits of thermocoke is its ability to reduce the carbon footprint of metallurgical operations by 20-30% compared to traditional methods.

The direct reduction of iron ore using thermocoke is an innovative approach that offers a significant reduction in energy costs - 15% compared to traditional processing methods. This significant improvement is achieved through the high reactivity of the thermocoke, which interacts effectively with the iron ore. As a result, iron is extracted from the ore without the need for additional steps, which are usually associated with significant energy costs.

The use of thermocoke in metallurgy contributes to a significant reduction in carbon dioxide emissions. Coal products play a key role in this industry as they are used by both coking plants and thermal power plants [Belozertsev, Belozertseva, 2023, p. 2]. In 2022, companies using thermocoke reduced CO_2 emissions by 1.2 million tonnes, which highlights the environmental benefits of this technology and its contribution to achieving sustainable development goals.

The economics of using thermocoke are confirmed by a 10% reduction in steel production costs. This is achieved by using cheaper raw materials and reducing energy costs. Thus, the introduction of thermocoke into production processes helps to increase the competitiveness of metallurgical enterprises [Dunikov, 2017].

Technologies based on the use of thermocoke are already being actively used by companies in Germany and China. These companies provide successful examples of the integration of thermocoke into production processes, which confirms both the efficiency and the prospects of this technology. According to Islamov, 'the most effective foreign development is the technology of Salem Corporation, implemented at the level of an industrial plant with a capacity of 105 thousand tonnes per year in Germany and Canada' [Islamov, 2010, p. 8]. This underlines the high level of implementation of thermocoke in modern production systems.

4.2. Hydrogen production from coal for direct reduction of iron ore

Hydrogen production from coal is a complex technological process based on coal gasification. In this process, coal is thermally treated in the presence of oxygen and water vapour, resulting in the formation of synthesis gas containing hydrogen and carbon monoxide. Gasification allows the efficient use of low-grade coal, which is usually unsuitable for traditional application methods, making the process more versatile and cost-effective. Coal gasification can be used to produce hydrogen and synthesis gas, which in turn helps to reduce the carbon footprint [Nefedov et al., 2008, p. 2].

Hydrogen is produced from coal by complete gasification, which involves the thermal decomposition of coal at temperatures up to 1300°C and limited oxygen content. This process produces synthesis gas, the main components of which are hydrogen, carbon monoxide and small amounts of methane. In the first stage, the syngas undergoes multi-stage purification to remove impurities such as hydrogen sulphide and carbon dioxide, which increases the efficiency of the subsequent hydrogen extraction. This is done using advanced technologies such as membrane processes, absorption processes and cryogenic units.

In addition, coal gasification is associated with the implementation of carbon capture, use and storage (CCUS) technologies that reduce the carbon footprint of the process. For example, carbon dioxide released during gasification can be captured and used to produce synthetic fuels or stored in geological formations.

One of the key environmental benefits of using hydrogen in metallurgy is the significant reduction in carbon dioxide emissions. The use of hydrogen in the iron ore reduction process can reduce CO_2 emissions by 60-70% compared to conventional methods. This is particularly relevant in the context of the global fight against climate change and the desire for carbon neutrality. At the same time, it is important to consider that 'the main trend in the global electricity industry of the 21st century is the transition to coal as a fuel' [Nefedov et al., 2008, p. 2]. The transition to hydrogen technologies can be an important step towards reducing dependence on coal and reducing the negative impact on the environment.

An example of successful implementation of the technology is China, which is actively developing coal gasification. By 2023, more than 400 plants using this technology will be operating in the country. European Union projects such as HYBRIT are exploring the possibility of using hydrogen from coal for metallurgical purposes.

Another example is South Korea, which is implementing coal gasification projects to reduce carbon emissions and improve the efficiency of energy systems. The country is actively developing carbon capture and storage (CCS) technologies to minimise the negative impact on the environment.

Coal gasification research is also underway in Australia, where new methods are being developed to use coal in a cleaner way. For example, the GASGAS project aims to develop more efficient gasification processes that can be integrated into existing energy systems.

These examples demonstrate the potential of technology and its importance in achieving sustainable development.

4.3. Hydrogen for plasma arc furnaces

Plasma arc furnaces are an innovative solution in the metallurgical industry to achieve high temperatures for metal processing. These devices use plasma generated by an electric arc to melt and process materials. The technology has become widely used in recent years due to its versatility and ability to process different types of raw materials.

The use of hydrogen in plasma arc furnaces offers significant advantages over traditional methods. First of all, it reduces carbon dioxide emissions by 90%, which helps to improve the environmental situation. In particular, the use of hydrogen to reduce iron oxides can significantly reduce environmental pollution [Boranbaeva et al., 2020, p. 2].

Despite the initial cost of implementing hydrogen technologies, the economic benefits are clear in the long term. According to studies, the transition to hydrogen technologies can increase costs by 20%, but thanks to lower carbon taxes and increased energy efficiency, the payback period is short. In addition, such investments help to strengthen the market position of companies.

An example of the successful implementation of hydrogen technologies is the Hybrit project in Sweden, where hydrogen is used to produce steel with a minimal carbon footprint *ArcelorMittal* is actively investing in the development of hydrogen technologies with a view to integrating them into its production processes.

Another interesting example is the H2GreenSteel project in Sweden, which aims to produce carbon-neutral steel using hydrogen produced from renewable energy. This project also includes the construction of a new plant that will use hydrogen instead of coal in the production process. In Germany *Thyssenkrupp* is working on a project to use hydrogen to replace coal in blast furnaces, significantly reducing CO_2 emissions.

In Australia *Fortescue Metals Group* is developing an initiative to produce green hydrogen for use in the mining industry, which could also reduce its carbon footprint.

These examples demonstrate the potential of hydrogen technologies in the metals industry and other sectors, highlighting their importance in achieving sustainable development and reducing environmental impact.

Most foreign researchers and experts at the European Institute of Plasma Metallurgy support the method of using plasma arc furnaces with hydrogen as the main energy source. This approach allows a significant reduction in carbon emissions, while offering high energy efficiency and versatility in processing different metals. This technology is suitable not only for the production of cast iron, but also for the manufacture of a wide range of commercial ferrous metallurgy products, including slabs, rolled products, high-strength alloys, machine parts and specialised structures for the aerospace and automotive industries. Research shows that the implementation of this technology can become the basis for the creation of a carbon-neutral metallurgical industry. International projects such as the Fraunhofer Hydrogen Initiative and experiments with hydrogen plasma in Germany and Sweden confirm its potential and necessity for the future sustainable development of the industry. This process requires significant capital investment, which is the main obstacle to its widespread adoption. The high cost of creating infrastructure, upgrading equipment, and the need to develop hydrogen logistics and supply networks are significantly slowing the pace of adoption of this technology in industry.

In modern industrial clusters, coal mining and metallurgical companies form a symbiotic relationship aimed at optimising resource consumption and minimising operating costs. Coal mining, as a supplier of critical raw materials, ensures the stability of the production cycles of metallurgical plants, which in turn transform raw materials into high value-added products (steel, alloys). This collaborative model, reinforced by the integration of technological and financial players, creates a synergy that reduces market volatility. Technology companies that provide digital platforms for monitoring ESG indicators and financial institutions that finance infrastructure projects act as catalysts for the stability of alliances [Potapov, Pinchuk, 2006].

The declared transition to a hydrogen economy is causing structural shifts in traditional alliances. Coal mining companies, faced with a decline in demand for coal, are forced to diversify their activities through the introduction of carbon capture and storage (CCUS) technologies and the production of blue hydrogen. The metallurgical sector is reorienting itself towards direct reduction of iron (DRI) technologies using H_2, which requires investments of $1.2-2 billion to modernise a plant. One example is the HYBRIT project (Sweden), where the replacement of coke with hydrogen has reduced the carbon footprint by 90%.

Previously supportive technology companies are becoming key players by developing hydrogen cycle solutions, from high-efficiency electrolysers to cryogenic storage systems.

Modern operating models for coal mining and metallurgical companies have historically been based on exploiting hydrocarbon resources, optimising profitability by scaling production and minimising operating costs. However, increasing regulatory pressure and changing stakeholder expectations in the context of the ESG agenda are initiating a structural restructuring of these industries.

The transformation of the energy base in favour of hydrogen is associated with capital-intensive investments in infrastructure (electrolysers, storage systems) and R&D. According to the model presented in [Bolshakov, Tuboltsev, 2023], the cost of creating a hydrogen hub with a capacity of 1 million tonnes per year is $3-4 billion. However, the long-term payback is ensured by:

– reducing carbon payments (in the EU, the price per tonne of CO_2 will exceed €100 in 2024);
– premium pricing for green steel (+15-20% of market value);
– access to green finance (the volume of global ESG funds exceeded $5 trillion in 2023) [Bolshakov, Tuboltsev, 2023].

Implementing hydrogen solutions, such as replacing natural gas with H_2 in direct reduction of iron (DRI) processes, requires overcoming technological barriers. A study [Bolshakov, Tuboltsev, 2023] shows that the transition to hydrogen in blast furnaces reduces productivity by 12-18% due to the need to reconfigure temperature regimes. To minimise losses, companies are implementing hybrid models combining hydrogen with biomethane (case of SSAB, Sweden). In parallel, the role of CCUS technologies is growing: projects such as

Nord Stream - Hydrogen in the Russian Federation aim to capture up to 50 million tonnes of CO_2 per year by 2030 [Knelts, 2022].

Industry pioneers such as *Thyssenkrupp*, are already implementing projects to replace 40% of coke in blast furnace production with hydrogen and have invested €2 billion in creating hydrogen clusters. In Russia, Severstal has launched a pilot DRI plant with a capacity of 1.5 million tonnes per year and predicts a 65% reduction in its carbon footprint by 2026. However, as [Knelz, 2022] points out, only 8% of Russian metallurgical companies have approved decarbonisation plans, reflecting institutional delays.

The transition to hydrogen business models requires companies to balance operational resilience with innovative aggression. Strategies must be integrated:

– phased replacement of assets, taking into account technological maturity;
– participation in public-private partnerships to reduce investment risks;
– development of cross-sector alliances (energy + logistics + IT).

As the authors [Bolshakov, Tuboltsev, 2023] summarise, 'the success of decarbonisation will be determined not so much by technology as by the ability of companies to turn institutional constraints into competitive advantages'.

5. Development of partnerships in the coal mining and metallurgical industries

The decarbonisation of industry, driven by the climate agenda, is reconfiguring the principles of forming strategic alliances in the coal mining and metallurgical sectors. As noted in [Adams et al., 2024], 78% of industrial companies have included hydrogen initiatives in long-term strategies, highlighting the need to move from competition to collaboration. A key trend is the creation of hybrid consortia that bring together traditional players (*Anglo American, Glencore*) and technology start-ups (*H2Pro, Sunfire*), which allows for the diversification of R&D risks and accelerates the commercialisation of solutions [Friedman et al., 2019].

The declining share of coal in the global energy mix (from 27% in 2022 to 15% in 2040, according to the IEA) is forcing coal producers to rethink their operating models. Adaptation strategies include:

– production of blue hydrogen using CCUS technologies (the Kuzbass Clean Coal Project with the potential to capture 10 million tonnes of CO_2 per year);
– integration into hydrogen clusters (BHP's partnership with Fortescue Future Industries to export H_2 to Asia);
– implementation of circular models (reclamation of mines for renewable energy installations).

The metallurgical sector is demonstrating an unprecedented pace of implementation of hydrogen technologies. *ArcelorMittal* pilot project in Gentach (Belgium) to replace 30% of coke with H_2 has reduced emissions by 1.5 million tonnes of CO_2 per year for an investment of €1.2 billion. However, the energy intensity of the processes remains a key barrier: the production of 1 tonne of green steel requires 4.5 MWh of electricity, compared to 0.8 MWh for the traditional method [Polevanov, 2020].

The formation of a global hydrogen infrastructure is accompanied by regional asymmetry:

- The EU emphasises standardisation (CertifHy 2.0) and the creation of 'hydrogen valleys' (HyDeal Ambition, 67 GW by 2030);
- Asia focuses on import corridors (Japan - Australia, $3.5bn investment);
- The Russian Federation develops export-oriented clusters (Sakhalin-2, potential 100 thousand tonnes of H_2 per year).

The International Energy Agency predicts that by 2050, 60% of hydrogen projects will be implemented through transnational alliances, which will require harmonisation of regulatory regimes.

The transition to hydrogen as a primary energy source requires significant changes in the technology and infrastructure of coal mining and metallurgical companies. Achievements to date, such as a 95% reduction in CO_2 emissions through the use of hydrogen in metallurgy, represent an important step forward. At the same time, the studies carried out indicate the need for further developments for the full implementation of hydrogen technologies. This is due to the need to improve the efficiency of existing processes and to adapt them to new conditions. In [Polevanov, 2020, p. 4] it is noted that 'a leap in energy efficiency is accompanied by increased requirements for energy production in general and its electrical form in particular'.

The main areas of research in this field are the development of more efficient technologies for the production and storage of hydrogen and the creation of an infrastructure for its transport. It is also important to investigate how hydrogen technologies can be integrated into existing production chains of metallurgical and coal mining companies in order to minimise transition costs and ensure the sustainability of new processes. [Vorobyov, Vorotnikov, 2022] emphasise that 'European leadership in hydrogen and fuel cells will play a key role in creating high-quality jobs, from strategic research and development to manufacturing and crafts'.

The successful implementation of hydrogen technologies is expected to lead to a significant reduction in the carbon footprint of the coal mining and metallurgy industry, contributing to the fulfilment of international environmental commitments. Research shows that carbon-free energy in commercial transport can be achieved by 2050, which will lead to cost reductions [Vorobyov, Vorotnikov, 2022, p. 4]. In addition, this will create new opportunities for cooperation between companies in the form of strategic alliances, which in turn will accelerate the development of innovation and increase the competitiveness of industries in the global market.

Conclusion

This study provides a comprehensive assessment of the changes occurring in the strategic alliances of coal mining and metallurgical companies in the context of the transition to hydrogen as a key energy resource. The current structure of the alliances, their dynamics and the impact of hydrogen energy on the interaction of the participants have been analysed. The prospects and challenges associated with the companies' adaptation to the new energy reality were considered.

Based on the analysis, it can be concluded that the transition to hydrogen has a significant impact on strategic cooperation in the mining and metallurgy industry. Companies are forced to review their strategies, implement innovative technologies and adapt to new conditions, which requires significant investments and coordination of efforts. These changes contribute to the creation of more sustainable and environmentally oriented interaction models, which are important for the future development of the industries.

Future research perspectives include the investigation of specific technologies and business models that facilitate successful adaptation to the hydrogen economy. It is also important to continue to analyse the role of international cooperation and government support in developing strategic alliances. These aspects can have a significant impact on the effectiveness of the transition to hydrogen and the strengthening of the competitive position of companies.

The study of changes in the strategic alliances of coal mining and metallurgical companies during the transition to hydrogen highlights the importance of strategic planning and an innovative approach in the context of global change. The findings may be useful for practitioners and researchers, as well as for the formulation of sustainable development policies aimed at reducing the carbon footprint and increasing the efficiency of industries.

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The interrelation between innovations and knowledge management systems: Justification and classification of knowledge-based innovations

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Abstract

This article exexamines the role of knowledge in the innovation process, highlighting knowledge creation as a key factor in successful innovation. Current economic realities underscore the importance of knowledge as a fundamental resource for creating unique competitive advantage. The relationship between innovation and the knowledge creation process, which is often overlooked or underestimated, is explored.

The article presents different approaches to defining and classifying innovation and knowledge creation models. The authors propose a classification approach for knowledge-based innovations based on parameters such as the type of knowledge according to novelty level (completely new knowledge vs. use of existing knowledge), knowledge creation (market knowledge vs. empirical knowledge), and knowledge characteristics (explicit vs. implicit). Empirical research on knowledge-based innovation has allowed us to complement the classification approach with information on the source of knowledge acquisition for innovation creation - a critical feature for company managers.

The conclusion underlines the importance of knowledge creation and integration for the successful implementation of innovation.

Keywords: innovations, innovation classification, types of knowledge, empirical knowledge, market knowledge, knowledge management.

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创新与知识管理的关系：基于知识的创新的原理与分类

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简介

文章致力于研究知识在创新过程中的作用，认为知识创造是成功创新的关键因素。现代经济条件强调了知识作为创造独特竞争优势的关键资源的重要性。 本文探讨了创新与知识创造过程之间的关系，而知识创造过程往往被忽视或低估。文中介绍了对创新和知识创造模式进行定义和分类的不同方法，包括作者基于知识创造和创新创造对创新进行分类的方法。 已形成的基于知识的创新分类包括知识的三个方面：根据新颖程度划分的知识类型（全新知识或使用现有知识）、知识创造（市场知识或经验）、知识特征（显性或隐性）。对以知识为基础的创新进行的实证研究，通过引入创新创造的知识来源信息作为公司管理者的一个重要特征，对所提出的分类方法进行了补充。结论是，创造和整合知识对于成功创新非常重要。

关键词: 创新、创新分类、知识类型。

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Introduction

Modern realities illustrate the tendency of both companies and the economy as a whole to perceive knowledge as the most important economic resource and source of non-copyable competitive advantages. In this context, the importance of considering knowledge-based innovation as a separate theoretical and practical category increases.

Successful implementation of knowledge-based innovation requires a well-designed knowledge management system that enables organisations to excel in the creation of technological, market and administrative knowledge. Innovation and knowledge creation are two concepts that have a strong but complex relationship that is rarely studied in detail. This article examines both concepts and attempts to show their relationship.

In addition, qualitative and quantitative research was carried out using in-depth interviews and questionnaires. The aim of the study is to identify the real attitudes of practitioners from different fields towards the types of innovation studied.

The result of the study presented in the article is a proposal for a definition and classification of knowledge-based innovations.

1. Theoretical review of the literature

1.1. Innovation: Concepts and models

Innovation is a continuous, cumulative process of multiple organisational decisions from the moment an idea is conceived until it is fully implemented. Academic definitions of innovation include the concepts of novelty, commercialisation and implementation. That is, if an idea has not been developed and implemented as a product, process or service, or has not passed the commercialisation stage, it is not considered to be an innovation.

Definitions of innovation can be found in the works of many authors [Rogers, Williams, 1983; Utterback, 1994; Afuah, 2003; Fischer, 2001; Garcia, Calantone, 2002; McDermott, O'Connor, 2002; Pedersen, Dalum, 2004] as well as in [Frascati Manual, 2015; Oslo Manual, 2018]. 'An innovative idea arises from the identification of new customer needs or the development of new production methods. It is formed through the accumulation of knowledge and the continuous development of entrepreneurial intuition. The implementation of this idea allows the creation of a new product or process, accompanied by a reduction in costs and an increase in efficiency' [Botega, Da Silva, 2020].

In [Afuah, 2003] innovation is seen as new knowledge integrated into products, processes and services; innovations are classified as technological, marketing and administrative.

Technological innovations involve knowledge about the components, interrelationships, methods, processes and techniques used in products or services. Such innovations may or may not involve administrative changes. Technological innovations can be in products, processes or services. Products and services need to meet specific market needs. Process innovations involve changes in the operational activities of the firm, such as the supply of materials, the specification of tasks, the flow of work and information, and the use of equipment to produce goods or provide services [Afuah, 2003].

Marketing innovation refers to new knowledge embedded in distribution channels, product applications and consumer demands, preferences and needs [Afuah, 2003]. The aim of marketing innovation is to improve the marketing mix, including the product itself, price, promotion and place of sale. According to [Frascati Manual, 2015], marketing innovation includes the development and launch of new products, as well as related activities such as test launches, product adaptation for different markets, and advertising campaigns, but does not affect the formation of distribution channels.

Management innovation concerns changes in the management structure and administration of companies. It focuses on strategies, structures, systems and human resources within organisations.

The Manuals [Frascati Manual, 2015; Oslo Manual, 2018] offer different approaches to understanding innovation, but they emphasise the importance of research and development (R&D) at all stages of the innovation cycle, not only as a source of ideas, but also as a tool for commercialising innovations - an integral part of the innovation concept.

For example, [Frascati Manual, 2015] defines the following terms: fundamental research, applied research, research and development. Fundamental research 'is experimental or theoretical work carried out primarily to obtain new knowledge about observed phenomena and facts, without having a specific practical purpose'.. Applied research is 'original research aimed at gaining new knowledge, primarily to achieve a specific practical objective or to solve a specific problem'. Experimental development is 'a systematic activity, based on existing scientific knowledge or practical experience, aimed at creating new or improved materials, products, devices, processes, systems or services'.

The Oslo Manual [Oslo Manual, 2018] defines innovation as the creation of a new or improved product or business process that is significantly different from the previous one. The current version of the Manual distinguishes two types of innovation:

– product innovation – improvement of existing products or creation of new ones;
– business process innovation – new approaches that improve existing business processes or create new ones for the organisation.

If we try to find common features of innovation in different approaches, we can trace the idea of the role of this or that knowledge as the basis of any innovation. This aspect was studied by P. Drucker in his study of possible sources of innovation [Drucker, 1985], of which he identified seven:

1) an unexpected event;
2) discrepancy between idea and reality;
3) the needs of the production process or the consumer;
4) the needs of the market;
5) changes in market structure;
6) changes in demographic indicators;
7) new knowledge.

Drucker's approach shows that this source creates either radical or disruptive innovations, which implies some specificity in the process of creating such an innovation as well as its further use. But it seems fair to clarify that an innovation based on a new idea should not be radical for the market, because new ideas can improve current business processes or the company's product range. The main sign that innovation is directly based on knowledge is the presence of such a stage in the process of creating innovation as the development of information available to the organisation, or, to put it in more practical terms, a knowledge systemIt is also important to clarify that new knowledge is not always obtained by processing information directly from the internal environment - after all, the market is very large and new knowledge appears among many of its participants from different fields, which suggests the possibility of integrating new knowledge even from completely different sectors of the market. In this case, it can be concluded that knowledge-based innovation is a commercialisable innovation that has arisen in the process of developing an organisation's knowledge management system or by integrating new knowledge from outside.

In addition to the approaches described, there are four well-known models of innovation classification based on knowledge [Abernathy, Clark, 1985; Henderson, Clark, 1990; Tushman et al., 1997; Chandy, Tellis, 1998].

Innovation Classification Model by W. Abernethy and K. Clark

According to the authors, innovations should be classified according to their impact on the firm's market competencies and technological knowledge. They focus on the preservation or destruction of these knowledge and competencies. For example, if technological capabilities become less important as new technologies proliferate

Table 1
Classification of innovations according to Abernathy and Clark

Types of innovation	Company knowledge and skills
Conventional innovation	Based on the company's existing technical and market knowledge and skills
Niche Innovation	Based on current technical knowledge, but accompanied by outdated market knowledge and skills
Revolutionary Innovation	Associated with outdated technical competencies, but market knowledge retained
Architectural innovation	Involves loss of both technical and market knowledge and skills

Source: compiled by the authors.

in the market, market knowledge and competencies may remain stable. Even if a firm loses its technological advantage, it can use its market knowledge to maintain its competitive position. The combination of market competencies and technological knowledge thus forms four types of innovation (Table 1).

Innovation Classification Model by R. Henderson and K. Clark

Henderson and Clark introduce the concept of two types of knowledge: (1) ‘component knowledge’, which is an understanding of the components that make up a product, and (2) ‘architectural knowledge’, which ‘changes the way the components of a product are assembled while leaving the basic design concept unchanged’. According to the authors, the success of new product development depends on the presence of these two types of knowledge: knowledge of individual components and understanding of the relationships between them (architectural knowledge). The combination of these two types of knowledge results in four types of innovation (Table 2).

Table 2
Classification of innovations according to Henderson and Clark

Types of innovation	Company knowledge and skills
Incremental innovation	Aims to improve components and architecture
Radical Innovation	Aims to significantly update both components
Architectural Innovation	Improves the components of the product, but changes the architecture
Modular Innovation	Updates the architecture while keeping the components

Source: compiled by the authors.

Table 3
Classification of innovations according to Tushman, Anderson and O’Reilly

Types of innovation	Company knowledge and skills
Architectural innovations	Create new markets with minimal technological improvements (e.g. Canon photocopiers, Sony walkie-talkies)
Incremental innovations	Improving technology while remaining in a stable market
Major product/ service innovations	Lead to significant technology shifts and the creation of new markets (e.g. the transition from DOS to Windows)
Major process innovations	Accompanied by profound technological changes, but operating within the existing market

Source: compiled by the authors.

Innovation Classification Model by M. Tushman, P. Anderson and C. O’Reilly

The Tushman et al. model considers technology cycles and innovation flows and distinguishes between types of innovation based on their impact on market knowledge and technology. Market knowledge is divided into ‘new’ and ‘existing’, which is similar to the ‘destroyed’ and ‘existing’ levels in the Abernethy and Clark model. Accordingly, the model distinguishes four main types of innovation (Table 3).

Tushman and co-authors also introduce the concept of general innovation, which reflects an intermediate stage where both the market and technology are in a state of constant change.

Innovation Classification Model by R. Chandy and J. Tellis

This model again draws attention to two key axes - technologies and markets. The first axis reflects the degree of novelty of the technology in the product compared to previous versions, the second the degree of satisfaction of key customer needs compared to current offerings. Combining these axes allows us to identify four types of product innovation (Table 4).

Table 4
Classification of innovation according to Chandy and Tellis

Types of innovation	Company knowledge and skills
Incremental innovation	Low in technological novelty and need satisfaction
Market breakthrough	Low in technological novelty but significant increase in need satisfaction
Technological breakthrough	High in technological novelty but insufficient need satisfaction
Radical innovation	High in both technological novelty and need satisfaction

Source: compiled by the authors.

Thus, each of the models considered offers a unique view of the nature of innovation, emphasising the interdependence of technological and market knowledge and competencies.

A common thread running through all the models presented is the distinction between incremental and radical innovation. Let us look at this difference in more detail. Radical innovations represent fundamental changes that are radically different from existing practices and are revolutionary in nature in the field of technology [Liu et al., 2022]. The authors of [Dewar, Dutton, 1986] argue that a theoretical model of innovation should consider three key aspects:

A common thread running through all the models presented is the distinction between incremental and radical innovation. Let us look at this difference in more detail. Radical innovations represent fundamental changes that are radically different from existing practices and are revolutionary in nature in the field of technology [Liu et al., 2022]. The authors of [Dewar, Dutton, 1986] argue that a theoretical model of innovation should consider three key aspects:

In [Urabe, 1988], innovation is seen as a combination of both large and small changes. Radical innovations, according to the author, represent significant changes, especially in technological terms. In the early stages of industry development, radical product innovations dominate, but their economic impact is small because the product is not yet stable and the market is not yet defined.

The authors [Pedersen, Dalum, 2004] believe that radical innovations are fundamental changes that reflect a new technological paradigm. As a result, existing codes of communication and understanding of technologies become inadequate. Radical change introduces a high degree of uncertainty into organisations and industries, destroying much of the previous investment in technical skills, knowledge, designs, production methods, plant and equipment. Changes affect not only supply but also demand and organisational structure.

Incremental innovations are changes to products and processes that do not involve a significant degree of novelty [Oslo Manual, 2018].

Since innovation is the result of the creation and application of knowledge, we next consider the key concepts for managing the creation and application of knowledge in organisations.

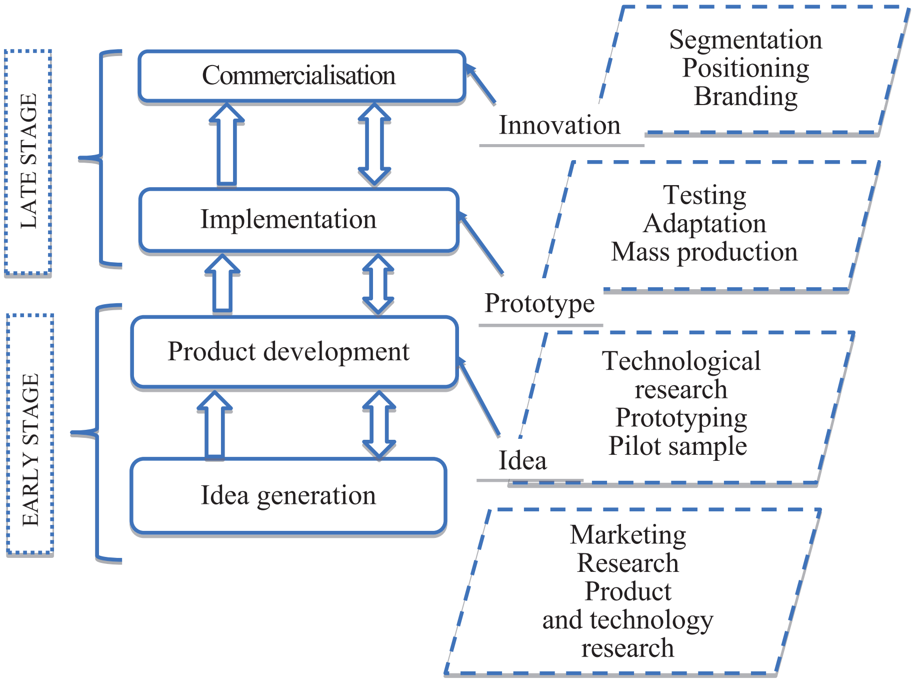
1.2. Knowledge creation in organisations: concepts and models

Knowledge is defined as a ‘justified true belief’ that enhances an organisation’s ability to act effectively [Nonaka, 1994; Nonaka, Takeushi, 1995]. Business-relevant knowledge includes facts, opinions, ideas, theories, principles, models, experiences, values, contextual information, expert judgement and intuition [Yang et al., 2022]. In [Ahlskog et al., 2017], knowledge is defined as a dynamic mix of experience, values, contextual information, and expert judgment that serves as a basis for evaluating and integrating new experiences and information.

The authors [Nonaka, Takeushi, 1995] see knowledge as consisting of two dimensions: tacit and explicit, based on the work of [Polanyi, 1967]. The tacit dimension is based on experiences, thoughts and feelings in a specific context and includes cognitive and technical components. The cognitive component refers to the mental models, beliefs, paradigms and views of the individual. The technical component relates to specific experience and skills applicable to a particular situation. The explicit dimension of knowledge is expressed, codified and communicated using symbols [Nonaka, Takeushi, 1995]. The explicit dimension can also be classified as object-oriented or rule-oriented. Knowledge is object-based when it is codified in words, numbers, formulae, or represented tangibly in the form of equipment, documents, or models. It is rule-based when knowledge is encoded in rules, procedures, or standard operating procedures [Hagedorn et al., 2018].

The authors [Liu et al., 2025] also discuss a third type of knowledge - cultural knowledge. This refers to ‘the assumptions and beliefs that are used to describe and explain reality, as well as the conventions and expectations that are used to give meaning and significance to new information’. Cultural knowledge is not codified, but is disseminated through the links and relationships that bind a group. Although the authors [Nonaka, Takeushi, 1995] do not mention cultural knowledge, they do distinguish between individual and collective knowledge. Individual

Fig. 1. Stages of the innovation process



Source: [Linder, 2021].

knowledge is created and exists in an individual according to his or her beliefs, attitudes, opinions and factors that influence the formation of personality. Social knowledge is created and resides in the collective actions of a group. It includes norms that govern communication and coordination within the group. In a specific context, collective knowledge could be classified as cultural knowledge.

In [Zhang et al., 2023], different classifications of knowledge are proposed depending on its use or usefulness. For example, according to [Zack, 1998], knowledge can be classified as procedural (knowing how), causal (knowing why), conditional (knowing when) and relational (knowing with whom). A more pragmatic approach classifies knowledge according to its usefulness to organisations. In this case, knowledge refers to the understanding of customers, products, processes and competitors, i.e. the components of the organisation's value chain [Porter, 1985].

One of the most influential theories of organisational knowledge creation is that developed by [Nonaka, Takeushi, 1995]. In their analysis, an organisation creates new knowledge through the transformation and interaction of its tacit and explicit knowledge. Understanding the interdependent relationships between these two types of knowledge is key to understanding the process of knowledge creation. The transformation of tacit and explicit knowledge is a social process between people and is not limited to one person. Knowledge transformation occurs in four modes:

– socialisation - from implicit to explicit knowledge;
– exteriorisation - from tacit to explicit knowledge;
– combination - from explicit to explicit knowledge;
– internalisation - from explicit to tacit knowledge.

According to [Nonaka, Nishiguchi, 2001], knowledge often depends on the perception of the observer, and a person gives meaning to a concept by how he or she uses it. As a justified true belief, knowledge is a construction of reality, not something objectively true or universally correct. Knowledge is both explicit and tacit: explicit knowledge is objective, whereas tacit knowledge is more hidden or empirical. Explicit knowledge is formed through research, analysis of written documents, reports and materials, while empirical knowledge is formed through experience. We call the first type of knowledge market knowledge and the second type empirical knowledge.

2. Classification of knowledge-based innovations

Thus, innovation is an idea that has been transformed into a product or service and commercialised, creating value for the company (Figure 1).

Ideas, in turn, are formed as a result of deep interactions between people in knowledge-creating environments. Therefore, based on the theoretical literature review above, we will formulate a classification of knowledge-based innovations that includes three aspects of knowledge:

– type of knowledge by degree of novelty - completely new knowledge or use of existing knowledge;
– creation of knowledge - market knowledge or empirical knowledge;
– characteristics of the knowledge - explicit or implicit.

The resulting classification is shown in Table 5.

Thus, the firm can create new products through research based on tacit knowledge and commercialise them using new knowledge about the market (4th column of Table 5). This scenario refers to radical innovation, where new ideas emerge unexpectedly, from new sources, usually through the intuitive knowledge of highly skilled employees.

The second option (3rd column of Table 5) is the creation of new products based on existing knowledge of the market. In this scenario, the product and its technology change, but the market remains the same. A company creates new products using existing explicit knowledge, but commercialises them using new market knowledge. Product development uses explicit knowledge about the market, product components and their combination. By redesigning product components, products can be created for new markets.

The third option (2nd column of Table 5) is when the firm creates new products using explicit existing knowledge about the market and commercialises these products using existing knowledge about the market. This means that gradual continuous improvements are created, which is a characteristic of incremental innovation.

Knowledge creation focuses on the application of knowledge to create new opportunities for the company. Innovation creation aims to transform this knowledge into products and services that have value in the markets. It is the interaction of technical and market knowledge that determines the company's ability to innovate and thus increase its competitiveness. At the same time, the conclusions drawn require empirical confirmation.

3. Methodology for research on knowledge-based innovations

To ensure maximum relevance of the research results, the sample for the qualitative and quantitative research was drawn from different market sectors.

The qualitative research was conducted through in-depth interviews with representatives from the following areas:

– banking and investment (CFO of a credit and investment organisation);
– hotel (CEO of a five-star hotel in the centre of Moscow);
– education (founder of a private school, professor at one of the country's leading universities).

The interview consisted of several logical blocks in which innovation activities, the knowledge management

Table 5
Classification of knowledge-based innovations

The knowledge creation process / The process of creating innovations	Market knowledge	Combination of market and empirical knowledge	Empirical knowledge
Idea	Marketing research, strategic analysis - product refinement based on consumer demand	Marketing research, strategic analysis - creating a new product based on existing knowledge	Product and technology research is a completely new idea based on new knowledge.
Product development	Prototyping	Prototyping / Technological Research	Technology research - new product features
Commercialisation	Exploitation of an existing product	Commercialisation of a new product using existing market knowledge	Commercialisation of a new product using new market knowledge
Types of innovations by degree of novelty	Incremental innovation - commercialisation through existing market knowledge	Creation of products based on existing knowledge, commercialisation of the product based on new knowledge of the market	Radical innovation - a completely new product

Source: compiled by the authors.

system and the interrelationship between these phenomena were discussed, leading to an argument about knowledge-based innovation.

The quantitative study was carried out using a questionnaire with a Likert scale, where 7 points means absolute agreement and 1 point means absolute disagreement, which allowed us to systematise the results obtained and identify the respondents' perception of the theses proposed in the questionnaire. 225 representatives of SMEs and larger companies took part in the survey.

4. Analysis of research results

4.1. Qualitative research

The results of an interview with a representative of a credit and investment organisation showed that in this sector the innovation process is an integral part, without which no company could continue to exist. It was also noted that participants in the financial industry consistently create up to five innovations per year, which may include product, marketing, technological and organisational (but if we rely on the modern categorisation according to [Oslo Manual, 2018], then process and product). As an example, the period of active digital transformation of the industry was cited, when all products and services of this market began to be offered to users through various IT products. As the interviewee noted, all the major players of this period began to develop their IT technologies in order to remain competitive, but this required not only large monetary investments in developments, but also a large knowledge base with high qualifications of both developers and managers of various levels, so that the process was equipped both from the technical side and from the organisational side, which is no less important. Thus, the discussion led to the justification of the need for a well-developed knowledge management system to facilitate fundamental innovation processes of this kind. As the interviewee noted, it was the knowledge management system with a large base of accumulated knowledge of the organisation that allowed a major step forward in the issue of development and technological innovation. In this context, the question of knowledge-based innovations and how exactly they are generated was considered. The respondent gave a clear answer in favour of the relationship between the knowledge management system and the innovation process, agreeing that they are complementary. And the end product of their complementarity is innovation, the core of which is knowledge, which in turn is knowledge-based innovation.

The interview with the representative of the Gnostic sphere was structured in the same way, so that the question of the innovation process was considered first. The interviewee emphasised that the sphere is not high-tech, so technological innovations are extremely rare, but the situation with product, organisational and marketing innovations looks the same. This is due to the fact that hotel services have to be constantly improved, not only by correcting mistakes but also by introducing new ones, as well as their promotion, which has to constantly adapt and improve in terms of marketing strategies and the tools used. All these improvements and innovations often lead to the need to improve the organisational process, which entails organisational innovations. As for the knowledge management system, this is not a common practice for this market, but the respondent shared that their organisation has it, and it was also emphasised that it is necessary for quality work - after all, it is a set of rules as well as a base where all the experience of the activity is stored. Therefore, the formed knowledge base is often a source of improvement of the above-mentioned innovations. Thus, the relationship between the knowledge management system and the hotel market has been highlighted, leading to the creation of knowledge-based innovations.

A representative of the education sector pointed out the importance of the innovation process in activities, since continuous improvement of the educational process increases customer satisfaction, which leads to their loyalty and commitment, and also popularises the school. The innovation process mostly concerns the product itself, since it is the main value in this market, and it allows not only to increase the indicators of overall competitiveness, but also to create non-copiable competitive advantages in the form of different methods and approaches. As for the knowledge management system, the respondent highlighted it as the main component of successful activity - after all, the main product of the analysed organisation's activity is knowledge. For this reason, it is necessary to create a knowledge base with various approaches to the educational process, methods, as well as the experience accumulated by employees during the entire period of their activity. In addition, the knowledge base focuses on the acquisition of external knowledge accumulated by other market participants rather than internal knowledge accumulated by the organisation itself. This is due to the fact that the respondent's educational organisation seeks to study new practices and integrate them into its activities with its own interpretation. This specificity is also due to the fact that staff are a very important source of new knowledge, as they are literally the bearers of the knowledge that they share with their students, and they receive this knowledge mainly from outside a single organisation. Thus, there is an emphasis on the acquisition of external knowledge, which leads to the creation of knowledge-based innovations.

4.2. Quantitative research

The quantitative study was conducted using a 7-point Likert scale questionnaire. The main objective of the quantitative study was to determine the actual perception of categories such as innovation process, knowledge management system and their relationship leading to knowledge-based innovation. Due to the specific nature of the questionnaire, it does not contain questions, but rather propositions that respondents can agree or disagree with.

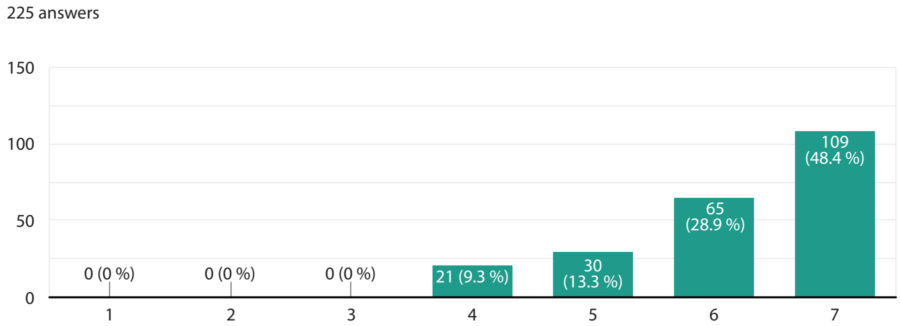
The first thesis concerned the role of the KM system in the management and operational activities of the organisation: ‘The presence of a knowledge management system improves the organisation of both the management and operational components of the company’ (Fig. 2).

As can be seen from the results, respondents were extremely consistent in their answers, as indicated by their clear tendency towards absolute agreement. It is also important to note that there was no disagreement among the 225 respondents, which is a positive sign.

The second thesis was as follows: To be successful, a company must invest its resources in the innovation processэ (Fig. 3).

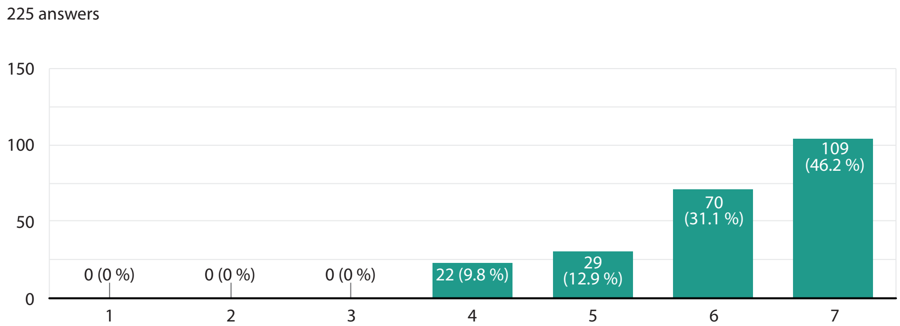
The result also deserves special attention because of its positive trend for the study towards absolute agreement with the statement regarding the importance of the innovation process for successful activity. It should also be emphasised that there were no negative reactions to the thesis.

Fig. 2. Respondents’ answers on the availability of a knowledge management system



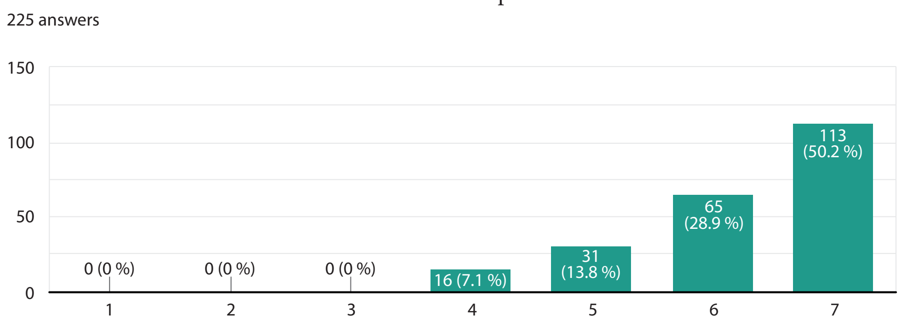
Source: compiled by the authors.

Fig. 3. Respondents’ answers on investment in the innovation process



Source: compiled by the authors.

Fig. 4. Respondents’ answers on the impact of the knowledge management system on the innovation process



Source: compiled by the authors.

The next question was the key one in the questionnaire, as the results would either confirm or refute the need to identify knowledge-based innovations: ‘The knowledge management system stimulates the innovation process of the organisation and creates knowledge-based innovations’ (Fig. 4):

As can be seen from the results in Fig. 4, the respondents agreed that knowledge-based innovation occurs in their practice as a separate type of innovation, which justifies the research question and also emphasises the need to study this topic.

Summarising the qualitative and quantitative research, we can conclude that:

- Respondents from different business sectors and sizes emphasise the importance of the innovation process for the success of their activities.
- Respondents highlight the importance of the knowledge management system as an important element in the life of the organisation.
- Respondents noted the relationship between the knowledge management system, where the knowledge management system stimulates the innovation process. It was also said that they can complement each other.
- The final outcome of the relationship between the knowledge management system and the innovation process is knowledge-based innovation.

5. Clarification of the classification of knowledge-based innovations based on the results of the empirical analysis

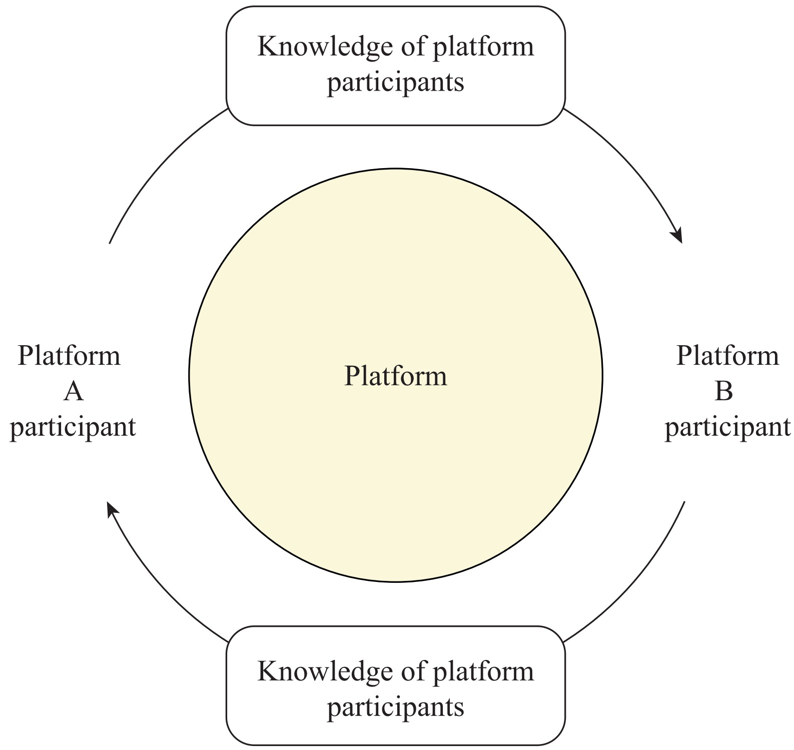
The empirical analysis carried out has allowed us to complete the developed classification of innovations based on knowledge by introducing information about the source of knowledge for creating innovations as an important characteristic for company managers. Knowledge can be:

- created on the basis of the knowledge of the organisation itself - this type of knowledge-based innovation consists in the fact that the enterprise creates process or product innovations on the basis of the knowledge it has accumulated and created within its organisational structure, without going beyond its boundaries. The main tool for creating this type of innovation is modern digital technologies, which help to store and replenish the relevant database, which can be used as the main source of obtaining innovations;
- the second type implies that the innovation is the result of knowledge sharing and management within networked organisations that may be in the same value chain or operating on the same platform. The supporting tool is modern cloud technologies, which enable the fast and secure transfer of knowledge between participants.
- a favourable factor for the creation of innovations based on this type of knowledge is the platform business model, in which each of its participants complements the others, and consumer value is increased by the increasing interconnection between the elements of the platform. This is because knowledge begins to circulate throughout the platform system, accumulating new knowledge and stimulating innovation. A kind of synergy is created. This process is shown schematically in Fig. 5;
- created on the basis of external knowledge - the last type is innovations whose source is knowledge created outside the structure of the organisation, and even outside the platform if it is located on one. This type of innovation based on knowledge can be one of the most important, since the amount of knowledge in the world is extremely large and a relatively large part of it can be integrated into one or another organisation, even if the "creator" of the knowledge is located in an extremely distant sector of the market.

Conclusion

The study demonstrated the importance and necessity of studying knowledge-based innovations due to their practical benefits for participants in different market sectors.

Fig. 5. Circulation of knowledge between the participants of the platform



Source: compiled by the authors.

Participants in the qualitative and quantitative research concluded that:

1. Innovative activity is important for the successful operation of an organisation because the presence of innovation implies the creation of competitive advantages.
2. The knowledge management system serves as a good tool for improving the quality of processes in the organisation, and also often has a positive effect on the innovation process due to its tendency to create new knowledge.
3. The relationship between the knowledge management system and the innovation process involves the creation of innovations based on new knowledge - knowledge-based innovations.

In the final part of the thesis, a classification of knowledge-based innovations was proposed in terms of the source of obtaining new knowledge that formed the basis of the created innovation. This classification is one of the possible approaches that can be proposed in the process of studying the issue.

Further research should concern a complete study of the process of creating knowledge-based innovations: their success may require both certain skills and technological support from the organisation. At the end of the study of this theoretical and practical category, it would be appropriate to propose a methodology for implementing knowledge-based innovations, which will be proposed by one of the authors as a dissertation study.

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Impact of digitalisation on increasing the fragility of the system (on the example of 'Digital Road' project)

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Abstract
Today, digitalisation is seen as a tool that can significantly improve the efficiency of all production processes. In fact, digitalisation has led to some impressive successes, but it has also brought with it some qualitatively new risks.
The article aims to examine the impact of digitalisation on the fragility of social and technical systems, using freight transport as an example. The development of 'Digital Road' is expected to radically improve the freight transport service system. However, with the advent of remote process control technologies, the main customers of transport services – the mining and manufacturing industries – could see radical changes in the transport system.
According to the author, routine and repetitive types of activities are most suitable for digitalisation while innovation and uncertainty hinder it. The maximum level of uncertainty is associated with social and natural factors that set the upper limit for the process of digitalisation of production activities.
Experience with the use of digital tools in various fields suggests that the consequence of this process is uniformity, increased monopolisation of markets, reduced diversity and the dominance of a single technological solution for typical situations. This reduces the technological adaptability of the production system and increases its vulnerability to social and natural risks. The article suggests that fragility in the transport sector could be halted by using a variety of transport services that would be in demand after mining and manufacturing industries move to fully unmanned and remote-controlled technologies.
Keywords: digital road digitalisation, transport, transportation service, routine, innovation, uncertainty, fragility, risk.

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数字化对加剧系统脆弱性的影响 (以数字之路项目为例)

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简介
如今，数字化已被视为一种能够显著提高所有生产流程效率的工具。事实上，数字化在许多领域都取得了重大进展，使数字化成为一个整体过程。然而，在这一过程中出现的新风险仍处于阴影之中。
本文旨在以货运为例，探讨数字化对社会技术系统脆弱性的影响。数字化道路的建立有望从根本上改善货运系统。然而，随着远程过程控制技术的出现，货运服务的主要客户--采掘业和制造业--可能会经历翻天覆地的变化。
作者认为，常规的重复性活动最适合数字化，而创新和不确定性则会阻碍数字化。不确定性的最大程度与社会和自然因素有关，这些因素决定了生产活动数字化进程的上限。
在不同领域使用数字化工具的经验表明，这一过程的后果是单一化、市场垄断加剧、多样性减少以及典型情况下只有一种技术解决方案的主导地位。由于这些原因，生产系统的技术适应性降低，其在社会和自然风险方面的脆弱性增加。文章认为，在运输领域，运输方式的多样性将克服脆弱性，在采掘业和制造业过渡到完全无人驾驶和遥控技术后，运输方式的多样性将成为需求。
关键词：数字道路、数字化、运输、交通、常规、创新、不确定性、脆弱性、风险。

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Introduction

Further research should concern a complete study of the process of creating knowledge-based innovations: their success may require both certain skills and technological support from the organisation. At the end of the study of this theoretical and practical category, it would be appropriate to propose a methodology for implementing knowledge-based innovations, which will be proposed by one of the authors as a dissertation study.

In the context of this article, digitalisation is understood as the process of transferring production functions from humans to artificial software and hardware systems, which is a consequence of the development of the technosphere (more precisely, a consequence of the process of improving tools).

Of fundamental importance is the digitisation of the economic infrastructure, especially transport, which directly or indirectly affects every inhabitant and every organisation in the country, and which has no close substitutes.

The set of digitisation projects in transport, which can be called the 'Digital Road', implicitly assumes that an information intermediary will first appear between technical systems and humans, which will then completely replace humans, leaving only the functional link 'technical system - programme'.

The set of projects 'Digital Road' concerns all the main elements of the transport system, including multimodal transport, transport and logistics hubs, transport process, traction vehicles, etc. [Sukonnikov, 2022]. At the same time, the same tools will be used as in other sectors of the economy: BigData, cloud technologies, new generation robots, virtual and augmented reality [Tsenzharik et al., 2020], machine learning technologies, automatic identification and tracking of objects, voice services, digital twins, electronic platforms, etc.

As rightly noted in the study [Plotnikova, 2020], the division of labour was a basic condition for digitalisation. According to the author of this article, the necessary conditions for digitalisation are:

1) the divisibility of the production process into separate stages (the possibility of constructing a process model): it is difficult to digitise the work of a universal (and therefore unique) specialist, as opposed to a labour process with clear stages of division of labour;
2) maximum transparency of the production process and quantitative expression of all its key parameters (possibility of formalising process data);
3) the standard nature of the product, work, service, which allows comparison, aggregation, planning, etc. (quantitative commensurability and reduction of variability);
4) the possibility of separating information and material flows (absence of tacit knowledge);
5) repeatability of the production process without significant changes that could affect the technology (routine);
6) The presence of a production management subject (process owner) with stable and quantifiable objectives.

The transport industry meets all the above requirements. In terms of routine, different types of transport have different levels of readiness for digitisation:

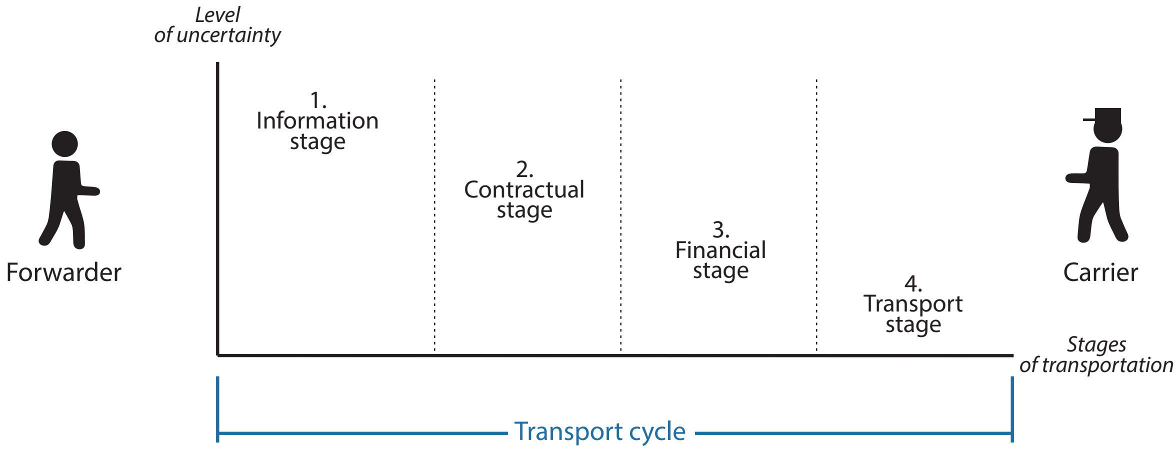
1) pipeline transport:
   – centralised transport system (new entrants to the market are limited),
   – minimal human presence,
   – means of transport remain stationary: the goods themselves move,
   – no need to return means of transport,
   – homogeneous mass goods,
   – impersonal consumer;
2) rail transport:
   – centralised transport system (limited entry of new players),
   – separate communication channels,
   – a significant number of industrial workers involved
   – rigid connection of transport to the railway network
   – limited number of professional operators,
   – concentration on long-distance transport of raw materials;
3) car transport:
   – unlimited number of participants,
   – decentralised transport system,
   – significant number of industrial workers involved,
   – maximum mobility of transport throughout the country,
   – focus on transport of processed raw materials over short and medium distances;
4) air transport:
   – centralised transport system,
   – limited number of professional operators (limited entry of new operators)
   – dedicated routes,
   – concentration on the transport of high value products over long distances;
5) water transport:
   – highly dependent on the state of the external natural environment,
   – wide range of participants,
   – connection of transport to the waterway network.

For example, pipeline and rail transport are the most ready for digitisation, as they are relatively less sensitive to the natural and social environment.

1. Routines and innovations

If we consider the relationship between the shipper and the carrier, each physical movement of the cargo is preceded by at least three specific types of activities, the implementation of which takes place sequentially: the exchange of information (on the parameters of the cargo, the technical possibility of transport, the route, etc.), the signing of a contract and the implementation of financial transactions (reservation of funds for payment, prepayment, cargo insurance, etc.). The sequence of these stages is called the transport cycle (Fig. 1).

Fig. 1. Successive stages in the freight transport cycle



Source: compiled by the author

Figure 1 shows that with each stage in the freight transport cycle, the level of uncertainty among stakeholders decreases. This in turn facilitates the digitalisation of these stages. In addition, each of the stages has its own duration. In the author's opinion, it can be assumed that in a routine situation (i.e. extremely stable and repeated an unlimited number of times), the duration of each preceding stage is significantly shorter than the duration of each subsequent stage. This can be expressed by the inequality:

$$T_I < T_C < T_M < T_T, \quad (1)$$

where T_I – duration of the information phase, T_C – duration of the contract phase, T_M – duration of the financial stage, T_T – duration of the transport stage.

A quantitative test of this disparity is unlikely to be feasible, but some arguments can be made in its favour. In particular, the more stable and predictable the market situation (there is information transparency), the less the need to update the content of contracts and the longer their validity. The risks of receiving payment are reduced, and partners can therefore refuse, for example, advance payments, insurance, guarantees, etc. As a result, more and more flights are carried out as part of a market transaction.

In times of unpredictable changes in the external environment, the opposite process occurs. An example of this is the situation with the Ever Given container ship accident, which led to the closure of the Suez Canal on 23 March 2021 [Gerson, 2023; Rakha, El-Aasar, 2024]. This event immediately increased the level of uncertainty among all transport stakeholders, which required an intensive exchange of information. Once the situation became relatively clear, a calmer revision of contracts for new transport on available routes began. And it was only after this significant preparation that the financial and transport phases were resumed.

If we are talking about new and strategically important deliveries, then agreeing the terms (this activity in Figure 1 corresponds to the information stage) can take years, but once signed they can be in force for decades[1] (contractual stage), which greatly increases the duration of other stages (financial and transport).

Thus, in a fundamentally new situation, the information phase closes in on itself and the next, contractual phase does not begin until some picture of what is happening has been formed. However, if such events become constant (military actions, pirate attacks, etc.), they will be incorporated into standard action algorithms, i.e. they will also become routine.

In very routine situations, contracts represent a public offer: the contract is automatically concluded with any interested party on the terms specified in the offer. Once the offer has been accepted, the movement of financial documents is automatically initiated and the cargo is sent along the planned route.

In the author's opinion, the types of specific activities shown in Fig. 1 have different degrees of readiness for digitalisation. The transport stage is currently being actively digitalised by replacing drivers with software and hardware systems, and the financial stage - with the help of online payment systems. At the same time, activities such as documenting the transport, concluding a contract, planning the transport are characterised by higher uncertainty and therefore require mandatory human participation, and the prospects for their digitalisation are extremely vague. These stages are shown in Fig. 2.

Fig. 2 shows that routine, repetitive operations are primarily digitised, whereas information activities are extremely difficult to digitise due to the unpredictability of the external environment.

In other words, full digitisation requires the complete routinisation of all types of activity and the minimisation of the uncertainty factor. To this end, there is an arsenal of measures in various stages of readiness, including:

1) a numerical expression of each transport process, allowing comparison and management. Numbers can be considered as a universal expression of a symbol [Kleiner, 2020]. In relation to transport, such relative

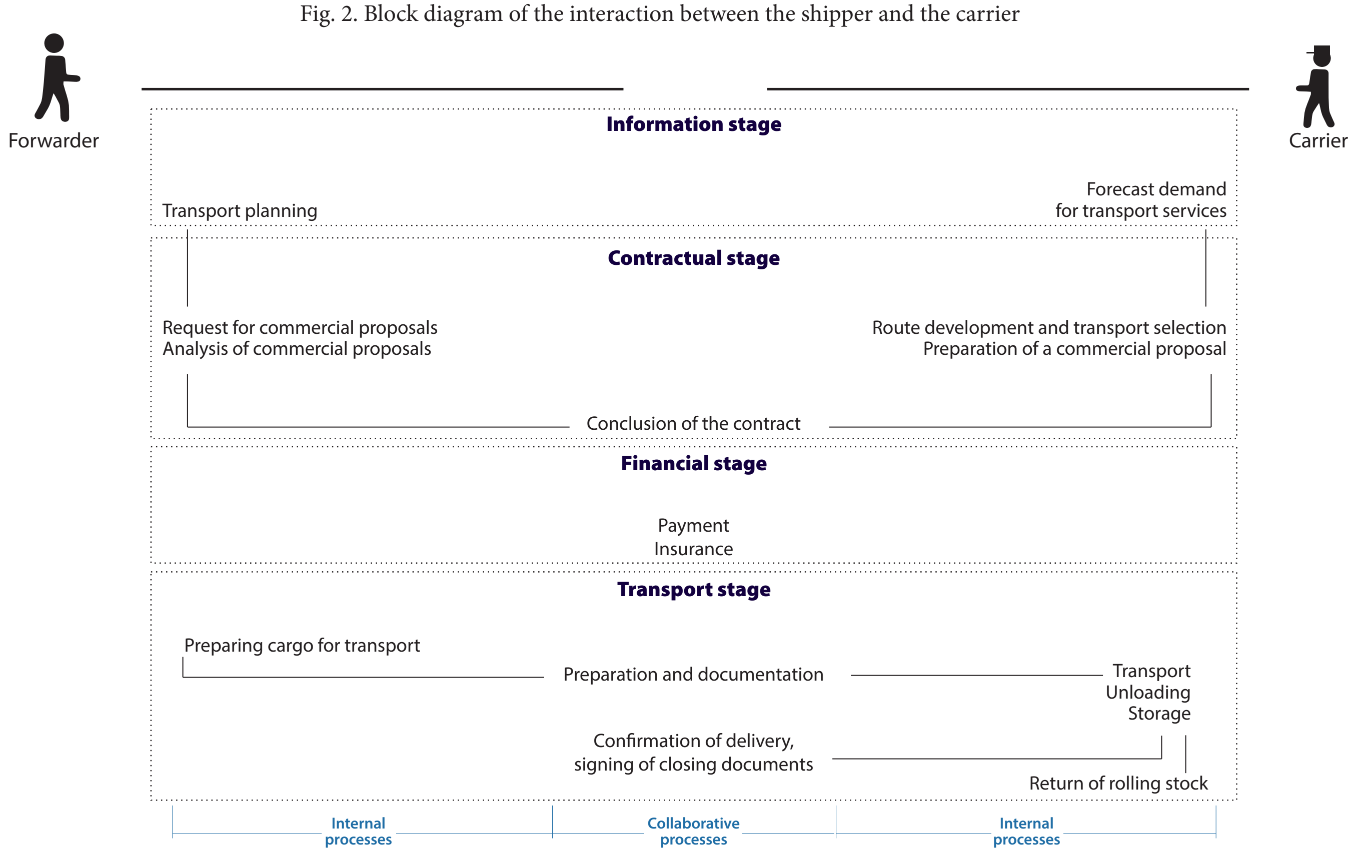
[1] Russia will sell gas to China with minimal profitability. https://www.rbc.ru/economics/21/05/2014/57041d219a794761c0ce9fb9.

and absolute indicators as freight turnover, average freight delivery speed, operating coefficient, average hourly productivity, throughput, transport network density, etc. are used;

2) unification and standardisation of the cargo unit: standard storage units (platforms, containers, tanks, etc.) have been developed for the entire range of cargoes, which greatly facilitates the transfer of cargoes between different modes of transport and also makes the transport process planned and predictable;
3) automation and maximum elimination of human beings from all areas of production. This will reduce the level of uncertainty, which can be clearly seen when studying the causes of accidents in transport: in road transport, 90% of all accidents are caused by human error [Andreev, Pavlov, 2015, p. 172]. In sea transport, the human factor is the cause of 80% of accidents [Ermakov, 2016], in rail transport - 75-80% [Klimov, Lezhenkina, 2006], in road transport - 85.2% [Kuprienko, Grefenstein, 2023];
4) gradual transfer of activities to the virtual world, improvement of artificial intelligence, etc., which also serves to eliminate the human factor;
5) regulation and algorithmisation of the actions of the participants. At present, at the information level, protocols have been developed for each routine and abnormal situation in order to neutralise the instability factor - this is a prescribed sequence of actions by all participants, initiated in response to a given event. Moreover, the more participants involved, the stricter the protocol: failure to comply with it is unacceptable, as it increases the risks of the entire system. At the contractual level, such protocols are codified in various forms of legal contracts (classical, neoclassical, relational, etc.) [Ivaschenko et al., 2019], which focus on a particular level of uncertainty.

In the long term, digitisation can instantly initiate the required protocol type (with the corresponding action algorithms), not only within an organisation, but throughout the entire production chain (right up to the end user). This allows the digitised transport system to function as a single whole - predictably and without delay. However, this is hampered by the uncertainty of the external environment (social and natural). Moreover, in an internal digital environment, the risks and uncertainties of a particular, even small, entity become the risks and uncertainties of the entire system. For example, a lorry on a local road may not affect the movement of other vehicles. On a digital road, the same truck can affect not only a specific section, but the entire transport system at once (e.g. by blocking a lane on a high-speed motorway).

Fig. 2. Block diagram of the interaction between the shipper and the carrier



Source: compiled by the author

Many researchers implicitly assume that full digital transparency will reduce some of the risks, or at least manage them effectively [Tagarov, 2023]. This is probably true to a certain extent, but it is also true that at the same time the system becomes qualitatively more fragile and more sensitive to any deviation from the norm. According to the author of this article, the reason for this is that digitalisation leads to the monopolisation of markets.

On the one hand, digitalisation makes production and market processes transparent and therefore predictable and manageable. On the other hand, it enables large companies to squeeze smaller competitors out of markets. This is the case in markets where small and medium-sized companies are currently protected by high transaction costs. Today, for example, production processes in areas such as car service, repair, household services, etc. are usually non-standardised and therefore unattractive for large players (their costs for individual services in the economy sector do not pay off). However, digitalisation can eliminate this factor (e.g. in the car service sector, this can be manifested in the fact that renting a car becomes more profitable than buying and repairing it, or in the transition to 'disposable' cars). This reduces the grey area of the economy and makes small and medium-sized enterprises less competitive.

As a result, digitisation is followed by monopolisation, which can be clearly seen in the example of taxi markets (the number of taxi companies is decreasing), operating systems (for mobile devices, this is Android and, to a much lesser extent, iOS; for PCs, this is the dominance of Windows with a very limited presence of macOS, Linux, Chrome OS), video hosting (despite many years of attempts, a real competitor to YouTube has not yet been created), city navigation systems (in Russia, this is only 2GIS and Yandex.Maps), etc. The same goes for rental markets, office equipment, online shops, ticket offices, tourism and much more. Even something as familiar as a bulletin board has become a monopoly in the Russian digital environment (the Avito Internet service). But this is only the first circle of monopolisation. The next circle is the monopolisation of access to markets. For example, Sberbank has clearly stated that it intends to cover all human needs [Galazova, 2023]. Such a continuous ecosystem will entail both the complete isolation of the consumer and a total monopoly. If competitors remain in any of the markets, they are likely to be little different from each other, being in fact variants of the same digital solution.

But more importantly, the number of technological possibilities in each market is now greatly reduced, and the economy is transforming from differentiated to fractal, where the same digital matrix is reproduced in each segment. This thesis can be explained using the example of the interaction between subjects.

In inter-subject interaction (coordinating the activities of many people), a single protocol is required. Moreover, the greater the number of subjects involved in the interaction, the smaller the variety of protocols and the stricter their observance. Although such a requirement existed before digitalisation, it previously concerned small groups and professional communities. Today, this requirement has become total: an increasingly limited list of digital systems and their protocols is used in every single field of activity. The same processes are taking place here as in linguistics: world languages are irrevocably absorbing local ones.

The history of languages also provides us with examples of the fragility of systems: many languages and writing systems have disappeared due to social and natural causes, resulting in the loss of a significant part of the accumulated knowledge. In the author's opinion, the digital system poses similar risks, caused by:

– dependence on one type of energy - electricity - which is slowly but surely becoming the only acceptable one (without convincing economic arguments);
– impairment of many important human abilities: spatial orientation, information retrieval, reading long texts, etc;
– the disappearance of human subjectivity: from a subject of control he becomes an object of control by depersonalised computer programs; instead of a full person, as a result, only his digital profile may remain [Kondakov, Kostyleva, 2019];
– intentional or accidental errors in digital systems, exacerbated by blurred lines of responsibility;
– distortion of human consciousness: misunderstanding of nature (man will be increasingly isolated from nature by the technosphere), deterioration of the understanding of cause-and-effect relationships (man can no longer repeat AI operations and double-check his decisions), deformation of the world view as a whole;
– isolation of individuals: gradually, all interaction becomes possible only through the mediation of digital systems (including social skills and connections);
– forgetting the knowledge accumulated by civilisation in favour of easier access to knowledge through artificial intelligence, which, as it turns out, is capable of falsifying data;
– the loss of the goals and values that man has set for the technosphere; in this case, man is transformed from a creator of meanings and values into a subordinate subsystem of the technosphere.

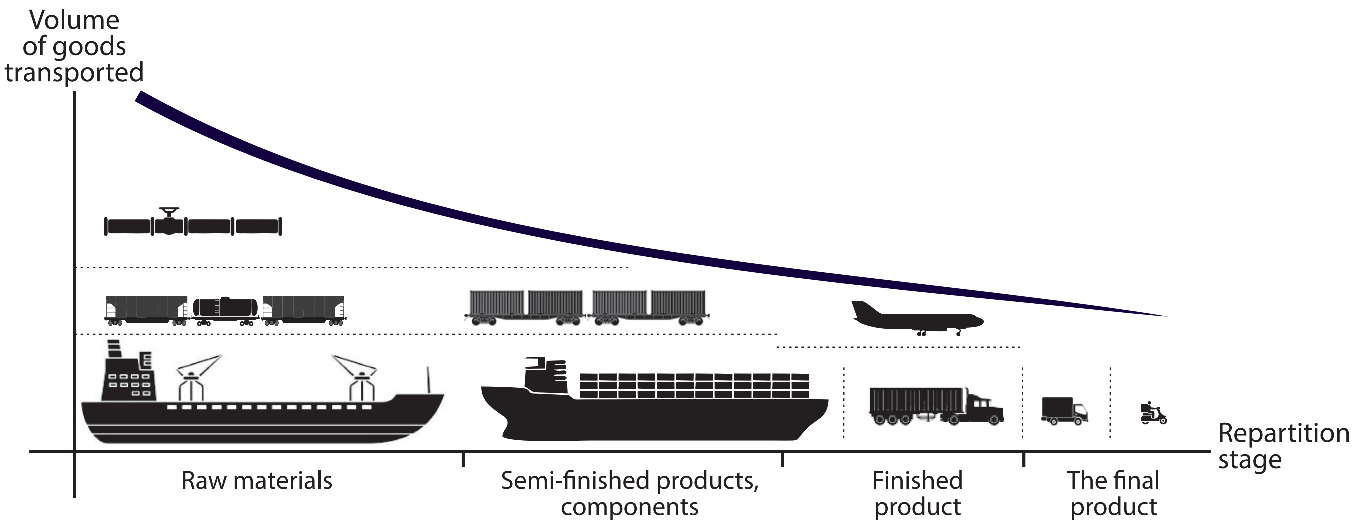
Each of these risks individually, and all of them together, means an increase in the fragility of both the macro-economy and the transport system. In the long run, even one of these factors will be enough to seriously destabilise the system.

So any monopoly is destructive, and a digital monopoly is many times more destructive because it penetrates all segments of the economy and irrevocably destroys competing technologies: a type of energy, a database, a way of interacting.

2. An alternative path to digitisation

Let's look at the consequences of digitalisation that are likely to be manifested in the interaction between industry and transport.

Fig. 3. Change in volume aof goods handled and type of transport by stage of processing



Source: compiled by the author

At present, transport is structured according to the type of cargo transported, the volume of which depends on the processing stage (Fig. 3).

Fig. 3 shows that the most voluminous cargo is raw materials, and the higher the stage of processing, the less transport is needed. Digitalisation can significantly change this situation.

Digitalisation is displacing humans from all areas of activity. As a result, the nature of both production and freight transport may change: many activities can already be performed remotely or unmanned (e.g. operating dump trucks in a quarry, piloting locomotives and aircraft). This involves major technological changes. For example, the development of a large mine today requires the relocation of hundreds or even thousands of workers and their families to the production site, which requires the creation of a capital-intensive social infrastructure around it. As a result, such production is tied to a specific territory. However, this link can be broken with the help of unmanned technologies, making the place where workers live and the place where they produce completely independent of each other. In such a scenario, a significant part of the production chain can be concentrated in one place: from the extraction of natural resources to the manufacture of the finished product. In this case, the need to transport the most bulky types of raw materials (oil, coal, ore, grain, etc.) disappears, and the transport system will only transport less bulky cargo with a high degree of processing.

For example, the digitalisation of manufacturing and extractive industries may lead to the concentration of their production in one place and to the transformation of some types of transport from interregional to intraregional (e.g. organised according to the conveyor principle).

This, in turn, will have the following macroeconomic consequences:

– radical reduction in the volume of freight transport and the consequent strain on roads and motorways, which will raise the question of the economic viability of their maintenance (passenger transport will not be able to cover the costs of maintaining the transport infrastructure);
– growing demand for differentiated delivery methods that do not require expensive and long roads: water and air transport. In turn, the elimination of roads will lower the entry threshold for many participants and increase the level of competition. In such a scenario, we should expect a renaissance of paraglider, seaplane, cargo airship technologies, etc.

The risk zone mainly affects rail transport, which focuses on non-containerised bulk goods (liquids, bulk goods, loose goods, etc.). The decline in demand also affects road transport, but to a lesser extent as it focuses on the transport of processed raw materials over shorter distances.

This means that, for technological reasons, the market for transport services will enter a phase of compression, requiring a transition from narrow specialisation to universality. As a result, instead of a large number of differentiated means of transport (tanks, wagons, refrigerators, etc.), there will be a need for a single means of transport suitable for transporting all or most types of cargo. In the future, this role could be played by containers, which are equally suitable for rail and road transport.

The container can also be presented in a more advanced form of contrailer[2], , which gives each specific transport unit the property of mobility and manoeuvrability. From here, it is only a step to give it complete autonomy, i.e. the ability

[2] A contrailer is a container fitted with car wheels and intended for the combined transport of goods: car-water, car-rail or mixed car-rail-water.

to move using its own engine, as well as the ability to plan its own route and carry out loading and unloading without human intervention.

If we continue with speculation and probabilistic scenarios, in the future contrailer vehicles travelling along the same route may acquire the technological ability to join together to form trains and travel as a single unit along the same route by combining their engines into a single power plant and then disassembling into individual delivery vehicles. In this way, piggyback transport will combine the advantages of both rail and road.

This scenario does not eliminate the risk of a person losing subjectivity and other risks generated by digitalisation, but it does eliminate one key risk - the risk of losing the plurality of technological solutions.

Conclusion

Digitisation must be cross-cutting, at least on a macroeconomic scale, and is therefore impossible without digitisation of the basic sectors of the economy: energy, transport, communications, trade. This article examines this process using the transport sector as an example.

Tools and other components of the technosphere were originally conceived as complements to the human body, but eventually became its substitutes. In other words, by creating and improving tools, humans created another self.

The highest form of development of the technosphere is digitalisation, which has so far functioned on the principle of 'in the interest of man, but without human participation'. However, the completion of the digitalisation process will ultimately mean that man will turn from the goal of the system into its subordinate subsystem on the principle of 'without human participation and only in the interest of the digital system'. At the same time, the system itself will lose the purpose and value of its activities, and will also become many times more sensitive to social and natural risks. It is already clear that digitalisation has led to a dramatic reduction in the number of market players, a decrease in diversity and the dominance of a limited number of technological solutions.

Digitalisation may also have consequences that are not yet apparent, in particular the reformatting of the industry and the elimination of demand for the transport of whole categories of goods, which will lead to a radical change in delivery technologies.

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The state of the Russian fuel and energy complex and development paths in the context of the fourth energy transition

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Abstract

Global electricity production is increasing as a result of population growth, technological development and the demand for electricity by people and industry in the context of the energy crisis. Accelerated electrification has become the main energy transition trend in the final use of energy resources. In response to the climate challenges of the green agenda, the global energy industry has embarked on the fourth energy transition, focusing on prioritizing renewable energy generation. The countries of the world are faced with the most urgent tasks: accumulation and reservation of generated energy for further distribution, and balanced planning of the location of energy generation facilities, taking into account territorial features, economic needs and other factors, taking into account the normalised cost of a unit of energy obtained from renewable and non-renewable sources. The review used the research results of Russian and foreign scientists, including the authors of the study. The world energy system and the Russian energy system are considered in terms of the cost of energy by type of sources.

Keywords: world energy, fuel and energy complex of Russia, fourth energy transition, fossil energy sources, renewable energy sources.

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俄罗斯燃料和能源综合体的现状以及在第四次能源转型条件下的发展途径

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简介

随着世界人口的增长、技术的发展以及人口和工业在能源危机下对电力的需求，全球发电量不断增加。在能源资源的最终消费方面，加速电气化已成为能源转型的主要趋势。为了应对绿色议程中的气候挑战，全球能源行业已经开始了第四次能源转型，重点是优先利用可再生能源发电。世界各国正面临着最紧迫的任务：积累和保留所产生的能源，以便进一步分配；根据地域特点、经济需求和其他因素，均衡规划能源生产设施的布局，同时考虑到从可再生和不可再生资源中获取能源的单位标准化成本。综述采用了俄罗斯和外国科学家（包括本研究报告的作者）的研究成果。从各类能源成本的角度对世界能源系统和俄罗斯能源系统进行了研究。

关键词： 世界能源、俄罗斯燃料和能源综合体、第四次能源转型、化石能源、可再生能源。

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Introduction

Global electricity generation reached 29,925 TWh in 2023, an increase of 2.5% from 2022, demonstrating that the global energy system is becoming more electrified to meet the needs of a rapidly growing global population (Figure 1).

Fig. 2 shows the structure of global electricity generation by energy source for the period 1990 to 2022. The graph shows that the world's leading electricity generation is still thermal power plants fired by coal and gas.

By consistently implementing the green agenda, the world's countries produced a total of 4,748 TWh[1]. of energy from renewable sources in 2023, 13% more than in 2022. This level of generation was almost entirely provided by wind and solar energy, accounting for 74% of all additional clean electricity generated, and in the EU countries, 60% of the electricity produced was based on renewable energy sources[2].

Table 1 shows data on consumption, production and demand for electric energy of the unified energy system of Russia for 2019-2025 (forecast). Energy production is given by energy production sources. The ratio shows that the Russian energy system follows global trends: the largest amount of energy is produced by thermal power plants, followed by nuclear and hydroelectric power plants, and the list is completed by energy from renewable sources.

In the case of surplus production, the problem of storing the electricity produced arises. It should be remembered that since 1991 the Russian Federation has had a federal law on energy saving[3], which has many local regulations and helps to save energy wisely and preserve nature in general.

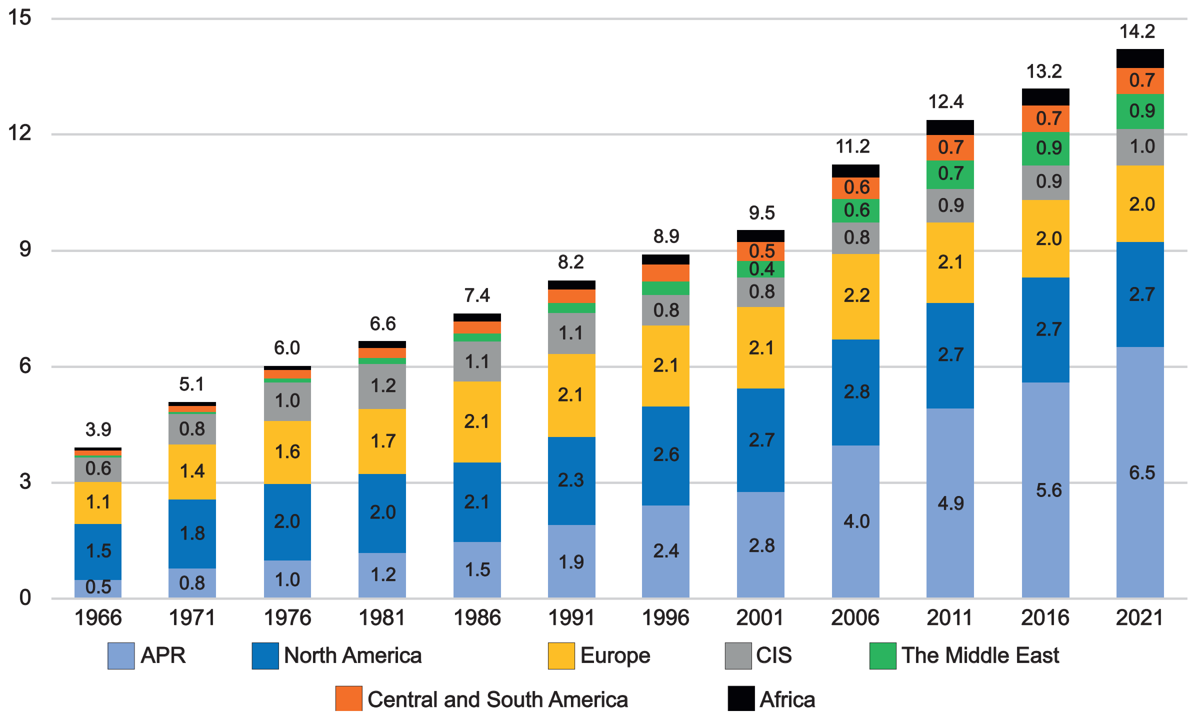
The main reason for using alternative energy sources is global warming caused by the use of fossil fuels. The depletion of energy resources, oil crises and the rising cost of energy production have forced the world to look for alternative energy sources.

Driven by changes in energy policy, the world is entering the fourth stage of the energy transition towards the widespread use of renewable energy sources and the displacement of fossil fuels. The development of renewable energy was spurred by the global energy crisis, which ended the long era of cheap fuel. In 1973, the world identified two ways out of the energy crisis[4]:

– intensive development of energy saving and energy conservation technologies, use of secondary energy resources;
– use of renewable energy sources.

With the growth of the Earth's population and its need for electrical energy, the development of industry in countries around the world, a related problem of accumulation and storage of produced energy has arisen. The use of energy

Fig. 1. Dynamics of world energy consumption for 1966–2022



Source: Statistical review of world energy. 2022, June. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf.

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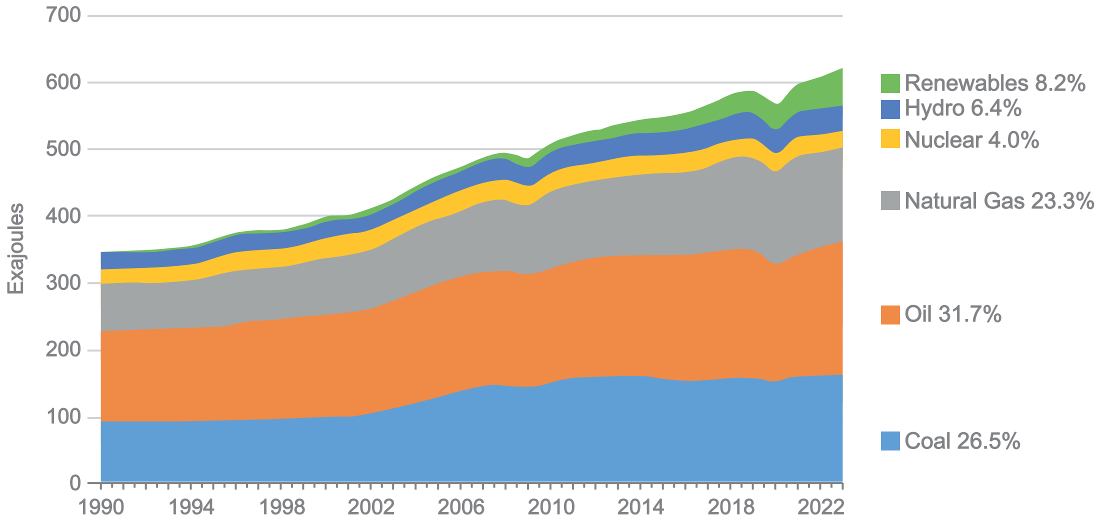
Fig. 2. World electricity production, 1990–2022 (% by energy source)



Source: Statistical review of world energy. Energy Institute releases, 2024. https://dieselnet.com/news/2024/06energyreview.php.

storage systems (ESS) is an integrated solution for the accumulation of electrical energy, its conversion and further use [Mazurov, 2017]. At present, there are no technical solutions and energy storage devices that can be used on the scale required by energy-intensive companies. However, these companies should be most interested in such solutions, as increasing energy efficiency is one of the factors in reducing production costs, which ultimately leads to an increase in net profit[5].

It is worth mentioning another underestimated source of energy production - biomass. In economically developed Europe, according to IAEA data for 2019, the share of completely non-green sources - bioenergy and waste - in the total volume of primary resources used is 8%, which is not small[6]. Russian analysts have calculated: 'Renewable energy sources currently provide about 15% of the world's primary energy consumption, but 13% is hydropower and biomass. The share of new types of renewable energy sources is only 2%'[7].

These statistics are somewhat at odds with what is generally known, but biomass has a chance of taking a certain share of energy production, although it is not a clean source.

The purpose of this study is to determine the optimal source or complex of sources for electricity production in the country in the context of the global energy transition, based on the analysis of the following factors:

- the life cycle characteristics of energy production from different sources;
- electricity demand of population and industry;
- territorial population density [Mokshin, Reut, 2023];
- life cycle characteristics of energy production from various sources;
- standardised costs of produced energy by type of fuel and energy.

The subject of the study is the unified energy system of Russia.

It is assumed that in the near future, i.e. up to 2050 and beyond, priority will be given to the production of energy from renewable sources. One of its main advantages will be its cost.

1. Methodology, sources

To achieve the stated goal of this study, it is necessary to conduct an analysis of the current state and prospects for the development of energy in the world and Russia, the stages of the life cycles of energy production from various sources, the impact on the safety of the population and the environment, the cost of the produced kilowatt-hour of electricity.

A multi-factor analysis of the cost of generating electricity from different sources may include the following indicators:

- economic: investment and operating costs (fixed and variable). For instance, renewable energy plants have virtually no variable costs thanks to their free sources. In contrast, fuel costs account for up to 80% or more

[5] Report on the functioning of the unified energy system of Russia in 2023 (based on operational data). https://www.so-s.ru/fileadmin/files/company/reports/disclosure/2024/ups_rep2023.pdf.
[6] Report on the functioning of the unified energy system of Russia in 2023 (based on operational data). https://www.so-s.ru/fi leadmin/files/company/reports/disclosure/2024/ups_rep2023.pdf.
[7] Renewables alone won't keep you clean. https://atomicexpert.com/res_will_be_used_more_widely.

Table 1
Electricity balance of Russia's unified energy system, demand and consumption volumes, 2019–2025

Name	Measurement unit	Forecast						
		2019	2020	2021	2022	2023	2024	2025
Energy consumption	bn kWh	1032.8	1050.3	1081.5	1071.5	1081.3	1093.8	1097.2
Including pumped storage cost	bn kWh	2.71	2.71	2.71	2.71	2.71	2.71	2.71
Export	bn kWh	11.63	11.68	11.82	11.85	11.98	11.98	11.08
Import	bn kWh	1.19	1.11	1.11	1.11	1.11	1.11	1.11
Electricity demand	bn kWh	1042.9	1060.6	1071.8	1081.9	1091.9	1104.4	1107.8
Total electricity generation	bn kWh	1042.9	1060.6	1071.8	1081.9	1091.9	1104.4	1107.8
Hydroelectric power station	bn kWh	153.5	170.5	170.5	170.6	170.7	170.8	170.8
Nuclear power station	bn kWh	202.8	198.5	199.8	197.2	196.5	201.3	198.9
Thermal power station	bn kWh	685.12	687.33	695.3	706.2	715.4	722.2	727.99
Hydropower, hydroelectric power	bn kWh	1.58	4.35	6.14	7.9	9.21	10.12	10.12
Total installed capacity	MW	236 828	235 879	234 320	235 400	237 031	237 246	235 803
Hydroelectric power station	MW	45 304	45 394	45 475	45 525	45 576	45 591	45 598
Nuclear power station	MW	30 282	29 282	29 432	29 432	30 632	30 832	29 382
Thermal power station	MW	15 8840	157 866	155 175	155 518	155 401	155 401	155 401
Hydropower, hydroelectric power	MW	2401.5	3336.6	4237.4	4924.4	5422.1	5422.1	5422.1
Number of hours of installed capacity								
Nuclear power station	Hour/year	6697	6777	6789	6700	6414	6529	6768
Thermal power station	Hour/year	4313	4354	4481	4541	4604	4647	4685
Hydropower, hydroelectric power	Hour/year	656	1302	1448	1605	1698	1867	1867

Source: Scheme and programme for the development of the unified energy system of Russia for 2019-2025. http://gost.gtsever.ru/cgi-bin/ecat/ecat.cgi?b=2&pid=1&i=4293727666&pr=1.

of the total operating costs of thermal power plants (TPPs) [Degtyarev et al., 2016].

- equipment disposal: The equipment disposal process for renewable energy generation facilities has been developed from a technical perspective, and can be launched within a short period of time (Dzedik et al., 2023).
- installed capacity utilisation factor (ICUF): for thermal power plants, this figure is 80–90%, which is four times higher than for renewable energy power plants. The ICUF for wind and solar power plants can vary widely depending on geography and natural conditions [Degtyarev et al., 2016].
- estimated service life;
- construction and commissioning costs;
- location area and choice of specific type of power plant, etc.

Therefore, the characteristics of each type of power plant should be taken into account when planning the country's energy system.

In order to achieve the objective of this study, the authors also relied on data obtained from studies of the global energy industry and the Russian fuel and energy complex conducted by other scientists. The life cycles of energy production from various sources were compared: renewable and non-renewable (see Appendix 1).

The analysis revealed the pros and cons of renewable and non-renewable energy sources. In order to implement a mechanism to support renewable energy sources in Russia, legislation was passed to establish maximum value indicators for renewable energy generating facilities, as well as target indicators for the input volumes of each type of facility up to 2035, and the degree of localisation[8]. Countries around the world have also adopted legislation on the use of renewable energy sources for energy generation. One important feature is the standardised cost per unit of energy for making decisions about the construction of specific types of power plant in specific areas, alongside other conditions.

Analysts from the Energy Research Institute (ERI) of the Russian Academy of Sciences conducted a comprehensive study (Makarov et al., 2024) on the current state and future development of Russia's fuel and energy sector. The study led to the following conclusion: 'Over the next 25 years, renewable energy sources and fossil fuels will be complementary rather than competing elements in most countries' energy systems.'

The ERI RAS study used a set of economic and mathematical models, with economic and demographic indicators and energy balances serving as the research tools. Calculations were based on various forecasting methods, including econometric analysis, cluster analysis techniques, optimisation, simulation and multi-criteria modelling. One of the issues identified by the ERI RAS study was the lack of a comprehensive approach to comparing the cost of producing a unit of energy from renewable energy sources and fossil fuels.

Researchers from the Institute of Energy Research of the Russian Academy of Sciences concluded that 'annual increases in electricity consumption will increasingly be provided by renewable energy sources, particularly due to their growing economic efficiency. By 2050, almost all the world's increased electricity consumption will come from wind and solar generation, with the shares of renewable energy sources and nuclear energy reaching 57–70% each (compared to 38% in 2021). Together with fossil fuels, these sources will form a complementary part of the future energy system' [Kulagin et al., 2024].

The final cost of switching to carbon-free energy sources depends on various factors, including the region's location, the availability of energy resources, import capabilities, demand levels and dynamics, solvency, economic sustainability, requirements for a sustainable electricity supply and the ability to synchronise with neighbouring regions' energy systems.

The increased use of gas and coal as reserve fuels in the electricity generation industry is expected to make their prices more volatile. The era of inter-fuel competition has arrived, with liquefied gas, ammonia and methanol set to grow in use for sea transport, electricity and gas, and for biofuels in road transport. Meanwhile, the transportation of passengers and goods by rail uses electricity or diesel-powered locomotive engines.

Clearly, as electricity consumption in Russia grows, the predicted indexation of regulated electricity tariffs will also increase: by 9% from 1 December 2022, by 6% from 1 July 2024, and by 5% from 1 July 2025. In certain regions of the Russian Federation, however, other tariffs may be established by the Government of the Russian Federation or FAS Russia[9].

The speed at which each country achieves the climate goals of the green agenda will be determined by its ability to offset the costs that would result from choosing a comprehensive solution to the energy supply problem associated with increasing the share of renewable energy sources.

2. Nuclear power

The use of nuclear energy for industrial purposes began in Russia in 1954 and is regulated by the federal law 'On the Use of Nuclear Energy'[10]. Nuclear power plants were commissioned in the UK and the US in 1956 and 1957. Thus, from the mid-20th century onwards, industrial energy production began at nuclear power plants around the world.

At the beginning of 2024, the share of nuclear energy in the world remained unchanged at 9% of the total energy generated[11]. In 2023, nuclear power accounted for almost 23% of Europe's total electricity generation[12], making it the largest source. This was driven by new nuclear power units coming online in Europe, China and the United States, as well as the restart of Takahama units 1 and 2 in Japan.

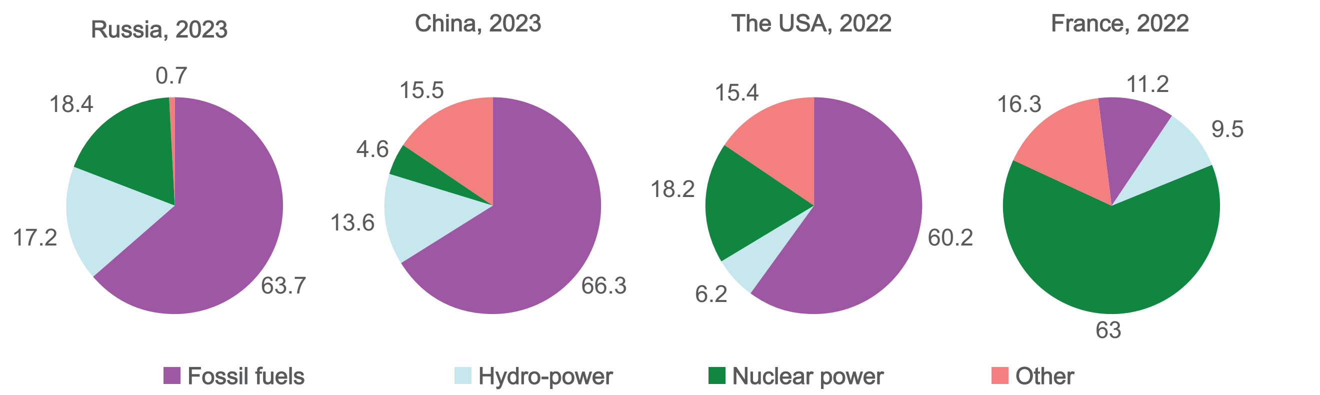
The life cycle of nuclear power plant units includes the following stages: placement; design; construction; operation; and decommissioning (Alshraideh & Engovatov, 2023). At each stage, certain risks arise that are associated with objective and subjective factors, which must be linked to the NPP's life cycle. The service life of an NPP is 45 years, with periodic certification required after 30 years of operation.

However, the share of nuclear generation worldwide remains below the level of 2000 (9.1% versus 16.6%) [Alshraideh & Engovatov, 2023]. This is due to the consequences of the disaster at the Fukushima-1 nuclear power plant, which has prevented the share of nuclear generation in Japan from returning to the 2010 level (7.6% versus 25.3%), as well as the delayed commissioning of nuclear reactors in developed countries[13].

First-generation Russian NPPs had significant shortcomings: an absence of a hermetic reactor compartment

[8] Report on the operation of the Unified Energy System of Russia in 2023 https://www.so-s.ru/fileadmin/files/company/reports/disclosure/2024/ups_rep2023.pdf.
[9] Forecast of the energy system of Russia for the period 2023–2028. https://conomy.ru/analysis/articles/1020.
[10] The latest revision of the Federal Law of 21 November 1995 No. 170-FZ 'On the Use of Atomic Energy'. https://www.consultant.ru/document/cons_doc_LAW_8450/?ysclid=m7t2gbjfa0327720229.
[11] Nuclear generation accounts for more than 9% of the world's energy production. https://www.atomic-energy.ru/news/2024/05/16/145868.
[12] For the first time, wind power in Europe has overtaken gas-fired power plants. https://www.vedomosti.ru/esg/reports/news/2024/02/07/1019064-vetroenergetika-v-evrope-vpervie-operedila-gazovie-elektrostantsii.
[13] Nuclear generation accounts for more than 9% of the world's energy production. https://www.atomic-energy.ru/news/2024/05/16/145868.

Fig. 3. Electricity generation in selected countries by energy source, 2023



Source: The electric power industry in Russia and other countries worldwide. https://refru.ru/power7.html#g3.

shell, use of the biblock principle, a conservative design service life of approximately 30 years, and, most importantly, no consideration or allowance for the decommissioning stage. Currently, Russia is launching projects to build NPPs of the fourth generation.

Russia's first (and currently only) floating nuclear power plant, the Akademik Lomonosov, began commercial operation in May 2020. It generates power from two 35 MW small modular reactors (SMRs). Other SMRs are currently being constructed or licensed in Argentina, Canada, China, Russia, the United States and South Korea.

Russia is the first country in the world to implement fourth-generation nuclear reactor technologies. A fast reactor and a closed nuclear fuel cycle will be built at the nuclear power plant. After reprocessing, irradiated fuel will be used to produce fresh fuel again. This will make the recycling system virtually autonomous and independent of external energy supplies. Rosatom is building the innovative BREST-OD-300 nuclear reactor as part of the Breakthrough project in the city of Seversk in the Tomsk Region. It is expected to generate its first electricity in 2028–2029.

The prospects for the development of global nuclear energy are impressive. As of May 2024, there are 416 operating reactors worldwide with a total net capacity of 374.6 GW. In addition, 59 power units with a total net capacity of 61.6 GW are under construction, 40 of which are in China, India, Turkey and Egypt[14]. In 2022, nuclear power plants were included in the EU taxonomy, which ranks energy sectors based on their contribution to sustainable development. Japan is calling for new-generation reactors to be constructed to replace decommissioned capacity. Another advantage of nuclear power plants is that they do not require long lines and can be used as an uninterruptible power supply for important industrial facilities, seaports and defence facilities.

Rosatom has begun construction of five low-power nuclear power plants in the Arctic, an area of strategic interest to several countries.

Given the promising development prospects, it is important to acknowledge the associated challenges in the construction and operation of nuclear power plants, including the high costs, lengthy construction periods, complexities, and high costs of waste disposal and decommissioning [Putilov & Mokshin, 2023].

In the coming years, Russia will begin the practical implementation of new-generation nuclear power plant (NPP) projects with small- to medium-capacity reactors (300–700 MW). These projects are promising for regions where the use of traditional organic energy sources is difficult or impossible. In Russia, these include the Far North, Chukotka, Kamchatka and the Far East. Preliminary designs for small and medium-capacity NPP units featuring SVBR-75/100, VVER-600 and SVBR-600 reactors have been finalised.

Figure 3 illustrates the proportion of electricity generated by different sources in Russia, China, the United States and France in 2023[15].

Despite the global green agenda, gas, oil and coal currently provide the bulk of electricity generation in the leading fossil fuel producing countries of Russia, the USA and China.

The Russian government has approved the General Scheme for the Placement of Electric Power Facilities up to 2042[16]. The plan prioritises increasing energy generation at nuclear power plants from 18.9% to 24%, and at solar and wind power plants from 0.8% to 3.3%, while reducing the share of thermal power plants from 62.7% to 57.4%. Currently, most of the energy generated in the country comes from fossil fuels, followed by wind and solar power.

[14] Id..
[15] Electric power industry in Russia and around the world. https://refru.ru/power7.html#g3.
[16] Decree of the Government of the Russian Federation dated 12/30/2024 No. 4153-r "On Approval of the General Layout of Electric Power Facilities until 2042". http://government.ru/dep_news/53923/.

3. Energy from renewable sources

In 2023, a world record was set for electricity production from renewable energy sources when the proportion of electricity generated from renewable sources increased from 29% to 30% of the total. South and Central America recorded the highest contribution of renewable energy sources at 72%. Primary energy use from renewable sources accounted for 8.2% of the total, or 14.6% including hydropower[17].

The largest proportion of solar and wind power plants in the total electricity generation mix is found in European countries: Denmark (61%), Lithuania (50.9%) and Greece (43.9%). The world leaders in terms of the capacity generated from renewable energy sources are China, the USA, Brazil, India and Germany, accounting for around 58.4% of the global total[18].

In 2023, electricity production in the Unified Electric Power System of Russia amounted to 1,149.984 billion kWh. Of this, 217.697 billion kWh (18.9%) was produced at nuclear power plants, 202.618 billion kWh (17.6%) at hydroelectric and pumped-storage power plants, 720.662 billion kWh (62.7%) at thermal power plants and 9.006 billion kWh (0.8%) at solar and wind power plants[19]. In 2023, electricity generation at Russian renewable energy enterprises was twice the level of 2020. Wind power plants produced 3.4 billion kWh and solar power plants produced 2.4 billion kWh, making them the leading producers of renewable energy in the country. Meanwhile, geothermal, biogas, biomass and wastewater energy plants produced 0.39 billion kWh[20].

Technologies used to generate clean energy are developing rapidly. For instance, Russian scientists have developed a compact hydroelectric unit that can generate electricity for remote northern regions such as Yakutia. This device is essentially a turbine with a built-in pump that is powered by the flow of water.

Many remote settlements in northern Russia do not have a central power supply, so electricity is generated by expensive diesel power stations. To solve this problem, scientists have developed a mini hydroelectric power plant that produces energy in a more environmentally friendly and cost-effective way. It is a hydro turbine with a built-in hydraulic pump that operates using the flow of the river.

The natural potential of hydro, nuclear, solar and wind energy is significant and practically inexhaustible. In Russia, the state programme supporting renewable energy has been extended until 2035, receiving funding of around 350 billion rubles. In the future, using renewable energy sources will greatly reduce coal and gas consumption in the country's and the world's energy balances.

Compared to fossil fuel-based energy generation, the cost of producing electricity from renewable energy sources is trending downwards. An increase in the proportion of renewable energy in the energy system will lead to higher system costs for fossil fuel-based energy. The speed at which countries achieve the goals of the green agenda will largely be determined by governments' willingness to strike a reasonable balance in the cost of electricity from different sources. According to International Energy Agency forecasts, renewable energy sources are expected to surpass coal power by 2025. By 2026, renewable energy and nuclear energy together are predicted to account for nearly half of the world's electricity generation [Plautz, 2024].

4. Solar energy

In 2023, China was the world leader in solar and wind power generation, producing 486.1 billion kWh of wind and solar power. The United States followed with 226.9 billion kWh, ahead of Germany (66.5 billion kWh), India (56.2 billion kWh) and Brazil (36.8 billion kWh) [21].

In 2023, the total share of renewable energy in EU countries increased to 44%[22]. European countries are therefore increasing their production of electricity from renewable energy sources in order to achieve the goal of zero emissions by 2050.

The first solar panels were offered on the market by Americans in 1956. By 1967, the USSR had launched the Soyuz-1 spacecraft into space — the first manned spacecraft to feature solar panels. In the context of countries' global transition to sustainable energy sources, wind and solar energy are becoming especially relevant. The economic efficiency of each energy source depends on a number of factors and is an important indicator.

5. Wind energy

In 2023, the total capacity of commissioned wind turbines (WTs) worldwide was 116,616 MW, a 50% increase on 2022. This was the highest commissioning volume on record and exceeded 100 thousand MW for the first time.

The top five global markets for new installations in 2023 were China, the United States, Brazil, Germany and India. Notably, India returned to the top group after a long absence.

As of the beginning of 2024, Russia's share of renewable energy sources in total electricity generation was only 1.1%.[23]However, wind power plants have enormous growth potential, partly due to the low cost of energy production compared to other sources, including renewable energy sources and fossil fuels.

[17] The world set a new annual record for electricity production from renewable energy sources in 2023. https://qazaqgreen.com/news/world/2122/.

[18] https://energy.hse.ru/Wiie.

[19] Order of the Government of the Russian Federation, dated 30 December 2024, No. 4153-R… http://government.ru/dep_news/53923/.

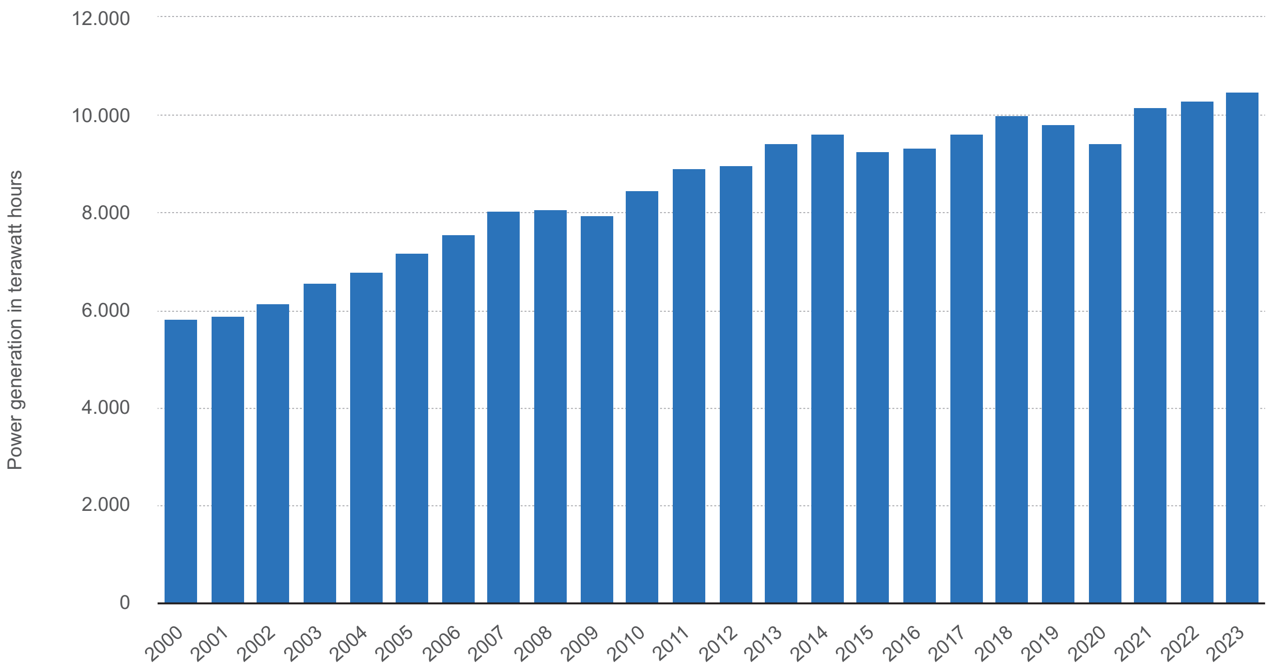
[20] Alternative energy in Russia. https://www.tadviser.ru/index.php.

[21] For the first time, wind power in Europe will overtake gas-fired power plants in 2023. https://www.vedomosti.ru/esg/reports/news/2024/02/07/1019064-vetroenergetika-v-evrope-vpervie-operedila-gazovie-elektrostantsii.

[22] Id.

[23] Wind power in Europe in 2023... https://www.vedomosti.ru/esg/reports/news/2024/02/07/1019064-vetroenergetika-v-evrope-vpervie-operedila-gazovie-elektrostantsii.

Fig. 4. Global coal-fired power generation, 2020–2023



Source: Coal-fired electricity production worldwide from 2000 to 2023. https://www.statista.com/statistics/1082201/coal-fired-electricity-generation-globally/

In late 2023, scientists and researchers from the Moscow Power Engineering Institute (MPEI) developed a hardware and software system to integrate renewable energy sources into traditional power systems[24]. This development comprises a microcontroller that controls converters at generating facilities based on renewable energy sources. The microcontroller implements an algorithm that simulates the operation of a synchronous generator with a specific level of inertia.

6. Water energy

In the structure of the world energy system, the share of hydropower in energy generation in 2023 amounted to between 14% and 18.4%, according to various estimates. This ranks second after energy generation from fossil sources, with a share approximately equal to that of solar energy generation.

However, global hydropower production is in decline. In the first half of 2023, there was an 8.5% historic decline in global hydropower production, and the six-month decline was greater than that recorded for an entire year over the past two decades. This is due to droughts caused by global warming resulting from the emission of greenhouse gases into the atmosphere from the processing of fossil fuels.

In this regard, the Russian Ministry of Energy prepared a decision in 2023 to support small hydropower facilities, which will enable the construction of an average of 70 MW of new small hydropower plants per year. According to the General Scheme for the Distribution of Electric Power Facilities, 17.6% of energy was obtained from hydroelectric and pumped-storage power plants in 2023. The prospective development of hydropower involves developing the hydro potential of the Siberian and Far Eastern regions, with a projected increase in the volume of hydroelectric power plants and the commissioning of new pumped-storage power plants to reach 7.756 million kW by 2042[25].

7. Coal-fired thermal power plants

Global coal-fired electricity generation has continued to increase steadily and peaked in 2023 (see Figure 4). In China, for example, coal-fired electricity generation accounted for over half of the global total in 2023, at 5,742 TWh.

It is expected that, by 2030, more than twenty EU countries will have phased out coal-fired generation. In line with the implementation of the green agenda, the global trend of decarbonising the electricity sector will continue.

Russia ranks second in the world for coal reserves, accounting for 15% of global reserves. However, coal is more expensive than gas in Russia and cannot be widely used in the domestic market. This is due to the lobbying

[24] Alternative energy in Russia. https://www.tadviser.ru/index.php.

[25] The Ministry of Energy plans to increase subsidies for building small hydroelectric power plants. https://itek.ru/news/minenergo-namereno-uvelichit-subsidii-na-stroitelstvo-malyh-ges/.

Table 2
Cost of building and operating the power plants needed to generate a given amount of electricity (17,613 GWh/year)

Power plant type	Investment costs (in millions of dollars)	The accumulated costs (investment and operating) over a given period of time					Share of investment costs in total structure over 25 years (%).
		5 years	10 years	15 years	20 years	25 years	
Conventional coal	3246	10767	12856	16945	20034	23123	15
Coal-based combined heat and power using coal gasification and carbon capture and storage.	15 609	19993	24377	28760	33144	37527	42
Conventional gas CHP	2119	6675	11231	15786	20342	24898	9
Gas: advanced CHP with carbon capture and storage.	4842	10493	16144	21795	27446	33098	15
Nuclear	12354	14435	16516	18597	20678	22754	54
GeoCHP	9533	10626	11718	12811	13904	14996	64
Biomass	19815	27650	35486	43321	51157	58992	34
Onshore wind	12713	13849	14985	16121	17257	18388	69
Offshore wind	34017	36028	38038	40049	42060	44070	77
Solar thermal	50893	54319	57700	61081	64462	67843	75
Solar PV	31148	32141	33134	34127	35120	36112	86
Hydro	11138	11407	11675	11944	12212	12481	89

Source: [Degtyarev et al., 2016].

policy of Gazprom in favour of its own interests. The cost of coal on the global energy market is significantly lower than that of oil and gas. Despite the oil and gas crisis observed worldwide in recent decades, coal continues to find its energy niche, particularly due to the attractive cost of generating a kilowatt-hour of energy at thermal power plants. The phase-out of coal will likely take several decades for the following reasons: coal is difficult to replace in industrial processes; coal-fired power plants are long-term assets with a design service life of at least 30–40 years; there are losses in the mining industry; workers are made unemployed; there is political lobbying of interests; and restructuring the industry and the economy is complex. Currently, emerging market countries account for 76.8% of global coal consumption, with China accounting for around 50%.

8. Gas power plants

Russia and the United States have traditionally held the leading position in global gas production for many years. Gas-fired power plants can be divided into two types: gas turbine and gas piston.

Gas turbine power stations are high-tech energy complexes that use coolant heated to a high temperature to generate heat and electricity. A gas turbine unit can have a capacity of several megawatts.

Depending on the installation method and design features, there are three main types of gas turbine station: stationary, mobile and mini-format. All installations require careful maintenance. While the systems pay for themselves in a short period of time, they are inferior to gas piston stations in terms of the cost of the energy generated.

Gas piston power plants (GPPPs) are widely used in industry and the municipal sector due to their high efficiency and ability to operate on various gases. This is an effective, environmentally friendly way of generating electricity in the face of high prices for traditional fuels and strict environmental standards. Although gas turbine power plants have high initial costs and depend on gas quality, their advantages make them an attractive choice for many industries.

In 2023, global electricity generation from gas reached a historical maximum of 6,634 TWh[26]. Currently, gas is the second most popular source of electricity after coal, with

[26] Gas-fired power generation reaches a historic high. https://globalenergyprize.org/ru/2024/05/10/jelektrogeneracija-iz-gaza-dostigla-istoricheskogo-maksimuma/.

a share of 35.5%, compared to 14.3% for hydroelectric power plants, 9.1% for nuclear power plants, 7.8% for wind generators, 5.5% for solar panels, and 10.8% for all other sources[27]. The world leaders in gas-fired power generation are the United States and China. In the near future, gas is expected to retain its primacy in the global energy balance, while the shares of coal and oil are predicted to decrease.

9. A comparison of the cost of generating a unit of electricity by energy type

The economic efficiency of energy production differs between power plants operating on fossil and renewable sources, and there are different approaches to determining this. The cost structures of the two types of plant differ fundamentally, and the economic efficiency of electricity production is essentially an integral indicator. Comparing the economic efficiency of energy obtained from renewable sources requires detailed consideration of the cost structure of each energy production method, taking projected energy resource prices into account. A group of Russian researchers studied the technical features of the life cycle of power plants operating on various sources, calculating the cost per unit of energy produced (see Table 2). The study resulted in the following conclusions [Degtyarev et al., 2016].

1. Renewable energy power plants have a low capacity utilisation factor. While there are no variable costs, there are high costs at the investment stage of the project. Therefore, renewable energy power plants will be more economically advantageous over the course of their long service lives.
2. Investments in gas thermal power stations, even environmentally improved ones, remain the lowest.
3. Due to high variable operating costs, the total accumulated costs will exceed those of hydroelectric, geothermal, nuclear and onshore wind power plants within 5 to 15 years of the plant's commissioning date.
4. Over a period of 5 to 25 years, hydraulic, geothermal and nuclear power plants, as well as onshore wind farms, proved to be competitive in terms of investment and total costs.
5. Although modernised coal-fired power plants have average investment costs, they have a service life of more than 15 years and are therefore inferior to most other types of power plant.
6. It will be expensive to operate biomass, solar, offshore wind and solar thermal power plants over a 25-year horizon or longer.
7. Onshore wind farms have proven to be cheaper than nuclear power stations and advanced thermal power stations with a service life of five to ten years.

Thus, the price of electricity from renewable energy power plants is becoming competitive with that from technologically and environmentally improved fossil fuel power plants. Increased use of renewable energy sources with unstable generation in the electricity industry will lead to greater volatility in gas and coal prices, as well as an increased need for backup and storage systems. Researchers from the Institute of Energy Research of the Russian Academy of Sciences [Kulagin et al., 2024] calculated the cost price of a unit of energy and obtained the following results.

1. The average weighted cost of electricity production at solar power plants decreased from $0.43 to $0.08 per kWh between 2010 and 2022, and it is projected that costs will decrease by another 30% by 2050.

2. After costs at onshore wind power plants decreased from $0.11 to $0.07 per kWh between 2010 and 2022, a further 10% decrease is expected by 2050. At offshore wind power plants, costs decreased from $0.20 to $0.11 per kWh, and a further 30% decrease is projected.

3. The cost of electricity production at large hydroelectric power plants is one of the lowest among alternative energy sources, starting from $0.01/kWh in 2023. However, it is important to consider that the global potential for hydropower is limited and that the costs of small, medium, and micro hydroelectric power plants are high.

4. Nuclear power also has the potential to reduce production costs. However, in most countries, nuclear power plants are more expensive than gas and coal power stations for electricity generation. However, unlike renewable energy sources, nuclear power plants provide stable and uniform electricity generation.

The cost of coal and gas power plants tends to decrease due to increased plant efficiency, but this depends on the price of coal and gas supplies, which tend to increase. Consequently, electricity production from gas and coal will increase. In the second half of the forecast period, however, the absolute volumes generated at these power plants will decrease as their use in backup mode becomes more widespread due to the uneven generation of renewable energy.

According to the Renewable Energy Agency (IRENA), 81% of the renewable energy capacity added in 2023 was cheaper than fossil fuel alternatives. This provides a compelling business and investment case for tripling renewable energy capacity by 2030.

Power engineers around the world have observed a trend towards a reduction in the average weighted cost of electricity generated by the following types of renewable energy power plant that have been put into operation:

- solar photovoltaic energy - by 12%;
- onshore wind energy - by 3%;
- offshore wind energy - by 7%;
- concentrated solar energy - by 4%;
- hydropower - by 7%[28].

[27] Gas-fired power generation reaches a historic high. https://globalenergyprize.org/ru/2024/05/10/jelektrogeneracija-iz-gaza-dostigla-istoricheskogo-maksimuma/.
[28] Record growth has given renewable electricity a price advantage. https://www.irena.org/News/pressreleases/2024/Sep/Record-Growth-Drives-Cost-Advantage-of-Renewable-Power-RU.

Based on the research results presented, we can express the ratio of the levelled energy cost (LEC)[29], produced from various sources using the following formula:

$$LECfec > LECaps > LECwps. \quad (1)$$

Thus, the hypothesis put forward by the authors of this study has been confirmed.

The development of Russia's Unified Energy System has been approved until 2029, with the cost of building a new 15.7 GW generation capacity included[30]. Thermal power plants are set to remain the primary source of energy generation, accounting for an estimated 65% of the total planned output. A serious problem requiring an immediate solution is the energy deficit in Siberia, the Far East, and southern Russia.

The Russian Ministry of Energy's REA presented its report on the forecast for the development of global energy up to 2050[31], Alongside three proposed scenarios, the report noted concerns that have emerged to date.

Despite the many different scenarios for the development of world energy proposed by various researchers, some of their conclusions are in harmony with each other and seem quite definite. These include:

- The fourth energy transition will take place, and all the prerequisites for this have been established.
- The investments required to achieve the declared level of carbon neutrality by 2050 exceed the existing capabilities of the global economy.
- The share of electricity in global consumption will increase sharply.
- The role of hydrogen and modern types of biofuel will become especially important.
- The share of renewable energy will grow, but the need for traditional methods of electricity generation will remain.
- Due to the economic inexpediency of replacing traditional carbon energy sources with carbon-free ones, it is necessary to develop the absorption capacity of ecosystems and the relevant technologies.
- A decrease in the overall need for fossil hydrocarbon resources will lead to a reduction in world trade against the backdrop of stagnation in the global economy.

Consequently, until 2050, the world and Russia expect the energy sector to transform against the backdrop of the energy transition and a significant slowdown in the growth of primary energy consumption, which is associated with the general long-term forecast of a slowdown in global economic growth[32].

Conclusion

Research by Russian scientists has shown that, while green energy is low-cost and does not emit greenhouse gases, it is characterised by the instability of electricity production (dependency on wind speed, the need to find optimal locations for wind farms), and low levels of solar insolation in northern regions. The development of green energy should be supported by the state through targeted technical and economic policies, such as providing tax incentives and subsidising R&D.

Nuclear energy has a high energy density and relatively stable production. However, there are problems with the disposal of nuclear waste and the risk of accidents, as well as the high cost of constructing and operating nuclear power plants.

Against the backdrop of a significant slowdown in global economic growth and, accordingly, primary energy consumption, researchers have considered forecasts for the development of global energy until 2050 and have developed several scenarios. The increase in global electricity consumption will primarily be provided by renewable energy sources due to their growing economic efficiency. By 2050, almost all the increase in global electricity consumption will come from wind and solar generation [Kulagin et al., 2024]. The world is not only faced with the problem of generating green electricity, but also of storing, transmitting and distributing it, which requires serious research and the finding of solutions.

In the modern world, transport and heating systems depend on fossil fuels rather than electricity generation. It is impossible to completely reject oil, coal and gas at this stage. Fossil fuels will remain the most accessible energy source in the coming decades.

Ideally, digitalisation in countries' energy systems should focus on spreading smart grids and smart devices — electricity consumers that can also generate and distribute electricity in the network.

The balance between fossil fuels and renewable energy sources in countries' energy systems is determined by many factors, including natural conditions, the availability of fossil resources, the possibility of synchronising energy systems with neighbouring states, pricing solutions that are acceptable to consumers, and the availability of established indicators for reducing emissions and developing the economy.

Currently, an effective option for generating electricity in a specific territory is a complementary model comprising different energy sources within a country's energy system, in a specific region, or even within a settlement. To achieve efficiency, it is worth considering combined-cycle power plants, taking into account the need for electricity linked to population growth and density, industrial and economic

[29] The levelised energy cost, or standardised cost, shows how much the objective function will change after a unit of this product is forced to be included in the optimal plan. If the product is profitable, the standardised cost will equal 0. https://www.sciencedirect.com/science/article/pii/S2352484723010569.

[30] The power system was planned. https://www.kommersant.ru/doc/6413256#:~:text=%D0%9D%D0%B0%20%D0%BD%D0%B0%D1%87%D0%B0%D0%BB%D0%BE%20 2023%20%D0%B3%D0%BE%D0%B4%D0%B0%20%D1%83%D1%81%D1%82%D0%B0%D0%BD%D0%BE%D0%B2%D0%BB%D0%B5%D0%BD%D0%BD%D0%B0%D1%8F,%D0%BE%D1%81%D1%82%D0%B0%D0%B2%D1%88%D0%B8%D0%B5%D1%81%D1%8F%201%2C9%25%20%E2%80.

[31] Scenarios for global energy development up to 2050. https://www.imemo.ru/files/File/ru/seminars/EnergyDialogue/2024/Drebentsov-26012024.pdf.

[32] Global economic growth is expected to slow to 2.4% in 2024. https://news.un.org/ru/story/2024/01/1448302.

Appendix 1

Life cycle comparison of renewable and non-renewable energy production facilities

Type of energy	Renewable sources of energy					Non-renewable sources	
	Wind	Nuclear	Solar	Water	Tides	Coal, gas, oil	Biomass
Advantages	The most promising source of energy. Ecologically clean. Conditionally renewable. Low operating and initial costs for energy production. Wind farms can be placed on wastelands and contaminated areas. Wind farms can help reduce unemployment in the regions where they operate.	It is a renewable source when operating in a closed fuel cycle. It has efficient fuel consumption. Environmentally friendly under strict operation. Low operating costs after start-up.	One of the promising energy sources. Environmentally friendly. Batteries do not require special maintenance. Reliability in operation. Easy installation of collectors	An ecologically clean source. Conditionally renewable. Hydroelectric power plants are highly efficient, with an efficiency rating of between 80 and 90%. The power plant can be stopped and started quickly. The system is proven and the operation of hydroelectric power plants is low-cost. The possibility of creating artificial lakes for the construction of hydroelectric power plants. Water resources are retained for agriculture	Ecologically clean source. Conditionally renewable	*Coal power plants:* Coal has a higher energy density than renewables. Of coal use, 72.8% is accounted for by electricity production, while 21.6% is used in industry. *Gas power plants:* Modern installations can be up to 45% efficient in electricity production. There is flexibility in the choice of fuel. Low emissions of harmful substances. They offer quick start-up and simple design. Economic efficiency.	Zero carbon emissions from biomass combustion. Lower emissions of sulphur dioxide, nitrogen oxides and carbon monoxide than fossil fuels
Disadvantages	Wind farms spoil the landscape. They are dependent on the weather and wind. Construction and maintenance are expensive. They occupy vast areas that could be used for agriculture. Turbine noise. They interfere with radio and television reception. Wind power plants are only 40% efficient.	There is a risk of man-made disasters in the event of accidents at nuclear power plants. There are also problems with spent fuel storage. High construction and decommissioning costs.	Technological obstacles: a large area is required for installation. Limited use: households, small farms and greenhouses. The source is inconsistent – it depends on the weather. The photovoltaic cells in the battery contain toxic elements. The daily solar radiation flux density is low.	Dependence on precipitation and the need to flood large areas and relocate people, which destroys the natural terrestrial habitat for plants and animals. The high cost of building hydroelectric power plants	Low profitability. Limited areas of use. Inconsistent energy generation.	*Coal-fired power plants:* depletion of global resources; environmental pollution from harmful emissions; the complexity and labour-intensive nature of coal extraction; and the high risk of accidents in mines resulting in human casualties. The phase-out of coal will take several decades. When burned, coal releases 2.2 times more carbon than natural gas. Methods of extracting fuel affect transportation needs and methane emissions. There are also losses of natural gas during transmission. *Gas power plants:* high initial costs; dependence on gas quality; need for regular maintenance; limited mobility; high noise level produced by turbine rotation (for turbine hydroelectric power plants)	Relatively low density of the raw materials makes them difficult to transport, store and dose. The high moisture content of the biomass makes it difficult to prepare for energy use. Raw materials have a low energy value. Some waste is only available seasonally.

Source: compiled by the authors based on the data from: [Tishchenko, 2018; Efimtseva et al., 2019; Spadaro et al., 2020; Buchnev, 2021]; Renewable energy sources. https://energy.hse.ru/Wiie; Krivonos A. (2023). Alternative energy sources: pros and cons. https://bezpeka-shop.com/blog/poleznye-sovety/alternativnye-istochniki-energii-plyusy-i-minusy/?srsltid=AfmBOormUIZKsWPUQgohZQVe9DX_UjPSnsMZCgMeLNYtEyxcoP9ndyDv; Bogmans K., Manji L.K. (2020). A greener future starts with the transition from coal to alternative energy sources. https://www.imf.org/ru/Blogs/Articles/2020/12/08/blog-a-greener-future-begins-with-a-shift-to-coal-alternatives; Advantages and disadvantages of gas piston power plants: what you need to know? https://aer-spb.ru/novosti/preimushchestva-i-nedostatki-gazoporshnevykh-elektrostantsiy-chto-nuzhno-znat/?ysclid=m5pmpdmna894702992; Gas turbine power plant (GTPP): what is it, advantages and disadvantages. https://gktex.ru/info/gazoturbinnaya-elektrostanciya/?ysclid=m5pnqmj94l73765493.

development, the natural landscape of the area and the efficient planning of power plant locations.

The authors of the study have stated that the global priority should be to use renewable energy sources for energy generation on a global scale. This hypothesis has not yet been justified, but it does fit organically into the development of the Russian fuel and energy complex. In Western countries and some EU countries, such as France, business interests are currently lobbying actively in favour of developing nuclear energy.

In summary, it can be confidently stated that the global energy sector will be heavily dependent on geopolitics, which will determine technology transfer possibilities, restrictions on trade flows, the ability to develop joint approaches to regulating foreign economic activity, and the overcoming of barriers to world trade.

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Are there enough resources to make a new turn in the domestic gas industry towards the East?

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Abstract

This article presents the results of the analysis of the economic situation in the domestic gas industry, including the activities of the flagship of the country's fuel and energy complex, the Public Joint Stock Company Gazprom Group of Companies, in terms of the sufficiency of financial resources for the implementation of the national programme of social gasification/pre-gasification of Russian territories. Problems of reorientation of gas raw material exports to the East, issues of creating a liquefied natural gas complex, fleet of icebreakers for transportation of LNG to old and new areas and sales points are considered. A separate research issue is the difficulties of implementing the state target programme of social gasification and pre-gasification of Russian territories. The purpose of this subject study is a comprehensive economic assessment of the implementation of state programmes for regional development based on the use of hydrocarbon raw materials, including the social gasification/pre-gasification programme in the constituent entities of the Russian Federation. The results of the research carried out by the authors of the article are limited to the analysis of non-public departmental information on the problems identified in the gas industry. The methods of comparative activity studies and economic statistics were used as research tools. The conceptual approaches involved are discussed. The article concludes with three tentative conclusions.

Keywords: pre-gasification, global market, gas standoff, supply routes, logistics connections, gas chemistry, ESG principles.

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是否有足够的资源形成国内天然气工业向东部的新转向?

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简介

文章介绍了对国内天然气工业经济状况的分析结果，其中包括国家旗舰燃料和能源综合体--俄罗斯天然气工业股份公司的活动，以及完成俄罗斯领土社会气化/天然气化国家计划所需的充足资金。该报告审议了向东出口天然气原料的调整问题、建立液化天然气联合企业的问题、向新老地区和销售地运输天然气的破冰船队问题。实施俄罗斯领土社会气化和预气化国家目标计划的困难是本研究的一个单独问题。本案例研究的目的是对以碳氢化合物原料利用为基础的地区发展国家计划（包括联邦主体的社会气化/预气化计划）的实施情况进行全面的经济评估。文章作者取得的研究成果主要是通过分析部门非公开信息发现的天然气行业问题。研究工具采用了行动比较法和统计学方法。对所采用的概念方法进行了讨论。本文最后得出了三个中间结论。

关键词：预气化、全球市场、天然气对抗、供应路线、联动物流、天然气化学、ESG 原则。

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本文是根据合著者在 2024 年 4 月 25-26 日于俄罗斯总统国民经济与国家行政学院西北分院（圣彼得堡）举行的第十五届国际科学与实践会议 "国家与企业。俄罗斯经济发展中的现代风险、问题和趋势"国际科学实践会议和在2024 年 11 月 1-2 日于圣彼得堡彼得大帝圣彼得堡理工大学举行的第十一届 "智能工程经济与工业 5.0（ECOPROM）"国际科学实践会议。合著者的科研活动部分反映在这些会议发表的成果（摘要）中。合著者进行的课题研究没有获得任何资助或任何外部资金支持。

Introduction

At present, the Russian gas industry is faced with the need to quickly develop a concept for reorienting the development strategy of the entire domestic gas complex and implementing the global gasification of the country, while at the same time implementing many national projects. Thus, at the plenary session of the International Forum ‘Russian Energy Week’ on 26 September, Russian President Vladimir Putin devoted a significant part of his report to these problems. He made it clear that the country is expanding the geography and scope of energy cooperation, while at the same time building new routes to dynamically growing and attractive markets, including the countries of the Eurasian Economic Community, the CIS and southern Eurasia. Accordingly, supplies through the Power of Siberia gas pipeline are increasing. Exports of liquefied natural gas (hereafter LNG [Tsatsulin, Bykov, 2023]) continue to grow. For our part, we note that in the conditions of gas confrontation on the European market, in 2024 the share of LNG in global gas consumption will increase from 30% to 48%[1], and the prospect of oversupply of the global LNG market is even looming.

In particular, the President emphasised: ‘LNG from the Russian Arctic has become one of the anchor and main cargoes of the Northern Sea Route. We will certainly continue to develop our own services and technologies in the LNG sector, create LNG transhipment, storage and trading centres, offer gas carrier projects and, of course, increase the capacity of our Arctic and Eastern sea ports, strengthen communications and the infrastructure of the Northern Sea Route’[2]. According to the authors of the article, this is all the more important as the Arctic routes cross nine regions of the Russian Federation and the country’s maritime border coastline exceeds 20 thousand kilometres.

During the aforementioned Russian Energy Week, the President of the Russian Federation noted that important strategic changes are being implemented in the gas industry, which are not so much related to the shift of export gas supplies from the West (the European market alone consumes up to 155 bcm per year) to the East, but to a significant increase in supplies to the domestic market, including the social gasification/pre-gasification programme, which has been in full swing since the beginning of 2021. The recognised leader in the implementation of this state programme is PJSC Gazprom, which together with the Government of the Russian Federation has developed a ten-year plan for the development of the gas industry.

Such a long-term plan, if fully implemented, will allow not only to ensure the sustainable development of the gas company itself, but also to create a new, modern infrastructure adapted to the changing vectors of supply geography, and will also provide an opportunity to improve the existing gas networks, It will also provide an opportunity to improve existing gas networks, organise the logistics of new connections, rationalise transport routes, and significantly increase the volume of processing of gas raw materials by Russian capacities of a high level in accordance with the established scale of production processes in favour of the creation of high-quality, innovative and high-tech products for the open domestic market and the somewhat tight foreign market. It is true that the successful implementation of all these urgent and useful projects will, in the authors’ estimation, require a radical institutional restructuring of the country’s export-oriented complex.

1. Clarifying the problem and purpose of the research

Here, of course, a delicate question arises: are there real opportunities to solve such important declared tasks, which presuppose the actual availability of our own high-tech machinery and sufficient financial resources on the part of those structures that are responsible for their solution today? After all, after the beginning of the EEV, the conventional West introduced many sanctions restrictions, more than 18 thousand items in the composition of 14 packages against our country (at the time of writing), including the sphere of LNG promotion to foreign markets.

[1] Plenary Session of the XIII International Gas Forum St. Petersburg ‘Gas Market-2024: Contours of the New World Order’. https://rutube.ru/video/6e3c439c68e13e7020eecc70069ac0b7/.
[2] http://kremlin.ru/events/president/news/75185.

Moreover, judging by fragmentary information from the Russian oil and gas market analyst - foreign agent M.I. Krutikhin, which needs to be verified, the European Commission has decided to impose a complete ban on gas supplies to EU countries from 01.01.2027[3]. Taken together, these massive Western sanctions pressures, which have already been felt by the Russian economy, have resulted in a 7-8% reduction in gas production and a 16% reduction in gas exports by the end of 2024[4]. Although last year friendly countries still accounted for over 90% of Russia's energy exports.

Thus, in June this year, the promising projects Arctic LNG-1 and Arctic LNG-3, Murmansk LNG, Gazprom Invest, Rusgazdobycha, Murmansk-Transgaz, and Ob Gas Chemical Complex fell under such sensitive sanctions and restrictions for the domestic gas transportation complex. In addition, our former pseudo and quasi-market business partners in the globalised economy declared their intention to limit the energy revenues of the Russian budget and hinder the development of already launched energy projects in the Fuel and Energy Complex (FEC).

How does the government of the country plan to overcome the problems caused by global instability and solve the tasks formulated by the President of the country? Are these problems surmountable when even in the draft State Budget of the Russian Federation for 2025-2027 the oil and gas revenues from the export of raw materials will not exceed 27%, and multiple types of tax pressure on the core sector will increase from 1 January 2025, along with the corporate income tax updated to 25%? At the same time, the government is also discussing the immediate stability of the VAT.

Russia's Cabinet of Ministers has approved an updated strategy for the development of the country's mineral resources base up to 2050. This was announced by Russian Prime Minister M.V. Mishustin at the opening of a working session with his deputies. 'The government has approved an updated Strategy for the Development of the Mineral Resources Base and has also extended the planning in this important area by 15 years, until 2050,' the Prime Minister said, adding that the document has updated the forecast technical and economic indicators and the target scenario has formulated the main objectives. These include the discovery of new hydrocarbon deposits, for which it is necessary to step up efforts to comprehensively explore and develop explored territories, especially in hard-to-reach areas, including the Arctic and the Far East, despite the new risks and threats that have emerged [Imanov, 2023]. Today, there are 153 officially explored gas fields in the country.

The mineral resource base is a natural basis for many manufacturing industries, such as metallurgy, chemicals, mechanical engineering, etc. The development of this base ensures the creation of new jobs, despite the extremely low unemployment rate in 2024, measured at the end of August at 2.4% for the three previous months[5] (a record low), and stimulates further economic growth, which is so necessary in the current difficult conditions, which have given rise to many new problems, not always foreseeable and sometimes not obvious in terms of their identification.

Raw materials are also necessary to meet the country's internal needs in the field of construction, energy, industrial production, to ensure comprehensive economic security and to maintain a reasonable export potential, including gas supplies of all types and forms. It is necessary to determine the range of real possibilities of the gas industry in order to form a new strategy for its development and/or to modernise the old strategy with elements of significant transformation of its vectors, but in any case taking into account the assessed risks, threats and the level of necessary sufficiency of financial resources. All this is the aim of the long-term research of the authors of the article.

The development of a strategy 'with a new geographical face' is extremely relevant, firstly, because it is necessary to overcome the main uncertainties in the development of the oil and gas sector/complex of the Russian Federation for the next 20-25 years [Fomin et al., 2024]. Secondly, it is natural gas - today the most environmentally friendly, acceptably efficient and still accessible hydrocarbon - which accounts for 48% of the country's energy balance. Together with nuclear power (NPP), hydroelectric power (HPP) and wind power (WPP), which have a minimal carbon footprint, this share is 85.2%.

2. Obtained results

Given the seriousness of these problems, the financial capacity of Russia's gas majors to undertake such significant transformations in the gas industry and implement truly large-scale projects comes to the fore. For example, in 2023, according to the RAS report, Gazprom had a net loss of 639 billion roubles and produced 156 billion m3 less natural gas than in the previous year. In the first half of 2024, Gazprom reported a net loss of 480 billion roubles in its financial statements according to Russian accounting standards, twice as much as in the same period of the previous year.

This loss of the corporation, which has almost 500,000 employees, is covered by the revenues of various structural divisions of the parent organisation Gazpromneft (a significant profitable asset of the holding, the management of which must be concerned about preserving the subsidiary) and Gazprombank. In general, according to consolidated IFRS reporting, the PJSC's net profit has tripled over the same period, but it is technically difficult for analysts to isolate the financial component for gas, and a reliable factorology is not always available.

Nevertheless, in all analytical estimates for the half-year by quantitative discrepancies, it is necessary to take into account the seasonality factors associated with the injection of gas into storage facilities for future sales. In

[3] https://www.youtube.com/watch?v=vGN-X2VjB90.

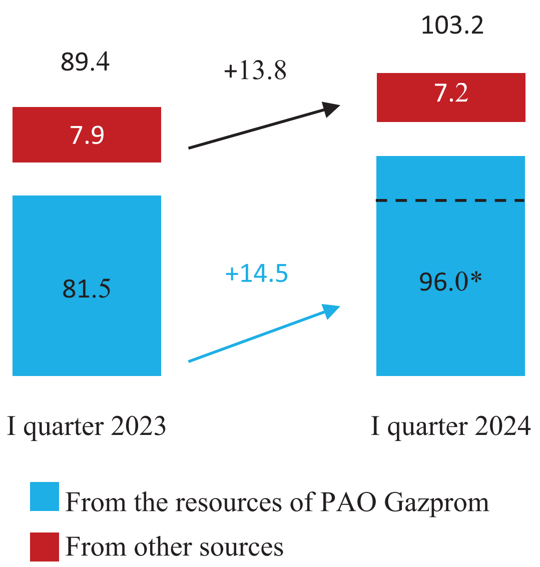
[4] https://rutube.ru/video/6e3c439c68e13e7020eecc70069ac0b7/.

[5] https://vk.com/fnprru.

addition to the traditional seasonality, there are imbalance factors due to the uneven production of environmentally friendly renewable energy sources (solar, wind, hydro, biomass, geothermal). There is also the constant factor of currency revaluation of the company's tangible and intangible assets. All this promises very high volatility in gas prices on the spot market[6] and the so-called contractual obligations market in the coming months of 2024 and the first half of 2025. However, the authors of the article believe that the RAS methodology, from the point of view of the principles of its balance sheet consolidation, more accurately takes into account the profit and loss of PJSC Gazprom according to the presented official financial statements.

However, despite this unfortunate circumstance, which is reflected in the RAS reporting and the quarterly statistical reports, the plans for the implementation of the gasification programme have not been disrupted. Thus, the volume of gas supplies after the commercial closure in the first quarter of 2024 amounted to 96 bcm, which is 11.2 bcm higher than Gazprom's target (84.8 bcm) and 17.79% higher than a year ago, as shown in Figure 1. On the other hand, deliveries from other gas sources for the implementation of this programme decreased by 8.86%, but in general the quarterly gas volumes involved in the programme together increased by 15.44% over the year.

Fig. 1. Gas supplies of Gazprom Mezhregiongaz Group in the first quarter of 2023–2024 (bcm)



Note. The target for the first quarter of 2024 is 84.8 billion m^3.
Source: compiled by the authors on the basis of the report of the head of Gazprom Mezhregiongaz dated 01.07.2024.

PJSC Gazprom's resource potential is truly vast. For example, the Kovyktinskoye field[7] estimated at 1.8 trillion cubic metres of gas and 65.7 million tonnes of oil and gas condensate, and the Chayandinskoye field[8] in the Yakutsk region, estimated at 1.2 trillion cubic metres and 61.2 million tonnes, are the largest explored underground gas reserves in Eastern Siberia. Yamburg, in Yamal, also has significant gas reserves: when the explored fields are added together, the gas deposits there are the fifth largest in the world outside the Arctic Circle in terms of reserves. They are already planned to be connected via Yelets (as the final point of the Yamburg-Yelets gas route) to pipelines extending to the western borders of the Russian Federation.

However, there is virtually no domestic consumer demand in the country for such significant volumes of potentially extracted gas raw materials, which is constrained in particular by insufficiently branched traffic, as the first two fields are located on the Power of Siberia route to Blagoveshchensk. Accordingly, the operation of the aforementioned Yamburg field has encountered its own technical difficulties, caused by the effect of diminishing returns against a background of rising production costs. As a result, the most important indicator of the efficiency of the activity - the internal rate of return (IRR), one of the profitability indicators in the oil and gas industry, which should not fall below 16.0%[9]. is decreasing. In addition, there are no real opportunities to ensure the gasification of the pipeline routes used to each house and to fully implement social gasification.

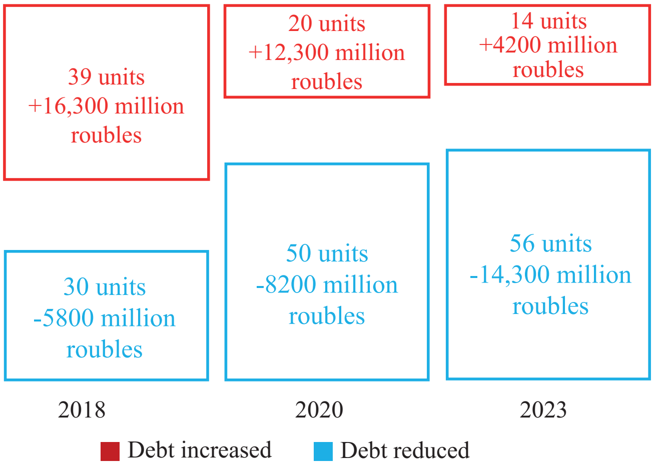
There are also no real possibilities of providing gas supply plans for the pipeline routes used to each home and to fully implement social gas supply.

Another obvious reason for the occurrence of the noted losses were overdue debts for gas supplied to end consumers, as evidenced by the data for individual subjects of the Russian Federation for the results of 2023. If we talk about the volume of gas supplied by regional gas sales companies (hereinafter referred to as RGCs) and gas distribution organisations (hereinafter referred to as GDOs), it is actually carried out in most subjects of the Russian Federation - more than 70. For most of these recipients, for various reasons, troublesome payment arrears have arisen, which are partly reflected in the graphs in Fig. 2.

In five years to the end of 2023, the debt was reduced in 56 subjects of the Russian Federation, i.e. in 2018-2023, the number of regions that reduced their debt to Gazprom Group almost doubled. In 14 subjects of the Russian Federation by the beginning of 2024, despite the satisfactory dynamics of its repayment, the debt remains in the amount of 4,200 million roubles, which reduces the standards of the required mobility of the holding's working capital.

[6] As a result, global gas prices fell in July-August compared to the previous year, amid growing global reserves and declining demand forecasts. This has had a corresponding impact on the profitability of gas producers (declining margins), such as the US company Cheniere Energy, whose third-quarter net income fell by half - to $893 million - due to a decline in margins, and quarterly revenue from the gas segment fell by 12% - to $3.55 billion.
[7] One of the priority facilities constructed at the field is the Integrated Gas Processing Plant No. 2 9UKPG-2.
[8] The natural gas from this reservoir has a complex composition, including significant amounts of helium.
[9] IRR (internal rate of return) – the interest rate at which the present (discounted) value of a company's future cash flows equals the value of the initial investment.

Fig. 2. Dynamics of overdue debts for gas supplied to end users by constituent entities of the Russian Federation for 2018–2023



Source: compiled by the authors on the basis of the report of the head of Gazprom Mezhregiongaz dated 01.07.2024.

A more detailed picture of debt volatility for the top 5 constituent entities of the Federation according to the grouping indicator of increase/decrease is presented in Table 1; the general trend of the regional 'fives' indicates a certain repayment of the incurred debt of +3400 mln roubles against -2600 mln roubles. At the same time, the implementation of the state programme of social gasification/pre-gasification in the country, supervised by Gazprom's specialised structure Mezhregiongaz, is in full swing [Tsatsulin, Bykov, 2024]. Thus, on 10 October 2024, the head of Mezhregiongaz S.V. Gustov launched via teleconference at the International Forum 'Gas Market-2024: 16 new regional networks of social gasification/pre-gasification: Contours of the New World Order' in St. Petersburg[10].

The dynamics of the implementation of the adopted plan and the prescribed forecast for 2024 for the implementation of the contractual discipline for the connection of households on the territory of the Russian Federation are shown in Fig. 3: the graph reflects the growing number of business contracts executed within the framework of the pre-gasification procedure up to the borders of the applicants' plots, the cumulative total, the dotted line indicates the forecast values of the main indicators for 2024.

The large-scale and widespread gasification of the country, which has been planned for many decades, has received additional incentives in recent years and new benchmarks have been set for the gas industry, which has had a positive impact not only on the availability of gas, but also on the overall development of the country's regions and the environmental situation developing in them, as fuels with a high carbon footprint, i.e. carbon emissions (CO_2 and other formations) into the atmosphere, are displaced. Russia is one of the world's most active countries in terms of contributing to the reduction of greenhouse gas emissions, and its energy balance is one of the greenest in the world. According to the head of state, by the end of 2024, the share of environmentally friendly gas, nuclear, hydroelectric and other more modest sources of conditionally clean energy in the Russian Federation will approach 85%.

However, in the near future, along with the implementation of gasification/pre-gasification plans, it is necessary to move on to solving the problems of sustainable and affordable energy supply, based on the use of the most rational options for such solutions among all available alternatives, taking into account the effectiveness of technological progress and regional characteristics of territories, breakthrough innovative achievements of scientific and technological progress, the pace of digitalisation of the economy, and even special promising developments in the field of artificial

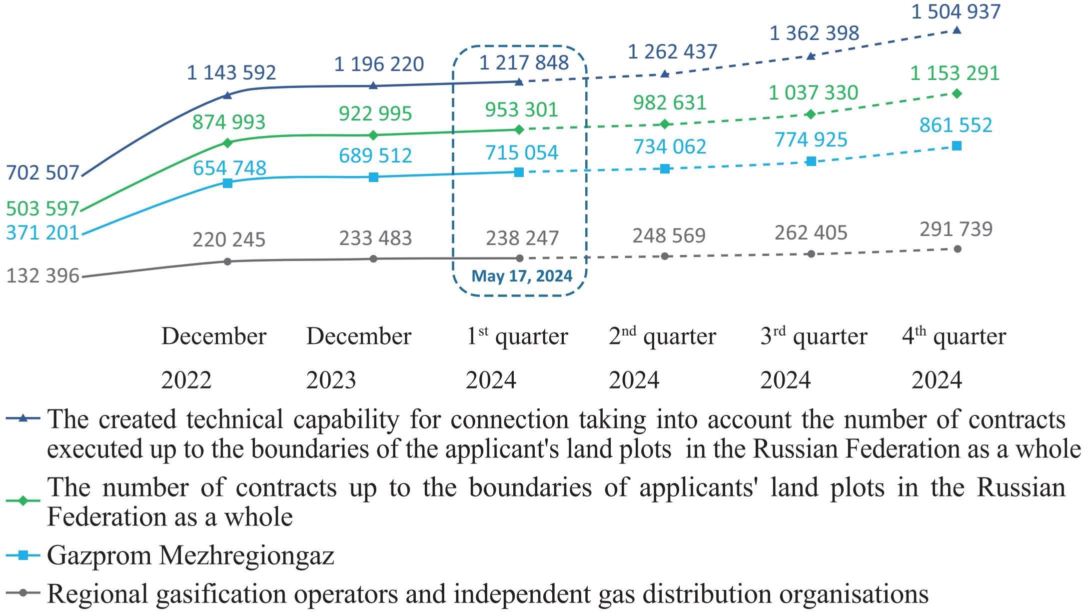
Table 1
Type of overdue debt in the regions of the Russian Federation
(mln rub.)

Subjects of the Federation with the largest annual increase in overdue debt	Debt increased	Subjects of the Federation with the largest annual reduction in overdue debt	Debt reduced
Tver region	+900	Krasnodar region	–800
Archangelsk region	+800	Moscow Region	–700
Yaroslavl region	+700	Perm region	–500
North Ossetia - Alania	+600	Vladimir region	–300
Primorsky Krai	+400	Samara region	–300
Total	+3400	Total	–2600

Source: compiled by the authors on the basis of the report of the head of Gazprom Mezhregiongaz dated 01.07.2024.

[10] https://musinlc.ru/peterburgskij-mezhdunarodnyj-gazovyj-forum-pmgf-2024/.

Fig. 3. Plan and forecast for 2024 for the execution of contracts for the connection of households within the framework of pre-gasification as of 17th May 2024



Source: compiled by the authors based on the report by the Head of Gazprom Mezhregiongaz on 1 July 2024.

intelligence in relation to the gas industry [Bogatyrev, Tsatsulin, 2024].

However, it is important to recognise that the gasification and additional gasification of small towns and rural settlements in Western and Eastern Siberia is becoming extremely expensive under inflationary conditions. The population may simply not demand the services offered by PJSC Gazprom for the installation of relatively expensive gas equipment due to the predicted decline in purchasing power, unfavourable inflation expectations, the accelerated spending of limited National Welfare Fund funds, and the threat of devaluation of the national currency. The entire social gasification/additional gasification project may turn out to be unprofitable, or even critically unprofitable, in the near future in cases of force majeure. The lack of financial resources, even if only felt remotely, indirectly affects the level of geological exploration and survey activity of gas companies.

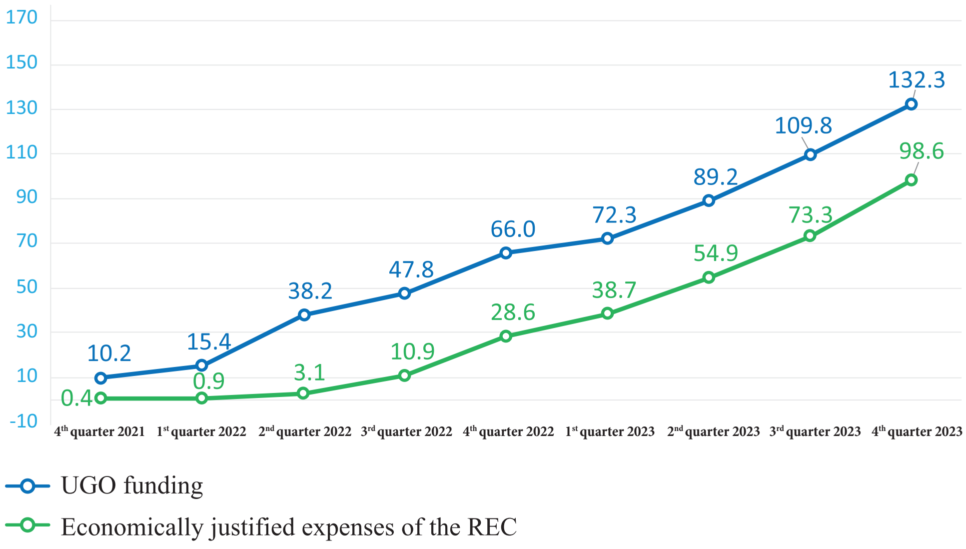
Thus, for purely economic reasons, the development of new fields in the Laptev Sea region has been suspended, with exploratory drilling postponed for five years. The ultra-fast development of fields explored in the 1960s and 1970s - such as Samotlor in the Tyumen Region and Urengoy in the Yamal-Nenets Autonomous District - was, to a certain extent, the main reason for their barbaric exploitation during the period of the international ‘pipe-for-gas’ deal. Consequently, some of the fields were damaged by the forced injection of water into the formations, as well as by the spontaneous flow of water from underground sources into formations that had been rapidly emptied of gas [Yalaletdinov et al., 2024].

The sad fate of many oil and gas fields cannot be justified by the ‘fat years’ of an economy based on unrestrained consumption, which then fell into a period of stagnation. We must recall the miscalculations of the previous country leadership, not to refute the attractive pragmatism of the toxic ‘After us, at least later’ meme, popular in the minds of many, by turning to the scientific heritage of the great scientist Academician V.M. Bekhterev [Bekhterev, 1990], but to highlight the absolutely irresponsible manifestation of this complex, behavioural and toxic meme. However, we must recognise that global challenges in the international hydrocarbon markets and the uncertain state of the global fuel and energy sector have paradoxically created favourable opportunities for the rational transformation of Russia’s oil and gas development strategy for the next two to three decades. It is here that we should recall the first Russian turn to the East, which was formalised at the time (1905–1906) through the efforts of the first chairman of the Council of Ministers of the Russian Empire, S. Yu. Witte[11].

Nevertheless, in 2023, the current financing processes under the Unified Gasification Operator (hereafter referred to as the UGO, the official responsibility centre) scheme, and the careful control of expenditure as economically justified regional energy commission (hereafter referred to as REC) expenses, were carried out steadily and systematically, without any sporadic disruptions. This is reflected in the curves of Fig. 4. At the same time, the financing rates of UGO events are consistent with the REC expenditure rates, and the statistical summary indicator of the analysed technical and economic characteristics in the form of the

[11] https://russiancouncil.ru/analytics-and-comments/analytics/sergey-vitte-i-pervyy-povorot-rossii-na-vostok/.

Fig. 4. Dynamics of financing and economically justified expenses according to the decisions of the REC based on the results of 2023 (bln rub.)



Source: compiled by the authors based on the report by the Head of Gazprom Mezhregiongaz on 1 July 2024.

distribution ratio (DR) was assessed as favourable at the end of the year:

$DR_{REC/UGO} = 98.6 / 132.3 = 0.74528 \sim 74.53\%$.

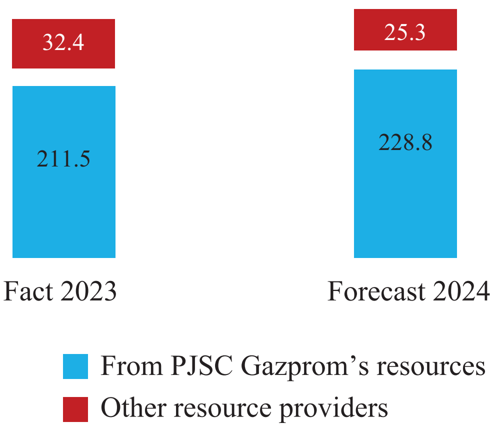
However, we cannot ignore the various problems with the transportation of hydrocarbon raw materials by pipeline that have recently become much worse. While the transport sector of the economy is gradually leaving the era of oil dominance, the fuel and energy sector is entering a new era of active interspecific fuel competition based on the targeted use of gas raw materials. It is noteworthy that the scope of LNG application is expanding rapidly in gas-powered transport, including public transport (for example, municipal buses in Volgograd are fuelled with LNG), agriculture (in particular, tractors and combines), and road transport, where hydrogen is even used as a motor fuel [Kulagin & Grushevenko, 2020][12].

Other promising areas for the use of LNG include rail and water transport and industrial rolling stock. New domestic models of specialised automobiles and construction equipment that use compressed and liquefied natural gas have already been developed.

In addition to LNG, ammonia and methanol will be in demand for sea and river transport. There are independent, highly favourable and completely non-fuel prospects for various inert gases, also known as noble gases, such as helium, krypton, neon, argon, xenon and radon. These gases, when used as additives in natural gas, significantly alter its calorific value and consumer properties, while retaining their own value in various consumer markets.

Given the scale of the domestic supply of gas raw materials to consumers, Gazprom continued to increase its natural gas supplies in 2024, provided that the official target supply indicator for 2023 was approved by the Board of Directors of PJSC Gazprom on 20 December 2022 (No. 3868), amounting to 209.9 billion m³, which was exceeded by 0.76%. This is happening against the background of a projected decrease in supplies from other market suppliers by 21.08%, as illustrated by Fig. 5.

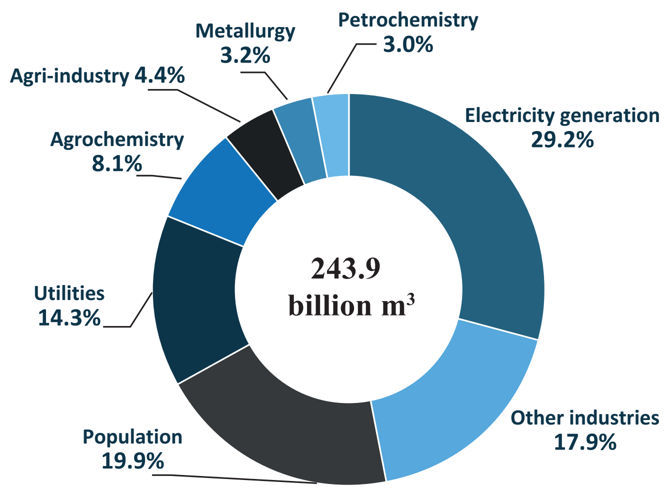
Fig. 5. Natural gas supplies of Gazprom Mezhregiongaz Group in 2023–2024 (bcm)



Note. The target for 2023 is 209.9 billion cubic metres.
Source: compiled by the authors based on the report by the Head of Gazprom Mezhregiongaz on 1 July 2024.

[12] Although hydrogen energy has been considered an attractive option for developing the fuel and energy complex since the mid-20th century and research into producing and combusting hydrogen has been conducted for around 200 years, as of 2024, its use as an energy source worldwide is still extremely limited. Almost all of its consumption occurs in the production of ammonia and methanol, as well as in metallurgy, oil refining, and petrochemistry. Typically, hydrogen is an intermediate element in production chains — it is produced in some processes and consumed in others within the same site [Global Hydrogen Trade, 2022]. The use of hydrogen as an automobile fuel was actively studied in the USSR during the Great Patriotic War, particularly by specialists from besieged Leningrad. One such specialist was the inventor B.I. Shelishche [Brodsky, 1975].

Fig. 6. Reported industry structure of Gazprom Mezhregiongaz Group gas supplies in 2023 (%)



Source: compiled by the authors based on the report by the Head of Gazprom Mezhregiongaz on 1 July 2024.

Of particular interest is the consumption structure of gas raw materials for industrial and social sectors in relation to the total volume of 243.9 billion m³ for 2023 as a whole. The role of gas raw materials in industrial processing schemes, including primary processing, and in end-use products in real-sector industries looks relatively modest. This is reflected in Fig. 6, which shows that only about 18.7% of all supplied gas is consumed when gas raw materials are used separately as fuel for the electric power complex of the national economy in metallurgy, petrochemistry, agro-industry and agrochemistry.

3. Cross-discussion

Industry experts and analysts assert that gas fields launched in the 1960s and 1970s are now significantly depleted, a claim that is not disputed. In order to revive them, it is necessary to drill through the Earth's crust to the gas-bearing strata at a depth of over 2,000 metres. However, these efforts will require more costly and science-intensive breakthrough technologies that the domestic oil and gas industry does not yet possess [Plis et al., 2024].

In Russia, hydrocarbon volumes are distributed unevenly across a large area of the country, from the Riphean to the Cretaceous stratigraphic ranges, at depths of 1,500–4,500 metres.

The southern territories of the Siberian Platform, covering an area of about 750 thousand square kilometres, include the southern part of the Krasnoyarsk Territory, the Republic of Sakha (Yakutia) and the Irkutsk Region. These territories have significant gas-bearing potential. Large gas fields have been discovered, explored and developed there, and the Kovyktinskoye and Chayandinskoye fields, which stand out for their reserves, are notable examples of this. Industrial development of these fields began in the mid-1980s.

The shift in production emphasis in the practice of territorial movement of gaseous hydrocarbons began during the period of establishing a gas confrontation with the collective West, beginning with the North-Eastern Front. Currently, eight small-tonnage LNG production complexes belonging to PJSC Gazprom are already operating in the eastern part of the country (in the Tomsk and Tyumen regions, among others), and the corporation's short-term operational plans provide for the construction of more than 60 mini-LNG complexes across Russia[13].

The products of small-tonnage LNG production are primarily intended for the autonomous gasification of consumers located far from the main gas infrastructure, as well as for the refuelling of vehicles. At the same time, Gazprom is establishing medium-tonnage LNG production facilities, such as the one in the Portovaya compressor station area and the one in the Ust-Luga area of the Leningrad Region. The latter facility involves the deep processing of ethane-containing gas on the basis of a standard gas chemical plant. Several such new standard enterprises have opened recently.

The implementation of new projects is also at risk of failure due to the impact of existing and developing sanctions packages. Currently, sanctions are being imposed on unfinished LNG vessels and fleet facilities that have already been launched, including those in the gas carrier series. However, the environmental characteristics of Arctic LNG-2 are very attractive since it operates using the cleanest ecological fuel[14]. Accordingly, the Yamal LNG plants, the Arctic LNG-2 company's process lines and plants, and even Gazprom's LNG plants in Tatarstan – mini-complexes representing a new format of gas assets – are capable of bunkering various classes of river and sea vessels. They are also forced to operate under special, commercially flexible regimes that are not always market-based.

[13] https://nangs.org/news/downstream/lng/gazprom-postroit-tretij-mini-kompleks-pro-proizvodstvu-spg-v-tatarstane.
[14] https://arcticspg.ru/.

There have also recently been a number of difficulties with land transportation of gas. The 1,000 km long Soyuz-Vostok gas pipeline runs through Mongolia to China and is essentially an extension of the 6,500 km long Power of Siberia 2 pipeline. Previous projects in Mongolia's economy and civil sector had envisaged using gas instead of coal, an extremely dirty and traditional fuel in Mongolia. It is well known that combustion of coal produces the main component of carbon emissions, making it difficult to implement the concept of a low-carbon green economy in Mongolia. This also leads to stricter requirements from observers and experts in international organisations for reducing CO_2 emissions.

Nevertheless, Mongolia has postponed its government's decision to switch to Russian gas until 2028. In the meantime, the political and economic project 'Power of Siberia-2' is not paying for itself within the planned parameters due to the unexpected position taken by the Chinese leadership. The option of merging it with Russian gas pipelines in a westerly direction is already being considered. Analysts believe that, as China slowly moves towards a green economy, it will not consume as much gas as was prescribed in intergovernmental agreements and medium-term plans (on behalf of PJSC Gazprom).

According to a team of highly qualified specialists and analysts from the Institute of Energy Research of the Russian Academy of Sciences, headed by the authoritative scientist Academician A.A. Makarov, the active revival of the specified project for these two countries can only take place on the predicted horizon of the intermediate cutoff in 2035, when the PRC will consume more natural gas than all European countries combined. The total consumption of Asian countries not belonging to the Organisation for Economic Co-operation and Development (OECD) will equal the volumes consumed in North America and exceed them by 2050. According to futurologists at the Institute of Energy Research of the Russian Academy of Sciences, countries in South and Central America, including Guyana, which became a major hydrocarbon producer after 2015, will surpass Asian OECD countries in terms of consumption by 2050 [Forecast for the Development of Energy, 2024]. In terms of the principles that will shape the future oil and gas market by 2050, it is reasonable to assume that the market will continue to be based on the 'three pillars': North America (including Canada), CIS countries, and the Middle East. These regions will together provide over 70% of the world's hydrocarbon production. The authors of this article also examined the structural forecasts of the gas component of the hydrocarbon market for three classic scenarios of the development of the global fuel and energy complex by 2050: pessimistic ('fog' in the terminology of the ERI compilers), optimal ('split') and optimistic ('key'). These were analysed in terms of both global primary energy consumption and global electricity production by type of energy resource, compared with 2021 [Forecast for the Development of Energy..., 2024]. This year obviously served as the initial base, i.e. the starting point, for implementing procedures involving either intricate extrapolation or econometric correlation-regression modelling.

The consumption and production structures projected over a 25-year horizon and presented in Tables 2 and 3 were determined according to the named scenarios, possibly taking into account a set of partial and pure elasticity coefficients of the factorial influence of a group of preliminarily selected, most significant causal features and factors on effective features and indicators[15]. Notably, the share of gas as an environmentally friendly natural consumption asset remains at a stable 23% in all structural development scenarios recorded in the presented diagrams (Table 2).

Table 2
Forecast structure of global consumption by primary energy source for 2050 in three scenarios for the development of the global fuel and energy complex (%)

Type of primary energy resource	Baseline extrapolation 2021	Forecast development scenario for 2050		
		Pessimistic	Optimal	Optimistic
Oil	29	29	27	25
Gas	24	23	23	23
Coal	27	21	21	17
Nuclear	5	6	6	6
Hydro	3	3	3	3
Bioenergy	9	11	11	11
Other RES	3	7	9	15
Total	100	100	100	100

Source: compiled by the authors and partly based on calculations [Forecast for the Development of Energy, 2024].

[15] This ERI report does not present the modelling procedures, methods and tools of analytical calculations, nor the author's forecasting concept, which is considered a generally accepted practice. Expert futurologists rarely specify the techniques and details of their econometric modelling for the forecast horizon.

Table 3
Predicted structure of world electricity production by source of origin in 2050
in three scenarios for the development of the global fuel and energy complex (%)

Source of electrical energy	Baseline extrapolation level 2021	Forecast development scenario for 2050		
		Pessimistic	Optimal	Optimistic
Oil products	2.5	1.5	1	1
Gas	22.5	16	16	15
Coal	36	25	23.5	14
Nuclear energy	10	9.5	9	8
Hydro energy	14.5	13	12	11
Bioenergy	3	4	3.5	3
Solar energy	4	16	18	24
Wind energy	7	14	16	23
Other renewable energy sources	0.5	1	1	1
Total	100	100	100	100

Source: compiled by the authors and partly based on calculations [Forecast for the Development of Energy, 2024].

In the interests of correcting the calculations shown in the work Forecast of Energy Development... (2024) by ERI RAS specialists, it should be noted that, in most of the initial forecast characteristics for the structural scenarios included in the report, the final calculation of the 'Structural Ratio (SR)' indicators by summation does not equate to 100% of total energy resources, which should naturally have been eliminated by the authors of this article in relation to both Table 2 and Table 3.

The ERI RAS team's forecast calculations of the structure of electricity generation in the global fuel and energy complex for 2050, by energy resource type, demonstrate a significantly lower gas share, ranging from 15-16% with a 1% variability level (Table 3), comparable to the statistical error margin. The authors of the article suggest that this downward trend is most likely associated with the gradual depletion of gas fields everywhere, as well as the expected growth of market prices (up to 500 dollars per thousand m³ according to the Chairman of the Management Board and Deputy Chairman of the Board of Directors of PJSC Gazprom, A. B. Miller[16]). It is also associated with the promotion of the green agenda amid long-term sanctions and global geopolitical and economic instability.

A comparative analysis can be used to interpret the INEI forecast of electricity production from petroleum products, which decreased from 2.5% to 1% in all scenarios (Table 3). It seems that the developers of the forecast have assumed that some types of fuel oil will be used indefinitely to power small mobile objects in the future. The accomplishment at a level of statistical significance of only 1%, expected in 2050, only serves to confirm and strengthen the validity of the aphorism of the eminent scientist Academician D.I. Mendeleyev: 'Burning oil is like heating a stove with banknotes.'[17].

In addition to the forecast situation on the world market, which may naturally be subject to adjustment and/or distortion by future decisions of the Forum of Gas Exporting Countries, the work 'Forecast of Energy Development... 2024' contains development scenarios for our country. In all the considered scenarios, gas consumption in the Russian Federation increases slightly, reaching 520–574 billion m³ by 2050 depending on the scenario selected.

The highest figures are, of course, found in the optimistic scenario ('key'), where increased efforts in energy efficiency and conservation are offset by faster economic growth, particularly in eastern regions, leading to higher gas consumption. The forecast can also be interpreted as indicating increased consumption of raw materials for internal use, including for the operation of LNG plants, greater use of gas fuels in electricity generation due to the partial replacement of coal, and increased electricity demand. We note that the actual range of variation of predicted gas consumption in the Russian Federation, estimated by the ERI RAS developers to be 54 billion m³ per year for the strategising period 2021–2050, coincides with the capacity of just one 'Power of Siberia-2' pipeline from PJSC Gazprom to China, at 50 billion m³ per year.

Another unfortunate misunderstanding has come to light, this time of a legal and technical nature. Rosnedra analysts[18], have drawn attention to alarming appeals to the relevant authorities from many private companies wishing to develop

[16] https://musinlc.ru/peterburgskij-mezhdunarodnyj-gazovyj-forum-pmgf-2024/.
[17] https://www.kron.spb.ru/press-center/likbez/neftepererabotka/.
[18] Head of Rosnedra https://rosnedra.gov.ru/.

subsoil resources containing sought-after and scarce minerals in a civilised and fair manner. This is due to extremely high starting payments, reaching several billion rubles, in the auction trade of lots for subsoil plots. This creates an insurmountable obstacle for companies that base their business on developing already explored subsoil, including hydrocarbon deposits, and wish to enter the market. The authorities introduced a decreasing coefficient mechanism with some delay, which is designed to streamline starting payments. However, the authors of this article believe that it will not solve the current problem.

Conclusions

1. The average annual growth rate of the national economy, as measured by the GDP macrostatistics indicator, is within the acceptable range of 3.7–3.9%. The implementation of the social gasification/pre-gasification programme, the active creation of a new pipeline infrastructure in the east of the country, the development of gas-powered transport, the development of corresponding innovative gas production technologies and plans to switch from coal to gas for the production of electricity and heat in certain regions, while strictly adhering to the principles of the green agenda (ESG), can create the appropriate conditions for expanding the range of production capabilities for the use of gas raw materials for domestic needs[19]), can create the appropriate conditions for expanding the range of production capabilities for the use of gas raw materials for domestic needs.

The planned launch of new export projects will also require an increase in gas consumption to meet the industry's own needs. At the same time, the Russian Federation has significant potential for energy savings. Even partial implementation of these savings could significantly reduce gas costs. However, it is important to bear in mind that weather conditions can cause annual gas consumption volumes to deviate by up to ±15%.

2. In terms of finding additional sources of economic growth and ensuring the country's security, the existing resource potential suggests real prospects for developing the petrochemical industry and related sectors. It is therefore necessary to adhere to this direction and not stop at the initial production stages, but rather to enter the segments of final products with a high degree of processing and significant added value in production chains, and ultimately, the release of consumer goods, including new products. In this context, the excerpt from the aforementioned report of the President of the Russian Federation is noteworthy, in which it was proposed to pay special attention to gas chemistry, given that consumer demand for its products will only grow and prices in the processing chains can sometimes increase 12-fold.

3. A set of mandatory strategic shifts will stimulate further GDP growth, improve existing technologies and create new ones, and generate corresponding jobs. According to the IMF, the Russian economy became the fourth largest in the world in 2023, with a share of 3.5% of world GDP calculated using the purchasing power parity assessment method. Russia has thus caught up with Japan (3.5%) and overtaken Germany (3.2%). Meanwhile, the top three remain China (18.8%), the USA (15.0%) and India (7.9%). Russia's position in the world ranking is also confirmed by World Bank data[20].

In addition to export markets, many types of derivative product have their own large domestic market, which is currently largely dependent on imports. Nevertheless, energy consumption volumes continue to grow worldwide, and the automation and digitalisation of fuel and energy complex facilities is being actively implemented. The solution to specific problems of increasing the competitiveness and energy security of the state is beginning to play a special role, which will certainly help to strengthen state sovereignty and overcome strategic uncertainty in the development of the domestic gas industry.

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[19] The abbreviation 'ESG' traditionally stands for environmental conservation (E), social responsibility (S), and quality of corporate governance (G) [Koryakin et al., 2024].
[20] https://spb.ranepa.ru/news/tema-dnya-reshetnikov-ekonomika-rf-prodolzhaet-rasti-tempami-vyshe-mirovyh/.

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Digital management: Fit Sevice company's experience

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Abstract

The development of the digital economy is accompanied by changes in the business management system, contributing to the emergence of a new management concept. However, the theory of digital management is still in its infacy and the existing scientific research in this field seems to be very fragmentary, which determines the relevance of this article, its theoretical and practical significance. The aim of the study is to identify the specifics of digital business management and changes in management processes by analysing the experience of digital management in a real company.

The research was conducted using the case study method, with a Novosibirsk company selected as the subject of the research, where a digital management system was created for the company and several hundred of its franchise partners in Russia and the Republic of Kazakhstan.

As a result of the analysis of management practice, the conceptual features of digital management were identified, the main stages of the formation of the process of 'variance-based management' were revealed, approaches to the formation of the company's key performance indicators were described, and the change in the role and functions of management in the digitalisation of business management was shown. The article contributes to the theoretical and managerial debate on the concept of digital management.

Keywords: key performance indicators, variance-based management, changes in management under digitalisation.

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数字化管理：Fit Service公司的经验

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简介

数字经济的发展伴随着企业管理体制的变革，促进了新管理理念的出现。然而，数字化管理理论刚刚形成，该领域现有的科学研究似乎非常零散，这就决定了本文的现实意义、理论意义和实践意义。本研究的目的是在分析一家实际公司数字化管理经验的基础上，确定数字化业务管理的具体内容和管理流程的变化。

研究以案例研究法为基础；研究对象是一家新西伯利亚公司，该公司建立了数字化管理系统，覆盖其在俄罗斯和哈萨克斯坦共和国的数百家特许经营合作伙伴。

通过对管理实践的分析，突出了数字化管理的概念特征，揭示了形成偏差管理过程的主要阶段，描述了形成公司关键绩效指标的方法，并展示了在企业管理数字化过程中管理层角色和职能的变化。 文章为有关数字管理概念的理论和管理辩论做出了贡献。
关键词：关键绩效指标、偏差管理、数字化下的管理变革。

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Introduction

Digital management is becoming a new reality in business, and it is necessary to adapt to it. However, researchers note the small number of studies examining the impact of digitalisation on management [Pashuk & Tuboltseva, 2022; Ayla, 2023], which is understandable given the limited experience of such management to date. Literature has comparatively thoroughly examined digitalisation issues in specific functional areas such as marketing, human resource management, management accounting, logistics and project management [Dmitrieva, 2020; Suslov & Minaev, 2021; Monge & Soriano, 2023]. A wide range of theoretical articles have been published on the digital transformation of business, the problems of the digitalisation of management and the use of digital technologies, such as artificial intelligence and big data analysis, in production and management organisation [Antonov & Samomudov, 2018; Levchaev, 2019]. Books and textbooks on digital management are also being published [Battal, 2022; Baumers & Dominy, 2022][1].However, the practical functioning of the digital management system, the underlying principles and methods, and the formation of the concept of digital management are not well covered.

Meanwhile, digitalisation technologies have led to significant management transformations, prompting experts to discuss changes to the role of managers, the formation of a new management system that transcends time and space restrictions, changes to managers' thought processes, the development of a new management model where traditional thinking may be ineffective, and the inevitable requirement for new management practices in the face of new technologies. Essentially, we are talking about forming a digital company management system based on data (data-driven management) [Trofimov & Trofimova, 2021]. However, the contours of the new management system are still poorly defined [Arenkov et al., 2018]. In this regard, describing the practice of digitalising business management is of both scientific and practical interest.

This article describes the specifics of digital management based on an analysis of the digital management experience of a specific company using the case study method.

1. Digital management: theoretical and methodological foundations of research

- An analysis of the ways in which the term 'digital management' is defined in scientific articles [Ozornin & Terlyga, 2021; Kalyazina, 2023] shows that it is considered from two standpoints: the technologies used, and the socio-economic aspects of management. In the latter case, we can talk about the conceptual and applied characteristics of changes in management. Broadly speaking, digital management is defined as the process of implementing global digital standards (technologies) that transform the management paradigm, presenting challenges to companies from the external environment [Larionov et al., 2020]. Researchers describe the advantages of the digitalisation of management. In

[1] See also: Maslennikov, V. V., Lyanday, Yu. V., Kalinina, I. A., Popova, E. V. & Biryukov, E. S. (2024). Digital Management: Textbook. Moscow: KroNus.

particular, they note that it increases the efficiency and speed of management decision-making, including through the use of artificial intelligence. It also accelerates the detection of problems (Levchaev, 2019), makes business processes observable and manageable, and ensures that decisions are transparent, justified and less subjective (Ruban, 2024).

As the issues surrounding digital management are extensive, several key research areas can be identified.

- Data-driven management decision-making processes, including the development of predictive and prescriptive analytics [Awamleh et al., 2024; Mekimah et al., 2024].

The renowned consultancy firm Gartner included this area in its top 10 technology trends for 2023[2]. Within this framework, approaches to solving digitalisation problems in operational management are being developed to improve production efficiency. Standard software products for managing equipment maintenance and repair have emerged, enabling the avoidance of equipment downtime due to breakdowns through preventive maintenance. Other digital solutions based on the Internet of Things (IoT) and artificial intelligence technologies are also being developed. According to the Higher School of Economics, new methods of processing and transmitting information prevail among the process innovations completed over the past three years [Innovation Activity Indicators, 2024].

- New business models, including platform business models and digital platform ecosystems [Gawer, 2021; Chen et al., 2022].

In the modern economy, companies' business models are becoming a tool for competition. The management systems of platform companies, which are based on digital platforms and develop using network effects, are inherently high-tech. Traditional companies can use digital technologies to promote and organise the sale of their products and create additional value for customers when changing business models, without changing business management processes [Ivanov et al., 2024].

- The digitalisation of management in certain areas, most frequently marketing, personnel management and project management [Dmitrieva, 2020; Suslov & Minaev, 2021; Monge & Soriano, 2023].

The market offers ready-made solutions for the digitalisation of auxiliary business processes in areas such as logistics, personnel management and finance. Widespread CRM systems allow sales and client interactions to be managed. However, this 'piecemeal' digitalisation usually does not affect companies' main production processes and, consequently, does not allow us to speak of a digital system for company management.

- Practical experience of the digitalisation of management in companies from various fields, considered at an individual level. This article presents the latter direction of research.

In our opinion, the main result of the digitalisation of management is not only the development of analytics and the use of data when making management decisions, or a change in the company's business model including new structures and functions. Rather, it is the restructuring of management business processes that leads to the formation of a digital business management system and, in theoretical terms, a new management concept.

2. Research design

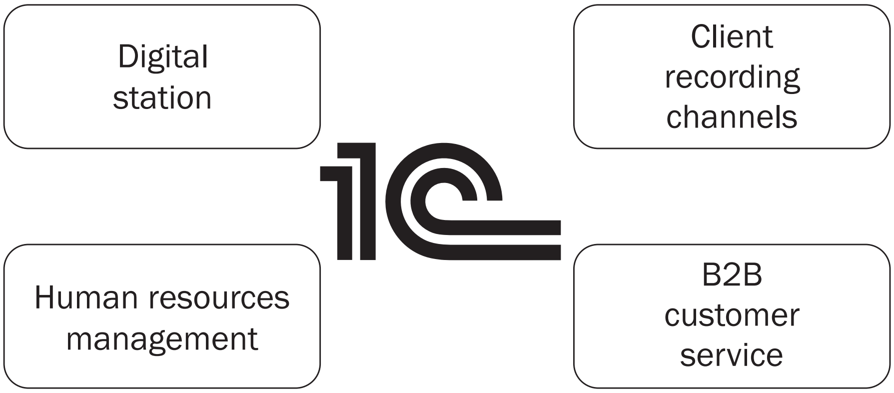
The study focuses on the Novosibirsk-based company Fit Service, which has established the largest franchise network of car service stations in Russia and the Republic of Kazakhstan, comprising over 300 stations in 157 cities. In 2023, the station network generated revenue of more than 9 billion rubles and served over 2 million clients.

The research method is a case study, involving a detailed examination and interpretation of results for a specific research subject (Thomas & Myers, 2015). This approach was chosen because sufficient experience has not yet been accumulated in the Russian digitalisation of management practices to form the basis for the theoretical development of the concept of digital management, which makes the presented article relevant.

One of the authors' involvement in the company's activities enabled a comprehensive analysis of the structure and content of the digital management system. It also made it possible to demonstrate the role of the company's key performance indicators in organising operational business management for deviations, as well as describing changes in the company's management system during digitalisation. This article does not cover organisational, technical or algorithmic tasks related to the data collection and processing system, nor the planning system. This approach allowed us to focus on conceptual changes in the company's management during digitalisation. Firstly, this concerns the operational business management system, which is based on creating a data flow panel using the company's key performance indicators. This panel then becomes the basis for daily monitoring and deviation management. This, in turn, changes the role of the company manager, freeing them from operational tasks so they can focus on the company's strategy and team development.

[2] https://trends.rbc.ru/trends/industry/cmrm/63c6ac409a794755f829a8a6?from=copy.

Fig. The main modules of the digital control system



Source: compiled by the authors.

3. Results

Fit Service has developed a multi-level digital management system based on the 1C platform (see figure). This system is continually being supplemented with new services and modules that are synchronised with other systems and partner products.

In the system under consideration, production business processes are presented in the Digital Station module. This includes the Digital Acceptance and Digital Workshop services, as well as the Planner. The former allows you to issue all documents (cash receipts, acts and work orders) electronically, as well as making online payments for orders. The Digital Workshop service is based on an automated auto mechanic workplace. It generates a digital car diagnostics report and searches for spare parts, sends a commercial offer to the client and then provides data on the results of repairing their car. Based on the issued work orders, the Planner system creates a calendar plan for the car service station, which uses colour solutions to show the station's workload by type of work over time on the screen of gadgets. Consequently, each car service employee can see what work needs to be done and when. The data generated by the Digital Station module forms the basis of management processes for the company and its partners.

The customer recording module supports the company's centralised call centre and uses chatbots and artificial intelligence technologies to automate customer communication processes. This module's services are used to record customers for servicing, change service times, send reminders to customers and send requests for repair work.

Operational data is collected based on digital modules and services, showing the state of the business in real

Table 1
Key performance indicators

Financial indicators	Auto service performance indicators	Customer service rating
Station revenue	Unique clients	Customer reviews of internet services
Purchase of spare parts from the parent company	Ratio of revenue from spare parts to revenue from services	CSI (Customer Satisfaction Index): a measure of customer satisfaction
Markup on spare parts	Number of standard hours worked	
Average revenue per client over the period	Number of work orders, including those with recommendations	

Source: Fit Service data.

time. This data is aggregated into key performance indicators and visualised on a data panel (dashboard) for owners and managers at different levels of management. The full version is available to company owners and managers on a phone or computer and contains data on the activities of all network stations. This allows you to identify and respond to emerging problems quickly. You can automatically receive reports for any time period, territory or station upon request, and view any indicator in comparison with the standard or over time. Overall, the Fit Service team manages the business based on data collected, aggregated and visualised online.

An analysis of the experience of implementing digital management in a real company has highlighted the key features of digital management. Let's consider these features.

- Transition from managing objects and functions to managing real processes.

Since its foundation in 2008, digitalisation of business has been considered a key investment project in Fit Service's strategy. As the initial goal was to develop a franchise network of car service centres, great attention was paid to building and debugging business processes, automating them, and creating a system for collecting and analysing data on which to base operational management. This enabled clear standards and regulations for the franchise to be established within a few years. When it comes to existing businesses, transitioning to process management involves consistently describing the main business processes and digitising them, i.e. transferring all data to a digital format.

- Creation of a set of key performance indicators to reflect the health of the business and monitor their achievement online.

The company's experience shows that key performance indicators should reflect different aspects of the business, such as its financial condition, production indicators in the context of a specific business and customer feedback on the quality of its goods or services. The indicators generated by the company in question are presented in Table 1. Depending on their position, managers can view any indicator in dynamics online for the company as a whole and for each station. Car service owners can also compare their indicators with those of other stations in the network to identify growth and development opportunities.

The next step is to establish the desired standard level for each indicator, as well as the permissible deviations from these standards. Excesses require management decisions. These standards and their associated deviations are determined through experience and expert knowledge, and can be adjusted as necessary.

- Organisation of operational business management based on deviations of the company's key performance indicators from the standards set for the planning period. This is made possible by defining a list of key performance indicators, their standard levels and acceptable deviations, and by generating these indicators online and presenting them on a dashboard.

Experts note that deviations can be precisely detected when analysing streaming data; aggregated data conceals them and is therefore useless [Jacobides & Reeves, 2020, p. 45]. Methodologically, deviation management differs from the approach to deviation management developed in the quality management system (QMS). Deviation management aims to prevent possible problems, errors and unexpected events by detecting, analysing and managing them early on. These processes can also be digitised [Kovrigin & Vasiliev, 2020]. In digital management, deviations from established parameters act as indicators used according to the traffic light principle: a green mark shows that everything is normal in the management system; a yellow mark draws managers' attention to an indicator; and a red mark requires intervention and the adoption of management decisions. During digitalisation, the organisation of deviation management of business processes lies in the fact that managers only intervene in current processes if a red mark appears on the data panel in the colour-coded indicator display, indicating a deviation from the norm.

- Development of regulations for how to act when deviations occur for each key indicator, and delegation of daily control of the system to company managers.

At Fit Service, control is delegated to bus station support managers, whose working day begins with analysing data on their assigned stations in the context of the planner and dashboard of indicators. If any indicators show red, an action plan is promptly adopted, involving employees from various management company departments if necessary.

The digital management features determine the specifics of the Fit Service franchise: entrepreneurs acquire a transparent business that is under control, where the owner always knows how efficient the processes and staff are. At the same time, many business processes are performed by the management company, which has eight departments with over 300 employees focused on the efficient operation and development of franchise stations. Equally important is the fact that key performance indicators reflecting different aspects of the business facilitate communication between partners, enabling them to speak the same business language.

- Changing the role of the company's manager to emphasise strategic activities and the development of his team, for which he will act as a mentor and coach.

Delegating operational control to managers frees up their time, as they only get involved in solving

Table 2
The manager's work plan with busineschi support managers

Frequency of meetings	Topic of the meeting
Once every two weeks	General team meeting: global tasks.
Once every two weeks	One-to-one meetings between managers to discuss individual development plans and problems.
Once a month/quarter	Monthly/quarterly results
Once every six months/year	Final meetings on the company's overall strategy
As needed	Cross-functional team meetings/working with other departments.

Source: Fit Service data.

current problems in the event of significant deviations. Consequently, they can dedicate more time to formulating strategies and making strategic decisions regarding the company's development and expansion, creating new products, collaborating with partners, and engaging with the external environment. The company analyses market and technological trends, studies best business practices (including those in other industries), acts as an expert on a large number of industry projects, promotes the brand, and actively shares its experience.

The change in the role of the Fit Service Manager when working with the team is reflected in their work plan with the company's managers (Table 2). Managers can still contact the manager directly with a problem or for advice when they are free.

The management system, formed through a lengthy digitalisation process, ensures transparency for owners, managers and partners. The openness and well-coordinated nature of all processes make the company attractive to employees and allow management to avoid "firefighting" situations. Describing the Fit Service company's experience of digital management contributes to forming a theory of management in the digital economy. However, the issue of creating comprehensive performance indicators that reflect the state of the business and form the basis for operational management based on deviations remains open for further research. Further theoretical understanding of changes to business management processes, particularly planning and operational control processes during digitalisation, is required.

Conclusion

The digitalisation of management, which involves organising the collection, aggregation and visualisation of online data on business activities, leads to a conceptual change in management within the company. This is evident in the fact that the primary principle of operational management is management by deviations, allowing control of processes to be transferred to company specialists. Consequently, company managers have more time to organise strategic activities and develop the management team. A planning and operational control system is necessarily formed in a digital management system, increasing the speed of response to deviations from planned results while creating prerequisites and opportunities for developing a strategy as a vector of company development. It should be noted that, alongside developing a strategy, management retains decisions that require expert knowledge.

The digital management system is oriented towards achieving the company's planned results with maximum openness and transparency, creating the basis for employee development, involvement in company activities, and increased responsibility for results. Therefore, a personnel management module is a mandatory component of the digital management system.

The digital management system was gradually developed in Fit Service and continues to evolve. This has enabled the company to become a market leader and innovator in technology, developing and scaling a network of car service stations while transforming the car service industry to meet the highest global standards.

In conclusion, we note that the company is open to sharing its successful experience of digitalisation.

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Strategic sustainability of an organisation and organisational innovation: An empirical study

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Abstract

Ensuring the strategic resilience of an organisation is important in the context of the need to develop the economy in a changing external environment. The presence of a significant proportion of strategically stable economic entities ultimately ensures the development of the national economy. The purpose of this work is to determine the relationship between the strategic sustainability of the organisation and the adoption of organisational innovation. Various methods were used to achieve this goal, including searching for information in open sources, conducting in-depth interviews and surveys of companies, and analysing the data obtained, including the use of update software. The article discusses key tools for ensuring strategic resilience. Interviews with industry experts revealed general criteria for an organisation that can be considered strategically sustainable. The novelty of this study is to determine the relationship between ensuring the strategic sustainability of an organisation through organisational innovation. Based on the analysis of 120 Russian companies from various industries, it was found that the majority of companies (72%) have introduced organisational innovations at least once, while in a significant proportion of companies the process of introducing organisational innovations is ongoing (38%). Organisations implement organisational innovations to maintain their own effectiveness and to remain competitive. In some cases, the introduction of organisational innovation may be a natural response to a change in the business model and/or an update of the organisation's strategy. The analysis revealed that the frequency of implementation of organisational innovations has a greater impact on the strategic stability of an organisation than just the fact of their implementation. Most strategically stable companies implement organisational innovation more often than strategically unstable companies. The practical significance of this study lies in the fact that the findings can be applied to the practical activities of organisations, and they also form the basis for further research in the field of strategic sustainability and organisational innovation.

Keywords: development, strategy, innovation, competitiveness, operational sustainability.

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组织战略稳定性与组织创新：实证研究

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简介

在外部环境不断变化的情况下，确保一个组织的战略稳定性对于经济发展的需要非常重要。战略上可持续的经济实体的大量存在最终会确保国民经济的发展。本文旨在确定组织的战略稳定性与实施组织创新之间的关系。为此，本文采用了多种方法，包括从公开来源中搜索信息、深入访谈和公司调查，以及分析所获得的数据，特别是借助现代软件进行分析。文章讨论了确保战略稳定性的关键工具。对行业专家的访谈揭示了可被视为具有战略稳定性的组织的一般标准。这项研究的新颖之处在于确定了通过组织创新确保组织战略稳定性的关系。根据对来自不同行业的 120 家俄罗斯公司的分析，我们发现大多数公司（72%）至少实施过一次组织创新，其中相当一部分公司（38%）持续实施组织创新。企业实施组织创新是为了保持自身的业绩，同时也是为了保持竞争力。在某些情况下，组织创新可能是对业务模式变化和/或组织战略更新的自然反应。分析表明，组织创新的频率而非实施创新的事实对组织的战略稳定性影响更大。大多数战略上可持续发展的公司比战略上不稳定的公司更频繁地实施组织创新。这项研究的实际意义在于，所获得的结果可以应用于组织的实际活动中，同时也为在战略稳定性和组织创新的框架内开展进一步研究奠定了基础。

关键词: 发展, 战略。

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Introduction

Although strategic sustainability has been studied in various works by both Russian and foreign authors, the relevance of finding ways to ensure it is growing. Over the past few years, the number of foreign publications devoted to this topic has increased by 50% [Colberg, 2022]. This is primarily due to the impact of economic shocks such as the Coronavirus pandemic, during which maintaining the sustainability of companies was of critical importance. This issue is also relevant for Russia due to the increasing impact of external factors (such as sanctions) on the economy, and the need to ensure progressive economic growth. Strategic sustainability enables economic entities to mitigate the impact of external and internal threats on their activities while continuing to develop, which should ultimately have a positive effect on the national economy. Another challenge in the current economic situation is the decrease in available resources coupled with an increase in their cost.

Strategic sustainability can be achieved in various ways, including through the creation and implementation of organisational innovations. According to the Oslo Manual (Oslo Manual, 2018), organisational innovations include the use of new methods to organise a company's activities (e.g. changes to management or organisational structure). At the same time, implementing organisational innovations does not imply significant capital expenditure, which plays an important role in the context of limited resources.

It is worth emphasising that the relationship between organisational innovations and strategic sustainability has not been widely studied in the scientific literature. In this regard, this paper aims to identify the relationship between implementing organisational innovations and forming an organisation's strategic sustainability. To achieve this, several tasks must be completed, including clarifying the concepts of 'strategic sustainability' and 'organisational innovations', and conducting an empirical study to identify the relationship between these categories. The results of the study could inform the development of more extensive methodological recommendations for ensuring the strategic sustainability of organisations.

To achieve the study's stated objective, a combination of qualitative and quantitative research methods was employed. A study of approaches to defining the concepts of strategic sustainability and organisational innovation was carried out by analysing scientific literature from open sources. To address existing knowledge gaps, in-depth interviews were conducted with twelve industry experts, providing the necessary sample size and data reliability [Guest et al., 2006]. Following the establishment of the theoretical framework and the in-depth interviews, a survey of 120 companies from various industries was conducted. A model of MS Excel software was used to analyse the results of the study. The author then analyses and synthesises the information obtained from the study to form final conclusions.

Fig. 1. Strategic sustainability and its components

Source: compiled by the author.

1. What is strategic sustainability, and which organisations can be considered as such?

The concept of strategic sustainability has been studied by foreign authors. For example, T. Colberg defines it as a company's ability to turn threats into opportunities (Colberg, 2022), while other researchers define it as a company's ability to identify threats in a timely manner and respond to them in order to achieve long-term goals (Hepfer & Lawrence, 2022). D. Coffaro considers strategic sustainability to be the ability to organise a company's work within a dynamically changing internal and external environment while maintaining necessary operational indicators and the capacity for development[1]. Foreign organisations have also paid attention to strategic sustainability. Thus, the OECD mentions strategic sustainability as the ability of an enterprise to continue its activities in a crisis, withstand crisis phenomena, and ensure recovery afterwards[2].

Russian researchers also pay considerable attention to strategic sustainability. Some researchers consider it in terms of competitive advantages. For instance, N. S. Rychikhina asserts that strategic sustainability involves creating and maintaining long-term competitive advantages, even in a changing environment. This ultimately improves the enterprise's financial performance [Rychikhina, 2008]. She also identifies several components of strategic sustainability, including financial, market and technological factors, as well as other types of sustainability. N.S. Yashin and E.S. Grigoryan take a similar approach, considering strategic sustainability to be ensured through competitive advantages. However, in their research, they identify additional components of strategic sustainability: operational, functional, and market [Yashin & Grigoryan, 2015]. Other researchers consider strategic sustainability in terms of mitigating threats in the event of negative changes to the internal and external environments, as well as ensuring development in favourable environments (Dudin & Lyasnikov, 2009). E.A. Tikhomirov defines strategic sustainability as the continuous development of an enterprise despite changes to its internal and external environments [Tikhomirov, 2020]. Within the framework of this work, it is worth noting that strategic sustainability is considered an independent concept, not referenced in relation to the term 'sustainable development', and is primarily used to describe a company's ability to recover from negative events. In English, this concept is equivalent to resilience[3]).

Based on the analysis of approaches to defining the concept of strategic sustainability within this study's framework, it is proposed that this category be considered, given that it encompasses market, operational, and innovative components (see Fig. 1).

In order to determine the extent to which an enterprise is strategically sustainable, it is necessary to establish a set of criteria. Some researchers propose determining the strategic sustainability of an enterprise through a system of balanced indicators and factors reflecting the company's ability to function and develop (Tsibareva, 2011). S.V. Grigorieva evaluates strategic sustainability using a formula that calculates and sums up various types of sustainability indicator based on different weights [Grigorieva, 2013]. Other authors categorise indicators to evaluate an enterprise's ability to manage risks, adapt to changes, and recover quickly [Erol et al., 2010]. However,

[1] Strategic resilience. Leadchange Group. https://leadchangegroup.com/strategic-resilience/.
[2] Boosting resilience through innovative risk governance. OECD/ https://www.oecd.org/en/publications/boosting-resilience-through-innovative-risk-management_9789264209114-en.html.
[3] https://dictionary.cambridge.org/dictionary/english/resilience.

almost all existing studies of the level of strategic sustainability do not develop unique indicators; rather, they use existing indicators in different combinations to evaluate individual areas of enterprise activity (e.g. financial, investment and technical).

Another approach is to assess the strategic sustainability of an enterprise based on compliance with the necessary criteria. Within the scope of contemporary studies, authors analyse the criteria of sustainable enterprises rather than those of strategically sustainable enterprises. A sustainable company is one that has stable growth and makes a profit (Chotchaev, 2011). Some researchers classify a sustainable enterprise solely in terms of financial stability (Vakhromov & Markaryan, 2008). Therefore, it can be concluded that existing studies do not have clearly formulated, universal criteria for determining a strategically sustainable organisation. This creates a knowledge gap that will be addressed in the practical part of the study.

2. Tools for ensuring strategic sustainability

Various tools can be used to ensure the strategic sustainability of an organisation. These tools can be implemented through organisational innovations, among other methods. Rychikhina (2008) distinguishes several types of restructuring as tools for ensuring the strategic sustainability of an organisation:

- Natural: it is advisable to carry out within the framework of the enterprise's normal activities to improve efficiency.
- Business: It is advisable to carry out within the framework of normal activities in the presence of reasonable negative forecasts.
- Crisis: it is advisable to carry out in the event of unfavourable events occurring, or their occurrence being guaranteed in the short term.

According to R.M. Gilmullina, ensuring strategic sustainability can be achieved through the following functional blocks: production (quality, marginality and output quantity); marketing (the company's position in the market); finance (profitability and solvency levels); personnel (labour resource efficiency and sufficiency); and innovation (technology development) [Gilmullina, 2016]. A.V. Gridchina believes that multi-level structural transformations of the ways activities are organised, as well as the stimulation and development of innovative activities, can reduce the volume and frequency of emerging threats and increase strategic sustainability. All of this can be implemented within the framework of an innovative development programme (Gridchina, 2015). I.P. Kuzmenko and V.P. Kirpanev study adaptability as a key element of sustainability (Kuzmenko & Kirpanev, 2011). They note that an economic system's adaptability increases with its size and its ability to reorient itself towards profitable market segments, while decreasing the seasonality factor.

Strategic sustainability is studied from different angles. For instance, researchers consider organisational experience to be a core aspect of strategic sustainability, emphasising the importance of certain conditions for achieving a high level of strategic sustainability: long decision-making processes, weak organisational support and a lack of staff involvement at all levels (i.e. a lack of conscious interaction) [Välikangas & Romme, 2012]. According to the consultancy firm McKinsey & Company, a business model that can adapt to significant changes in consumer demand, the competitive environment, technological changes and the regulatory framework is required for sustainability[4].

Another important factor in ensuring strategic sustainability is the creation of an antifragile organisation. Creating an antifragile organisation can also contribute to strategic sustainability. To achieve this, we should consider the concept of the triad 'fragility – invulnerability – antifragility' in more detail. Antifragility can be achieved using the following methods:

- create excess reserves, even if this reduces efficiency.
- allow some parts of the system to be fragile, ensuring they can recover and self-organise.
- 'Barbell strategy': invest approximately 10% of projects in high-risk areas [Taleb, 2014].

The tools under consideration can be used in organisational activities, particularly through organisational innovation (or change) and/or the development of organisational competencies, as presented in the table.

3. Organisational innovations

Within the existing research framework, several approaches have been adopted to define the concept of organisational innovation. J. Schumpeter, for example, classifies organisational innovations as those related to intra-organisational relations (Schumpeter, 2024). The Oslo Manual (2018) defines organisational innovations as the use of new methods in company management. Rosstat uses a similar definition, classifying them as new ways of organising a business and increasing efficiency[5]. It is noted that an innovation is considered to be an organisational innovation if it is implemented for the first time within the framework of an organisation's activities. For example, if such an innovation has been implemented on the market before, but is being implemented for the first time within a company, it will be considered an

[4] From risk management to strategic resilience. McKinsey, 2022. https://www.mckinsey.com/capabilities/risk-and-resilience/our-insights/from-risk-management-to-strategic-resilience.
[5] Innovative activity of organisations (the proportion of organisations that implemented technological, organisational or marketing innovations during the reporting year, as a percentage of the total number of organisations surveyed). Rosstat. https://rosstat.gov.ru/free_doc/new_site/business/nauka/minnov-1.html.

Table
Classification of tools for ensuring strategic sustainability

Type of tool	Method of tool implementation
Functional block management	Implementing organisational innovations (or changes) and developing organisational competencies
Structural transformation of the forms and methods used to organise activities	
Strategic development of sustainability to create a competitive advantage	
Creating an antifragile organisation	
Timely decision-making	Development of organisational competencies
Learning from experience	
Restructuring (natural, business or crisis)	Implementing organisational innovations (or changes)

Source: compiled by the author.

organisational innovation. Thus, there are many different types of organisational innovation: process, organisational, informational and motivational (Meshcheryakov, 2012). Some authors highlight a change in the business model as an organisational innovation (Trapeznikov, 2010). In general, the list of possible innovations in organising an enterprise's activities is extensive and varies from enterprise to enterprise.

Based on the analysis of the theoretical part, the following conclusion can be drawn: the concept of 'strategic sustainability' is currently well researched and represents a company's ability to continue its current activities and develop in the face of adverse changes in the internal and external environment. Although there are a number of methods that allow one to assess certain components of an organisation's strategic sustainability based on generally accepted indicators (financial, investment, etc.), these methods are not specific to the assessment of strategic sustainability. It is important to emphasise that, currently, criteria have been established for identifying sustainable enterprises, but not those that are strategically sustainable. This creates a knowledge gap and the need to address it through in-depth interviews with industry experts. To ensure strategic sustainability, organisations can use various tools, such as developing organisational competencies or introducing organisational innovations. Organisational innovations are innovations in the organisation of a company's work and there are many different types. Within the framework of existing studies, the relationship between organisational innovations and strategic sustainability has not been analysed. In this regard, the following hypothesis has been formulated: organisations that implement organisational innovations achieve strategic sustainability. This hypothesis will be tested in an empirical study.

4. Results and discussion

The practical part of the study was conducted in two formats: in-depth interviews were conducted with experts, and organisations were surveyed. As previously mentioned, existing studies do not clearly define the criteria for a strategically sustainable organisation. Therefore, during the in-depth interviews, the experts were asked: 'Which organisation can be considered strategically sustainable?' To ensure consistency in the interview results, the experts were offered a definition developed in the theoretical part of the study. Analysis of the responses revealed four main criteria for a strategically sustainable organisation (see Fig. 2).

Following the interview, the experts concluded that, in order to be considered strategically sustainable, an organisation must meet all the criteria, rather than just one or several.

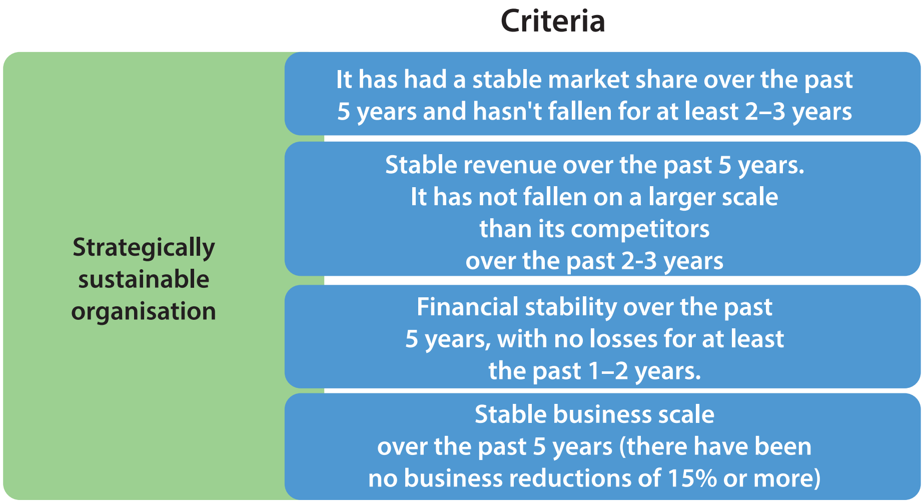
As part of the study, 120 companies from various industries were surveyed. At the first stage, the formed criteria were used to determine whether the organisation was strategically sustainable. Most of the companies that participated in the survey were found to be so - 72.6% of them.

The survey included companies in the service and industrial sectors, but no direct correlation was found between strategic sustainability and the type of activity.

Key features of managing organisational innovations in companies were identified as part of an in-depth interview with industry experts. Based on the results, closed questions were formulated for organisations. The survey showed that organisational innovations had been implemented in most companies (72%).

Moreover, of the companies that had implemented organisational innovations at least once, 38% had a continuous process, 29% implemented them once

Fig. 2. Criteria for a strategically sustainable organisation



Source: compiled by the author based on interviews with experts.

every two to three years, 26% implemented them once every year to one and a half years, and 7% implemented them less than once every three years. Notably, among strategically stable organisations, organisational innovations were implemented at least once in 80% of cases (57 out of 72 companies), compared to 60% of cases (29 out of 48 companies) among strategically unstable organisations. This confirms the importance of organisational innovations for strategic sustainability.

The main reasons for implementing organisational innovations are:

– the company's desire to improve efficiency.
– responding to changes in the external and internal environments;
– the need to implement changes following a change in strategy (or business model);
– responding to market competition.

Thus, it emerged that most companies implement organisational innovations, and that this process is ongoing.

The next stage of the study involved analysing the correlation between organisational sustainability and the implementation of organisational innovations, as well as the frequency with which they are implemented. This analysis was carried out using MS Excel software. The following parameters were selected for the analysis:

– dependent variable – strategic stability: 1 – for strategically stable companies, 0 – for strategically unstable companies; - independent variables: the fact of implementation of organisational innovations (implemented – 1, not implemented – 0) and the frequency of implementation of organisational innovations (not implemented – 0, less than once every 3 years – 1, once every 2-3 years – 2, once every 1–1.5 years – 3, continuous process – 4).

The following results were obtained after the analysis:

- The correlation between strategic sustainability and the implementation of organisational innovations is 0.2, indicating a weak dependence on innovation implementation.
- The correlation between strategic sustainability and the frequency with which organisational innovations are implemented is 0.78. This suggests that strategic sustainability is significantly influenced by the frequency of organisational innovation implementation.

The findings obtained during the empirical study confirm the hypothesis that organisations that implement organisational innovations achieve strategic sustainability.

Following the analysis, we can also conclude that companies that are strategically sustainable implement organisational innovations more frequently than those that are not. However, implementing organisational innovations alone does not lead to an increase in strategic sustainability; it is much more important that the process is carried out continuously.

Conclusion

The strategic sustainability of an organisation is important for ensuring its current operations and progressive development. The dynamic development of economic enterprises allows the national economy to develop as a whole. A sufficient number of studies have been devoted to the strategic sustainability of organisations. An important element of strategic sustainability is its criteria. These have not yet been identified in existing literature, but a survey of experts has revealed a number of criteria. The most important of these concern the stability of company operations over a period of five years. In the context of decreasing available resources, ensuring strategic sustainability can be achieved through relatively inexpensive methods, such as organisational innovations.

Most of the organisations that took part in the survey are strategically sustainable and continuously implement organisational innovations. It does not matter whether the company belongs to the manufacturing or service industries. The main reasons for implementing organisational innovations are increased efficiency and changes in the internal and external environments, as well as market competition. Thus, the objective of the study is realised - the relationship between organisational innovations and strategic sustainability is determined. For an organisation to be strategically sustainable, the frequency of innovation is more important than innovation itself.

Further research on this topic should focus on developing the necessary methodological recommendations for creating and implementing organisational innovations, ensuring continuous work with them. This will increase the strategic sustainability of organisations and have practical significance for economic entities. The lack of research on this topic in existing studies suggests that significant advances in scientific knowledge can be expected in this area.

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Discussion of the concepts underlining the source of competitive advantage of modern commercial airlines

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Abstract

The article examines the most prominent theories of strategy, business models and competitive advantage and their applicability to the current situation in the commercial airline industry. The purpose of the article is to explain the basic concepts of strategic management using the example of a very crisis-prone (e.g. COVID-19, geopolitical instability) but socially important industry of civil aviation. Finally, we visualise the strategic concepts discussed and provide ideas for future research on competitive advantage and strategy in commercial airlines.
Keywords: commercial aviation, ancillary revenue, ancillary services, company competitiveness, resource-based view, strategic analysis.

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现代商业航空公司竞争优势的基本概念回顾

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简介

文章回顾了最著名的战略、商业模式和竞争优势理论及其对商业航空业现状的适用性。本文旨在以一个具有重要社会意义的经济部门--民航为例，揭示战略管理的主要概念。 对所讨论的战略概念进行了形象化，并就竞争优势和商业航空公司战略这一主题的未来研究提出了建议。
关键词： 商业航空、额外收入、额外服务、公司竞争力、资源方法、战略分析。

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At the outset, it should be noted that the commercial aviation industry is very crisis-prone, and therefore the macro environment is driving business decisions to increase the revenue and profitability of airlines not only in Russia, but all over the world. For the most of the 21st century, commercial airlines have been battling multiple crises, each more damaging than the last. It is clear that the COVID-19 pandemic was the most impactful crisis the industry has ever experienced, with total international airline revenue falling by more than 50% in 2020 compared to the pre-pandemic

2019[1]. It is obvious that the macro environment has really shaped the aviation industry in general and, clearly, the business models and sources of competitive advantage by which it operates.

For most of its history the commercial airline industry has struggled through one crisis after another. Moreover, according to M. Porter, the commercial airline business is extremely competitive, with low profit margins and a large number of competitors [Porter, 1996]. Thus, this makes it even more difficult to adapt current business practices to the new realities of the changing world order. The most significant of these are those related to public health, economic conditions and geopolitics. Only in the 21st century has the airline industry been hit by at least three major global 'black-swan' events that have derailed the growth process.

The problem of business strategy in the airline industry is therefore very interesting. The discussion addresses the question of how airlines create their competitive advantage from the perspective of the fundamental strategic concepts of 'cost leadership' vs. 'differentiation' [Porter, 1996] and the internal environment analysis approach of the resource-based view (RBV) [Barney, 1991; Grant, 2018].

It then examines the theory of the commercial airline industry itself and previous research on airline competitive advantage to see if it can be applied to the basic approaches considered above. For this part, reference is made to the works of the professors of the University of St. Gallen – A. Wittmer, R. Mueller, T. Bieger. In particular, their book [Wittmer et al., 2021], which is regarded as an almanac for all things related to the business of commercial aviation.

Let's start by defining competitive advantage as a wide range of activities that make up the development, sale and distribution of products or, in our case, services. However, the biggest question of how to do this is still being debated by managers and researchers in many different industries, particularly the commercial airline industry.

When researchers talk about competitive advantage, they usually refer to the famous business strategist – Michael Porter. Therefore, key concepts, derived from this author's work need to be established for this article. In his work 'What Is Strategy?', Porter provides some key insights that are necessary for our discussion. First and foremost, companies must pursue operational efficiency to remain competitive. Operational effectiveness, in the words of Porter, is 'doing similar activities better than competitors do them' [Porter, 1996]. Efficiency contributes to, but does not complete, operational effectiveness. Operational effectiveness includes those practices that enable an organisation to make the best use of its resources, for example, airlines can reduce in-flight service costs or reconfigure the fleet composition to have a single type of aircraft. There are huge differences in the operational effectiveness of companies: some are better at motivating their staff, others are better at using modern technology. These differences are a key source of profitability between competitors as they have a direct impact on cost positions.

Continuous improvement in operational effectiveness is very important for superior earning results, Porter argues, but it is not sufficient most of the time. Practices that underpin in operational effectiveness are easily copied and imitated by competitors. New management techniques, for example, are now often adopted by other companies, no doubt with the help of consultants. Modern technologies are increasingly available and companies are adopting them, following the example of their competitors. As a shining example, over the past decade Russian commercial airlines have adopted comprehensive IT services, from high-quality websites to mobile applications and chat bots. Initially, this took a lot of the cost out of ticket distribution, but as the practice became more commonplace in the industry, its ability to differentiate the company from its competitors diminished.

This brings us to Porter's second argument about the inadequacy of operational effectiveness. The author calls this 'competitive convergence,' which means that companies are becoming largely indistinguishable from each other [Porter, 1996]. The problem surely lies in the very idea of benchmarking, and the more organisations do it, the more similar they become. Therefore, competition based on operational efficiency leads to progress in absolute terms, but almost no improvement in relative terms.

At this stage of the industry's development, the question of profitability and operational efficiency is of paramount importance. But from a strategic perspective, companies are looking for a sustainable competitive advantage [Wittmer et al., 2021]. In simple terms, Porter's definition of sustainable competitive advantage is 'doing different activities or doing similar activities in different ways.' In the case of commercial airlines, the second scenario is more applicable – doing similar activities but doing them slightly differently.

Let's look at the strategy of modern commercial airlines through the prism of the Resource-Based View (RBV), which defines the path to sustainable competitive advantage in a very comprehensive way. The highest theoretical impact is provided by the acclaimed works of J. Barney 1991–2001 on the Resource-Based View. R. Grant [Grant, 2018] also contributes to the theory of RBV, which is used in the research. From this literature, the Resource-Based View approach is considered as an analysis of the organisation's resources, including: tangible, intangible and human; capabilities of different functional areas, such as: corporate functions, operations, information management, marketing, sales and distribution and service. Therefore, with this theoretical background, it is assumed that resources and the right combinations of these resources create capabilities. These capabilities create 'core capabilities,' which in their turn lead to a competitive advantage. Returning to Porter, an organisation's competitive advantage contributes significantly to its performance [Porter, 1996].

Let's take a closer look at these theoretical concepts in more detail. In this article, resources are defined as 'productive assets owned by the firm' [Grant, 2018]. These resources can be categorised as tangible, i.e. financial and physical assets

[1] Effects of Novel Coronavirus (COVID-19) on civil aviation: Economic impact analysis (2022). Montreal, ICAO. https://www.icao.int/sustainability/Documents/COVID-19/ICAO%20COVID-19%20Economic%20Impact_2022%2008%2012.pdf.

that can be measured. For example, an airline's physical resources include aircraft, airport concessions and other facilities. The next category is intangible resources, which are much harder to measure and include customer loyalty, brand image and, of course, corporate culture. And last but not the least, there are human resources, which include the skills, training, experience and efforts of a company's employees. In fact, for commercial airlines, this type of resource is extremely important, especially for the front-line staff who interact directly with passengers.

As Grant suggests, 'resources alone are not productive,' so they need to be combined and mixed in order to form capabilities or, interchangeably, competences. In essence, if a company were to look at capabilities as they are, it would eventually end up in the 'competitive convergence' mentioned above. To avoid this, a concept of 'core competencies' is needed, as introduced by [Hamel, Prahalad, 1989; 1993]. 'Core competencies' are those competencies and capabilities that can create a competitive advantage when properly integrated into the strategic (or business) model.

When considering the importance of resources and capabilities and their potential to be a 'core competence,' the 'VRIO Framework' proposed by [Barney, 1995] is used. The name of the framework is an acronym that stands for Value, Rarity, Imitation, Organisation. The idea behind the framework is to draw conclusions on four key questions: 'Do the resources/capabilities add value?', 'How rare are these resources/capabilities?', 'Is imitation of these resources/capabilities difficult or costly?' and 'Does our organisation make full use of these resources/capabilities?'

Again, as suggested by both Grant and Porter, a sustainable competitive advantage is achieved through the right fit between a core competency and a strategy model. In fact, classical business strategies or sources of competitive advantage are defined by [Porter, 1996]. As we shall see, the classic 'cost leadership' and 'differentiation' strategies fit very well into the most popular 'low-cost' and 'full-service' business models of commercial airlines.

Now to the question of commercial airline business models. Clearly, the differentiation of business models and strategies began long before the COVID-19 pandemic. The liberalisation of the airline industry markets in the US in 1978, which then spread to the rest of the world [Doganis, 2010], created an opportunity for new faces to enter the market. These new players had a very different way of doing business – the low-cost model.

Comprehensive definitions of the two main business models are provided by the professors at the University of St Gallen in Switzerland – A. Wittmer, R. Müller, T. Bieger. In their book, 'Aviation Systems. Managing the Integrated Aviation Value Chain. Second Edition' (2021), the authors define 'full-service network carriers' (FSNC) and 'low-cost carriers' (LCC). First, full-service airlines are those whose strategy is based on 'hub and spoke' networks, a strong brand and prestige service levels. It is important to note that these airlines are usually members of an alliance and tend to focus on business travellers who require premium service and good flight connections [Wittmer et al., 2021]. Second, by definition, the low-cost carriers have traditionally pursued a 'cost leadership' strategy [Porter, 1996]. These companies offer point-to-point networks with limited service levels in order to reduce costs. Moreover, they do not usually participate in any alliances and put a strong focus on dominating specific routes [O'Connell, Warnock-Smith, 2013]. In addition, LCCs have a more uniform fleet of aircrafts, as can be seen from the way *Ryanair* and *Pobeda* operate. They fly only the Boeing 737-8 family, have higher seat densities and, crucially, unbundled fares with ancillary services offered for a fee [Magdalin, Bouzaima, 2021].

Interestingly, researchers have found that some representatives of low-cost carriers have adopted some of the characteristics of the full-service carriers [Lohmann, Koo, 2013] and some FSNCs have also started to use some of the low-cost carriers' solutions to stay competitive, especially the selling of ancillary services. The question arises as to why the full-service carriers would start to drift towards low cost practices.

A study [Fontanet-Pérez et al., 2022] concluded that lowest-fare and lowest-cost models were more stable and successful than full-service strategies in the face of the unexpected crises that the entire industry is constantly facing. The five years leading up to the last major pandemic crisis can be characterised by steady growth in demand. This allowed the commercial airlines to comfortably increase their profitability and the differences were not necessarily due to business models. It was only when the crisis hit that the discrepancies became apparent. The data suggest that having lower operating costs gives an advantage in a situation of sudden drop in demand and therefore opportunities to generate revenue.

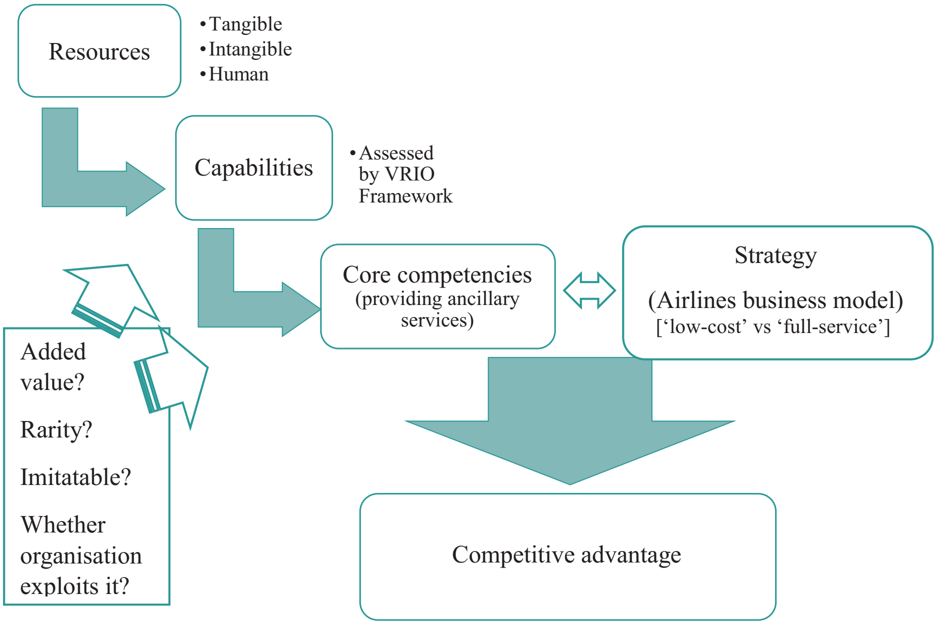
Returning to the discussion of airlines' competitive advantage and strategy, it can be seen that the crisis-prone nature of the industry has really shaped progress towards more profitable business models, with airlines pursuing the operational efficiency suggested by Porter. In addition, the research found that ancillary services are indeed becoming a competitive factor for both 'full-service' and 'low-cost' carriers.

Through the analysis of the existing literature, it is defined that the competitive nature of the airline industry is based on the principles of low marginality, intense rivalry among competing companies and, most importantly, high vulnerability to crisis situations. All in all, the key to the competitiveness of commercial airlines is their ability to withstand market rivalry and survive through crisis situations. Ultimately, the pursuit of a sustainable competitive advantage is essential to the long-term success of any business.

To conclude the discussion paper – a visualisation (Fig. 1) of the strategic Resource-Based View concepts is created to attempt to fit the ancillary services of commercial airlines into these concepts.

Further research clearly implies a thorough investigation of possible core competences that airlines need to develop in order to gain competitive advantage. One of these core

Fig. 1. Place of ancillary services in the RBV analysis



Source: compiled by the author on [Barney, 1991; Grant, 2018; Wittmer et al., 2021].

competences is likely to be the provision of so-called ancillary services that generate additional revenue and provide additional operational efficiency.

As external environment has become more volatile and unpredictable, the airline industry has seen a significant increase in the trend to generate additional revenue to the main passenger revenue – in academic and professional literature this is referred to as 'ancillary revenue,' i.e. revenue generated by offering and selling ancillary services. Over the past decade, the share of ancillary revenue in the total passenger revenue has increased by more than 200%, from 6% of total passenger revenue in 2011 to around 20% – in 2021, on average for all reporting airlines. This trend is strongly supported by the growing number of 'low-cost carriers' (LCCs), as their business model is highly dependent on ancillary revenues. Industry examples such as *Spirit*, *Ryanair* and *Wizz Air* generate around half of their total turnover from ancillary revenues [The 2022 yearbook.., 2022]. But even the 'full-service network carriers' (FSNCs) are realising the value of offering ancillary services. On average, the major US carriers (*Alaska Air*, *American Airlines*, *Delta*, *Southwest* and *United*) generate 22.2% of their total revenue from ancillary services [The 2022 yearbook.., 2022].

Commercial airlines around the world are turning to increased ancillary revenue generation, especially in times of crisis. An analysis of industry reports shows that in the pandemic year of 2020, the decline in ancillary revenues was less than the decline in total passenger revenues. More importantly, the recovery of ancillary revenues is twice as strong as that of total passenger revenues – 54% year-on-year growth in 2021 compared to 24% year-on-year growth in the same year [The 2021 Yearbook.., 2021; The 2022 Yearbook.., 2022]. Ancillary revenues and the services that support them are therefore of strategic importance to airlines around the world. As stated, there is room for research into the resources and skills required to operate effectively with ancillary services.

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