energies

Special Issue Reprint

Innovative Economic Technologies and Policies in the Energy Sector

Edited by
Alex Borodin

www.mdpi.com/journal/energies

MDPI

Innovative Economic Technologies and Policies in the Energy Sector

Innovative Economic Technologies and Policies in the Energy Sector

Editor

Alex Borodin

MDPI • Basel • Beijing • Wuhan • Barcelona • Belgrade • Manchester • Tokyo • Cluj • Tianjin

Editor
Alex Borodin
Head of the Center for the
Development of Forms of
Integration of Science and
Education, Russian Research
Institute of Economics,
Politics and Law in Science
and Technology (RIEPL)
Moscow
Russia

Editorial Office
MDPI
St. Alban-Anlage 66
4052 Basel, Switzerland

This is a reprint of articles from the Special Issue published online in the open access journal *Energies* (ISSN 1996-1073) (available at: https://www.mdpi.com/journal/energies/special_issues/Innovative_Economic_Policies_Energy).

For citation purposes, cite each article independently as indicated on the article page online and as indicated below:

LastName, A.A.; LastName, B.B.; LastName, C.C. Article Title. *Journal Name* **Year**, *Volume Number*, Page Range.

ISBN 978-3-0365-8122-4 (Hbk)
ISBN 978-3-0365-8123-1 (PDF)

Contents

Alex Borodin, Galina Panaedova, Irina Ilyina, Mustafa Harputlu and Natalia Kiseleva
Overview of the Russian Oil and Petroleum Products Market in Crisis Conditions: Economic Aspects, Technology and Problems
Reprinted from: *Energies* **2023**, *16*, 1614, doi:10.3390/en16041614 . . . . **1**

Alex Borodin, Galina Panaedova, Svetlana Frumina, Aidyn Kairbekuly and Natalia Shchegolevatykh
Modeling the Business Environment of an Energy Holding in the Formation of a Financial Strategy
Reprinted from: *Energies* **2021**, *14*, 8107, doi:10.3390/en14238107 . . . . **19**

Zahid Mamedov, Irina Vygodchikova, Ayaz Aliev, Lira Gurieva and Natalia Rud
Modeling Multivalued Dynamic Series of Financial Indexes on the Basis of Minimax Approximation
Reprinted from: *Energies* **2022**, *15*, 366, doi:10.3390/en15010366 . . . . **37**

Irina Vygodchikova, Mikhail Gordienko, Natalia Natocheeva, Natalia Rud and Anzhela Namitulina
Assessment and Integral Indexing of the Main Indicators of Oil and Gas Companies by Circular Convolution
Reprinted from: *Energies* **2022**, *15*, 877, doi:10.3390/en15030877 . . . . **55**

Cemal Zehir, Melike Zehir, Alex Borodin, Zahid Farrukh Mamedov and Sadiq Qurbanov
Tailored Blockchain Applications for the Natural Gas Industry: The Case Study of SOCAR
Reprinted from: *Energies* **2022**, *15*, 6010, doi:10.3390/en15166010 . . . . **68**

Alex Borodin, Vladislav Zaitsev, Zahid F. Mamedov, Galina Panaedova and Andrey Kulikov
Mechanisms for Tax Regulation of CO_2-Equivalent Emissions
Reprinted from: *Energies* **2022**, *15*, 7111, doi:10.3390/en15197111 . . . . **87**

Natalie Gryzunova, Kirill Vedenyev, Victoria Manuylenko, Igor Keri and Michał Bilczak
Distributed Energy as a Megatrend of Audit of Investment Processes of the Energy Complex
Reprinted from: *Energies* **2022**, *15*, 9225, doi:10.3390/en15239225 . . . . **102**

Yuliya Tyurina, Svetlana Frumina, Svetlana Demidova, Aidyn Kairbekuly and Maria Kakaulina
Estimation of Tax Expenditures Stimulating the Energy Sector Development and the Use of Alternative Energy Sources in OECD Countries
Reprinted from: *Energies* **2023**, *16*, 2652, doi:10.3390/en16062652 . . . . **118**

Ayaz Aliev, Madina Magomadova, Anna Budkina, Mustafa Harputlu and Alagez Yusifova
EU: The Effect of Energy Factors on Economic Growth
Reprinted from: *Energies* **2023**, *16*, 2908, doi:10.3390/en16062908 . . . . **135**

Elena Fedchenko, Lyubov Gusarova, Timur Timkin, Natalie Gryzunova, Michał Bilczak and Svetlana Frumina
Methodology for an Audit of Institutional Projects in the Energy Sector
Reprinted from: *Energies* **2023**, *16*, 3535, doi:10.3390/en16083535 . . . . **154**

Dzikri Firmansyah Hakam
Mitigating Market Power and Promoting Competition in Electricity Markets through a Preventive Approach: The Role of Forward Contracts
Reprinted from: *Energies* **2023**, *16*, 3543, doi:10.3390/en16083543 . . . . **170**

energies

Review

Overview of the Russian Oil and Petroleum Products Market in Crisis Conditions: Economic Aspects, Technology and Problems

Alex Borodin [1,*], Galina Panaedova [2], Irina Ilyina [3], Mustafa Harputlu [4] and Natalia Kiseleva [5]

1 Department of Sustainable Development Finance, Plekhanov Russian University of Economics, 117997 Moscow, Russia
2 Department of Tax Policy and Customs Affairs, North-Caucasus Federal University, 355017 Stavropol, Russia
3 Director of the Russian Research Institute of Economics, Politics and Law in the Scientific and Technical Field (RIEPP), 127254 Moscow, Russia
4 Governor of Antakya, 31000 Antakya, Turkey
5 Department of State and Municipal Administration and Law, Russian Presidential Academy of National Economy and Public Administration, 357502 Pyatigorsk, Russia
* Correspondence: aib-2004@yandex.ru

Abstract: In the last decade, global discussions on the role of the Russian Federation in the energy supply system have continued to be relevant. Taking into account this context, the purpose of the article is to study the impact of the Russian oil and petroleum products market on sustainable development in the conditions of the "energy transition" declared in the country and to substantiate the mechanism of transition to a diversified energy model during the period of global geo-economic turbulence. The authors propose a methodological approach for conducting a comparative assessment of the level and dynamics of the development of the industry in the country and regions, based on the use of a set of objective indicators and the concept of taking into account the level and quality of life of the population. Using panel data on the country, federal districts and vertically integrated companies of Russia from 2005 to 2020 for empirical research, we found the determining influence of external and internal factors on sustainable development. The results revealed the problems regarding the current state of the Russian oil and petroleum products market. Summing up, it can be argued that the results presented in this article prove the need to solve industry problems and form innovative strategic directions of development in Russia in modern conditions of energy transformation.

Keywords: oil and petroleum products market; economic development; oil companies; engineering

Citation: Borodin, A.; Panaedova, G.; Ilyina, I.; Harputlu, M.; Kiseleva, N. Overview of the Russian Oil and Petroleum Products Market in Crisis Conditions: Economic Aspects, Technology and Problems. *Energies* **2023**, *16*, 1614. https://doi.org/10.3390/en16041614

Academic Editor: Behnam Zakeri

Received: 12 December 2022
Revised: 27 January 2023
Accepted: 1 February 2023
Published: 6 February 2023

1. Introduction

One of the important conditions for the sustainable development of the market economy and its integration into the world economy is a comprehensive and deep modernization of the domestic oil and petroleum products market, aimed at the successful functioning of the economy in the changed economic conditions. The oil market was the engine of modern industrial development throughout the twentieth century. However, the transition of society from an industrial type of development to a post-industrial (informational) type is accompanied by the transformation of market mechanisms, including segments of the oil and petroleum products market in the direction of effective economic growth and emerging new factor proportions of the reproductive process. In the 21st century, the oil market is characterized by high volatility, due to the restructuring of the regional structure of oil production, changes in the qualitative characteristics of the extracted oil, the structure and directions of international oil supplies, the transformation of the role of oil in the programs of energy strategies for the development of the world's largest economies against the background of increasing environmental requirements in society.

The relevance of the study of the economic aspects of the development of the national oil and petroleum products market of the Russian Federation is due to the need to study its current state in conditions of turbulence and ongoing socio-political processes that have a decisive impact on the development of the Russian economy. In Russia, the oil and gas sector plays a leading role in economic development, as its share in federal budget revenues has been stable over the past ten years and is in the range of 40–50%. It should also be noted that the nature and impact of the oil and petroleum products market on the economy of the country and regions has not been sufficiently studied, which determines the relevance of research in this field of scientific knowledge [1–7].

When conducting a practical study based on a descriptive-correlation approach, analytical grouping, parallel series, and graphical methods were used. In total, extensive statistical data were collected for the period 2005–2020. From the websites of the EIA (Energy Information Administration) [8], BP Statistical Review of World Energy [9], OPEC Annual Statistical Bulletin [10], The Bureau of Labor Statistics (BLS) [11], the Federal State Statistics Service of the Russian Federation (Rosstat) [12], the Analytical Center under the Government of the Russian Federation [13]. The selected sample also includes data on federal districts and the largest Russian vertically integrated oil companies.

2. Research Results

The analysis of the national oil and petroleum products market will be carried out in the context of comparison with the main oil-producing countries, since the Russian oil market is a single interconnected phenomenon functioning on the basis of changing rates of development of the world oil market, fluctuations in supply and demand, schemes for promoting goods on world markets.

One of the most important development problems that have a direct impact on the dynamics of oil production growth is the adequacy of the replenishment of the resource base. Proven reserves are oil reserves, which, based on the analysis of geological and engineering data, can be said with a high degree of confidence that they are commercially recoverable from a certain date, based on known reserves and in current economic conditions. Proven reserves is a term used by the world's most widespread global classification, which takes into account not only the probability of finding oil and gas in the field, but also the economic efficiency of extracting these reserves. Some statistics in this list are controversial and contradictory, as different sources (OPEC, CIA World Factbook [14,15], oil companies) give different figures, and there are different types of oil. In addition, the results of the calculation of proven reserves in certain countries may change, since previously economically inefficient deposits can be assessed as effective.

The study of oil reserves considered by us in comparison with the main oil-producing countries showed their extremely uneven distribution across the countries and regions of the continent. Table 1 presents data on oil reserves and production volumes in the main oil-producing countries of the world [16].

Based on the data in Table 1 compiled on the basis of the Statistical Review of World Energy for 2020 by British Petroleum, it can be emphasized that the proven world oil reserves in the world are estimated at 242.17 billion tons, of which OPEC countries accounted for 70.5% of world reserves. The countries with the largest proven oil reserves were: Venezuela, with 300,878 billion barr. or 19.9%; Saudi Arabia, with 297,700 billion barrels, or 16.7%; and Iran, with 211,600 billion. barr. or 11.9% of the global reserves. Additionally, among the 10 largest countries were Canada, Iraq, the United Arab Emirates, Kuwait, Russia, Libya and Nigeria. In the table, in addition to the number of oil reserves, the projected year of depletion of oil reserves in the current production and production of oil in the countries of the world is indicated. So, in Russia, according to forecasts, if no new deposits are discovered or current consumption does not decrease, oil reserves may be exhausted by 2039. In general, according to experts, the world's oil reserves are sufficient to meet the growing global demand for about 40 years.

Table 1. Ranking of the world's countries by proven oil reserves, 2020. (Oil reserves in the world by country list 2021. Proven reserves. [electronic resource]. Access mode: https://www.xn-----7kcbmkfaolw0acwp3ak9a0lg.xn--p1ai/zapasi-nefti-v-mire-po-stranam, accessed on 20 October 2022).

No.	Country	Reserves, Billion Barr.	Reserves, Billion Tons	Share, %	The Year of Exhaustion
1	Venezuela	300,878.0	41.0	16.9	2380
2	Saudi Arabia	297,700.0	40.6	16.7	2368
3	Iran	211,600.0	28.9	11.9	2163
4	Canada	169,709.0	23.1	9.5	2144
5	Iraq	142,503.0	19.4	8.0	2106
6	United Arab Emirates	105,800.0	14.4	5.9	2104
7	Kuwait	101,500.0	13.8	5.7	2113
8	Russia	80,000.0	10.9	4.5	2039
9	Libya	48,000.0	6.6	2.7	2149
10	Nigeria	37,062.0	5.1	2.1	2069

The Russian Federation ranks 8th in proven oil reserves with reserves of 80 billion. barrels, which is 4% of global reserves, and for the production conditions of the Russian Federation, the use of this volume is likely to be 22.5 years. At the same time, the availability of reserves in the main oil-producing countries is: 86 years in Saudi Arabia, and more than 100 years in Iran and Venezuela. Assessing the oil reserves of the Russian Federation by districts, it should be noted that the state reserves balance takes into account 2525 oil fields, of which about 2/3 of the explored reserves are concentrated in 150 large facilities, and most of the Russian fields are medium and small and their share in many regions reaches 20–50%. Empirical analysis of oil reserves in the context of federal districts revealed their shares in the domestic market [17]: Ural, 36%; Volga, 22.6%; Siberian, 16%; Far Eastern, 7.8%; Northwestern, 6.6%; Southern, 5.7%; North Caucasian, 5.3%. Another problem is the inefficient structure of the reserves being developed, and as a result, oil production at 50% of the country's fields is unprofitable, and the share of hard-to-recover and low-efficiency reserves in the total balance of proven reserves has reached 55%.

Next, let us look at the dynamics of oil production by the leading countries of the world—Table 2 [18].

Analysis of the dynamics of oil production by the leading countries of the world has shown that the dynamics of replenishment of oil and gas reserves in the world does not correspond to the dynamics of production.

The structure of the modern Russian oil and petroleum products market, formed at the beginning of the XXI century, is a set of markets: resource oil raw materials, extraction, transportation, petroleum products, production of goods and services, and consumption. At the same time, the oil market of recent years has been characterized by its serious transformation, manifested in a significant diversification of its institutional structure, in the functioning of traditional, innovative market segments: spot market and forward contracts, and a futures segment, which is accompanied by a change in the positions of the main participants and the emergence of new players. The scheme of the national oil and petroleum products market of the Russian Federation is shown in Figure 1.

Table 2. Dynamics of oil production by the leading countries of the world and the share in world production for 2015–2021, million tons (Compiled according to the "Statistical Review of World Energy 2022", British PetroleumBp Statistical Review of World Energy/2022 p. 16 [Electronic resource]. Access mode: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdf/energy-economics/statistical-review/bp-statsreview-2022-full-report.pdf, accessed on 20 October 2022.

	Country	2015	2016	2017	2018	2019	2020	2021	Share, %
1	USA	567.1	542.6	574.1	669.1	749.9	711.6	711.1	16.8
2	Russia	544.6	558.5	558.5	567.9	573.4	524.4	536.4	12.7
3	Saudi Arabia	568.0	586.7	559.3	576.8	556.6	519.6	515.0	12.2
4	Canada	216.1	218.8	236.6	257.7	263.5	252.0	267.1	6.3
5	Iraq	195.6	217.6	222.4	227.0	234.2	202.0	200.8	4.8
6	China	211.6	199.7	191.5	189.3	191.6	194.8	198.9	4.7
7	Iran	180.2	216.1	231.9	219.2	158.3	143.2	167.7	4.0
8	United Arab Emirates	176.1	182.4	176.2	176.7	180.5	166.6	164.4	3.9
9	Brazil	132.2	136.7	142.6	140.6	151.2	159.3	156.8	3.7
10	Kuwait	148.2	152.7	145.0	146.8	143.4	130.3	131.1	3.1
	World total	4364.9	4379.6	4386.4	4486.8	4477.6	4170.9	4221.4	100

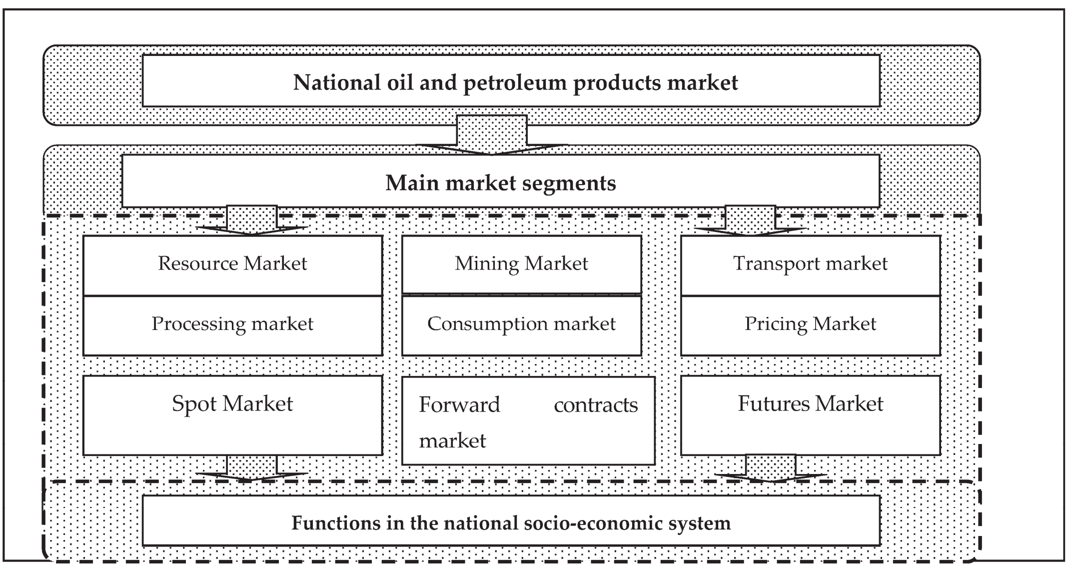


Figure 1. Structure of the national oil and petroleum products market of the Russian Federation.

The modern Russia, steadily developing the oil and petroleum products market, significantly affects the pace of economic development, and trends show that the main macroeconomic parameters of the country are characterized by positive dynamics: the growth of the most important economic indicators of development, a decrease in inflation, population growth, and the preservation of high oil prices. However, the growth of the main economic parameters is not sustainable over the long term, due to their provision, to a large extent, and due to the favorable conjuncture of the world oil markets.

The stability of the extractive industries largely depends on the volume of preparation and quality of the mineral resource base (MSB), the parameters of the process of reproduction of reserves. In the period from 1991 to 2004, there was a steady decline in the rate of preparation of the raw material base of oil; in 2004, the increase in reserves amounted to only 218 million tons, or 47% of the current level of oil production in the country. However, with the rise in world oil prices and the need to replenish the raw material base, the growth rate of reserves began to grow, and in 2008, for the first time in 15 years, the volume of preparation of new reserves corresponded to the level of current oil production (500 million tons).

In the period after 2004, up to 2010, there was a steady excess of the increase in oil reserves over production. The increase in oil reserves as a result of geological exploration carried out at the expense of the federal budget and subsoil users in 2020, according to the Ministry of Nature of Russia, amounted to 614 million tons, an increase of 29 million tons or 5.0% compared to the previous year. In general, the dynamics of oil production, its reserves, as well as the multiplicity of replenishment of oil reserves in the Russian Federation for 2004–2010 is presented in Figure 2 [19].

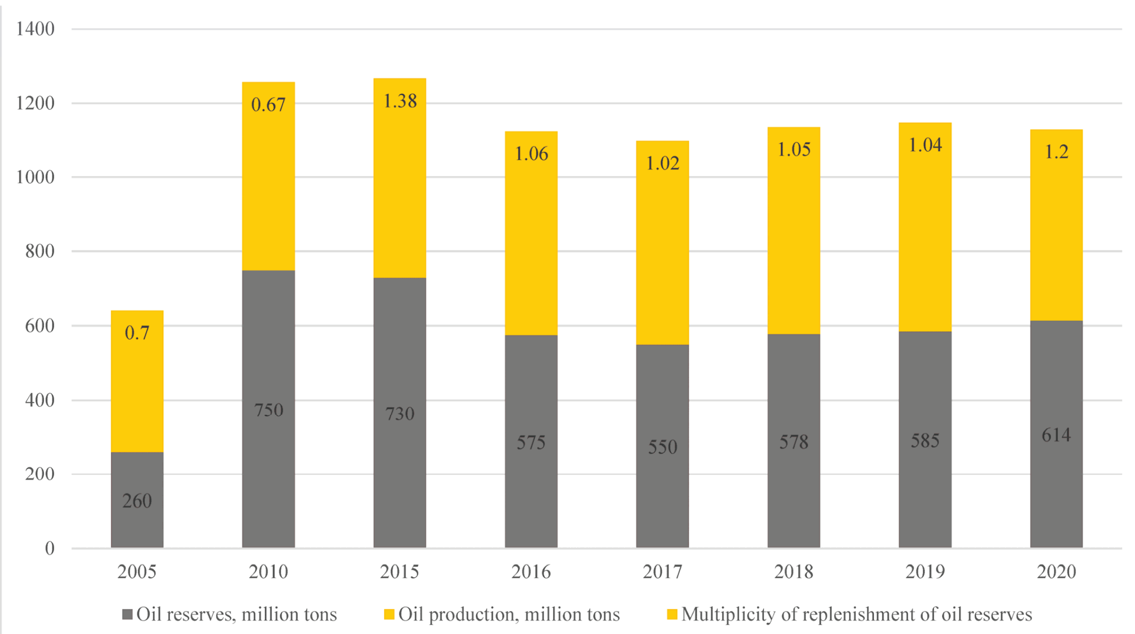


Figure 2. Dynamics of oil production and availability of oil reserves in the Russian Federation for 2005–2020. Compiled by the authors according to: Regions of Russia. Socio-economic indicators. 2021. 612–613. Region_Pokaz_2021.pdf (accessed on 5 October 2022).

It follows from the data in Figure 2 that the reserves of crude oil in Russia for the period from 2010 to 2020 decreased by almost a third. Thus, oil reserves in the country in 2010 amounted to 28.2 billion tons, and in 2020, this value was 19.1 billion tons. At the same time, compared to 2019, 2020 stocks increased by 2.1%. The minimum increase in reserves over the past decade was noted in 2017, when it compensated for a decrease of only 3%. In 2019, the excess of growth over production was 14%. In 2020, the excess increase in oil reserves amounted to almost 70%, due to a sharp decline in production and a significant increase due to exploration.

In the production of liquid hydrocarbons in Russia over the past decade, positive dynamics has been observed and an increase of 9.3% has been noted. Oil production in Russia peaked in 2019 at 561.0 million tons. During the analyzed period, the exception was 2020, which revealed a decrease in oil production. According to the results of 2020, the volume of national crude oil production decreased by 48.4 million tons (−8.6%) compared to 2019 and amounted in absolute terms to 513.1 million tons at least over the past 10 years.

Against the background of the spread of coronavirus, restrictive measures were introduced in many countries of the world, which led to a reduction in business activity, a decrease in consumer demand and prices for hydrocarbons. The decrease is also due to Russia's fulfillment of its obligations to curb national oil production at the level of quotas established under the OPEC+ agreement, which eliminated the entire ten-year growth.

Another important factor in the efficiency of the industry is the territorial location of production. The grouping of the federal districts of the Russian Federation by the volume of production of liquid hydrocarbons in Russia by federal districts is presented in Figure 3.

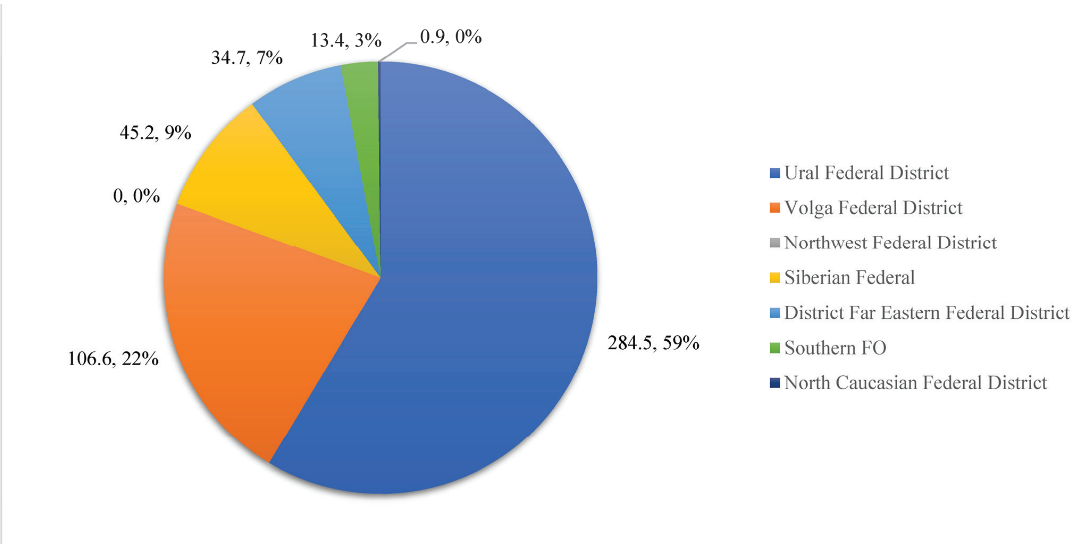


Figure 3. Grouping of federal districts of the Russian Federation by oil production volume, 2020. Compiled by the authors according to: Regions of Russia. Socio-economic indicators. 2021. 612–613. [Electronic resource]. Access mode: https://rosstat.gov.ru/storage/mediabank/RegionPokaz_2021.pdf; Oil production by the subjects of the Russian Federation (thousand tons) Electronic resource] ((date of application 7 October 2021). Access mode: https://www.gks.ru/bgd/regl/b08_13/IssWWW.exe/Stg/d3/13-27.htm (date of application 7 October 2021).

Based on the data in Figure 3, it is possible to draw conclusions about the territorial localization of oil production in the federal districts of the Russian Federation, which showed that in 2020 they excelled in industrial production: Ural (60.7%) and Volga Federal districts (21.2%). In Group 2, the Siberian (5.8%), Far Eastern (3.6%), Northwestern (6.3%) federal districts. The lowest level of oil production is in two federal districts: the Southern (1.8%) and the North Caucasus (0.4%).

Figure 4 shows the dynamics of oil production by federal districts of the Russian Federation for 2005–2020.

The presented statistical data in Figure 4 allow us to conclude that the leader in 2020 in oil production is the Ural Federal District, in which about 67% of Russia's oil reserves are concentrated and 284.5 million tons of oil were produced. In the Khanty-Mansiysk (KhMAO) and Yamalo-Nenets Autonomous Okrugs, which are part of the district, oil fields are exploited, which belong to the West Siberian oil and gas province. The Volga Federal District was in second place in terms of oil production, where in 2020, oil production amounted to 106.6 million tons. The largest oil-producing entities of the district are the Republic of Tatarstan and the Republic of Bashkortostan, within which the main oil production regions are located, which are part of the Volga-Ural oil and gas province. In third place was the Siberian Federal District, where there is a tendency to increase oil production due to the discovery of new fields in Eastern Siberia. Thus, oil production in the district increased almost 4 times: from 14.3 million tons, in 2005, to 45.2 million tons, in 2020. Next on the list are the Far Eastern District, with an oil production volume of 34.7 million tons, and the Northwestern Federal District, where the volume of oil production in the region amounted to 27.6 million tons. The Southern and North Caucasian Federal Districts complete the rating, with production volumes of 13 and 0.9 million tons, respectively.

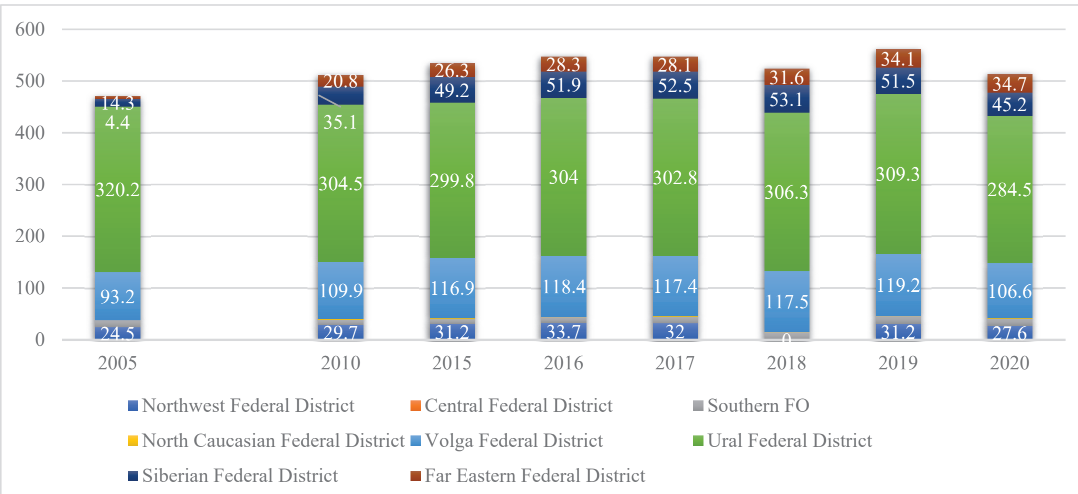


Figure 4. Dynamics of oil production by federal districts of the Russian Federation for 2005–2020, million tons. Compiled by the authors according to: Regions of Russia. Socio-economic indicators. 2021. 612–613. [Electronic resource]. Access mode: https://rosstat.gov.ru/storage/mediabank/RegionPokaz_2021.pdf; Oil production by the subjects of the Russian Federation (thousand tons) Electronic resource]. Access mode: https://www.gks.ru/bgd/regl/b08_13/IssWWW.exe/Stg/d3/13-27.htm (accessed on 5 October 2021).

The presented statistical data in Figure 4 allow us to conclude that the leader in 2020 in oil production is the Ural Federal District, in which about 67% of Russia's oil reserves are concentrated, and 284.5 million tons of oil were produced. In the Khanty-Mansiysk (KhMAO) and Yamalo-Nenets Autonomous Okrugs, which are part of the district, oil fields are exploited, which belong to the West Siberian oil and gas province. The Volga Federal District was in second place in terms of oil production, where in 2020, oil production amounted to 106.6 million tons. The largest oil-producing entities of the district are the Republic of Tatarstan and the Republic of Bashkortostan, within which the main oil production regions are located, which are part of the Volga-Ural oil and gas province. In third place was the Siberian Federal District, where there is a tendency to increase oil production due to the discovery of new fields in Eastern Siberia. Thus, oil production in the district increased almost 4 times: from 14.3 million tons, in 2005, to 45.2 million tons, in 2020. Next on the list are the Far Eastern District, with an oil production volume of 34.7 million tons and the Northwestern Federal District, where the volume of oil production in the region amounted to 27.6 million tons. The Southern and North Caucasian Federal Districts complete the rating, with production volumes of 13 and 0.9 million tons, respectively.

Oil companies are currently of decisive importance in the Russian oil industry. In 2020, 285 organizations with licenses for the right to use the subsoil carried out oil production on the territory of the Russian Federation, including: 98 organizations included in the structure of 11 vertically integrated companies; 184 independent mining companies; and 3 companies operating under the terms of production sharing agreements. The main volume of national oil production formed by the five largest vertically integrated companies is large joint-stock companies controlled by the state (Rosneft, Gazprom Neft) and private shareholders (LUKOIL, Surgutneftegaz, etc.). In fact, the share of the free oil market in the Russian Federation is about 15–20%, which indicates its oligopolistic nature.

Figure 5 shows the dynamics of oil production by the largest Russian vertically integrated oil companies for 2005–2020 [20–25].

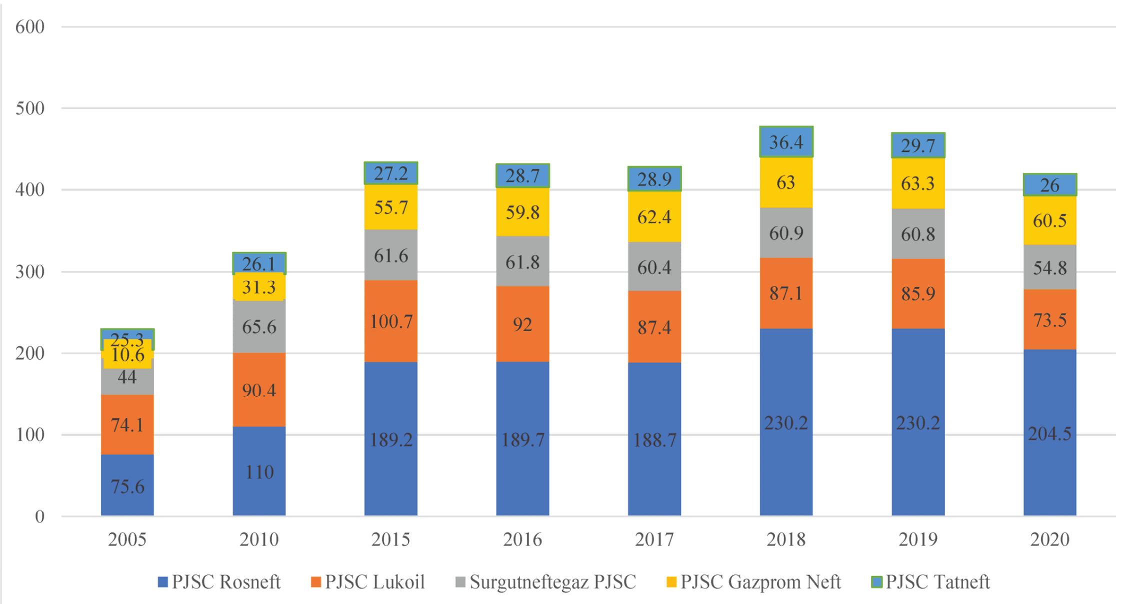


Figure 5. Dynamics of oil production by Russian vertically integrated companies for 2005–2020, million tons. Compiled by the authors according to: The annual report of PJSC NK Rosneft. 2020. 22. [Electronic resource]. Access mode: https://www.rosneft.ru/upload/site1/document_file/a_report_2020.pdf; Annual Report of OAO Lukoil. [electronic resource]. Access mode: https://lukoil.ru/FileSystem/9/553791.pdf; Annual Report of Gazprom Neft.2020, [Electronic resource]. Access mode: https://www.gazprom.ru/f/posts/57/982072/gazprom-annual-report-2020-ru.pdf; Annual report of PJSC Tatneft. [electronic resource]. Access mode: https://www.tatneft.ru/uploads/publications/61725c8bbfaca243850193.pdf (accessed on 9 October 2021).

An analysis of the dynamics of oil production by Russian vertically integrated companies in Figure 5 showed that in 2020, there was a decrease in oil production, as the OPEC+ countries, including Russia, reached an agreement to reduce oil production by 2 million barrels per day, which was the largest reduction since the beginning of the Aids-2019 pandemic. Thus, PJSC Rosneft accounted for the largest amount of oil production, the volume of which amounted to 230.2 million tons, in 2019, and 204.5 million tons, in 2020. In second place was PJSC Lukoil, with 85.9 and 73.5 million tons, respectively. Next is PJSC Surgutneftegaz, whose operating data for 2020 showed that oil production amounted to 54.7 thousand tons, which is 10% lower than in 2019. Revenue also decreased synchronously by 31% in 2020, but profit increased almost 7 times compared to the previous year and amounted to 742 billion rubles.

During the analyzed period, there is a tendency in the structure of oil production to reduce the share of vertically integrated companies and strengthen the positions of independent producers. Thus, in the structure of oil and condensate production, 78.5% is accounted for by vertically integrated companies, 17.9% of hydrocarbons are produced by independent companies, and 3.6% of production is accounted for by companies operating under production sharing agreements. The average growth rate of oil production by independent companies over the past 10 years was 7.8%, and the crisis of 2020, to a lesser extent, affected the level of their production, in which production decreased by 3%, while vertically integrated companies were forced to reduce production by 10%.

Another important segment of the oil market is the refining sector. According to the Ministry of Energy of the Russian Federation, in 2020, 32 large oil refineries, 250 mini-refineries, 6 specialized plants for the production of specialized oils and lubricants operated in the country, with their placement being closer to the places of consumption [26]. The volume of refined petroleum products was 6.9 million barrels daily, with a volume of 7% of the world market. The leader of the international oil refining market was the USA, with a 20% share, 130 refineries and a production volume of 18.9 million barrels per day. The second place was occupied by China, with a market share of 17% and an oil refining volume of 13.5 million barrels. per day.

In the Russian Federation, the largest refining capacities belong to the refineries of Rosneft, Lukoil, Gazprom Neft and Surgutneftegaz. The main volume of primary oil refining is accounted for by PJSC Rosneft, which operates 9 refineries in the country (Komsomolsk (Komsomolsk-on-Amur city, Khabarovsk Territory, Tuapse (Tuapse city, Krasnodvrsky Territory), Kuibyshevsky (Samara city, Samara region), Novokuibyshevsky city of Novokuibyshevsk, Samara region), Syzransky (Samara city, Samara region), Achinsky (Bolsheuluysky district of Krasnoyarsk Krai), Saratov Refinery (Saratov city, Saratov region), Ryazan Refinery (Ryazan city, Ryazan region) and Angarsk Petrochemical Company (Angarsk city, Irkutsk region)). In general, the plants of PJSC Rosneft processed 77.5 million tons of oil in 2020, which is 3.2 million tons or 4.1% less compared to 2019. The refineries of PJSC Lukoil processed 45.6 million tons of oil in 2020, which is 0.8 million tons less than in 2019. There are fewer indicators of Rosneft plants. At the same time, it is necessary to take into account the average production per enterprise, which is 12 million tons of oil per year. In this aspect, Surgutneftegaz Joint-stock Company is the leader, since with only one enterprise, its capacity amounted to 22 million tons.

The regional structure of the oil refining sector evidently represents the territorial location of oil refineries in the federal districts of the Russian Federation. The largest number of enterprises are located in the Volga Federal District, with 14 large factories and 16 mini-factories, and in the Central District, with 5 large factories and 16 mini-factories. The grouping of the federal districts of the Russian Federation by volume of oil refining, for 2020, is presented in Figure 6 [27].

The analysis of Figure 6 shows that in terms of oil products production for 2020, the leaders are: Volga, 116.4 million tons (42%), and Central, 41.8 million tons (14.6%), federal districts. In Group 2, the leaders are: the Siberian, 38.1 million tons (14.2%), the Southern, 27.3 million tons (11.0%), and the North-Western District, 26 million tons (9.9%), districts. In the group of outsiders, the leaders are: the Far Eastern, 13 million tons (4.6%), and the Ural 8 million tons (2.9%), districts. In the North Caucasus District, the production of petroleum products has been discontinued.

In the regional industry structure, the Volga Federal District occupies the first place in terms of primary oil refining, which accounts for 36.4% of primary oil refining in Russia. The district has large oil refineries owned by Lukoil (Nizhegorodnefteorgsintez and Lukoil-Permnefteorgsintez), with a capacity of 17 million tons and 13.1 million tons, respectively. Significant capacities in the district are concentrated in the Bashkir group of enterprises and in the factories of the Samara region (Novokuibyshevsky, Kuibyshevsky and Syzransky). The region also has the most technologically advanced plants with a processing depth of about 99% (“Mari”, “TANECO”).

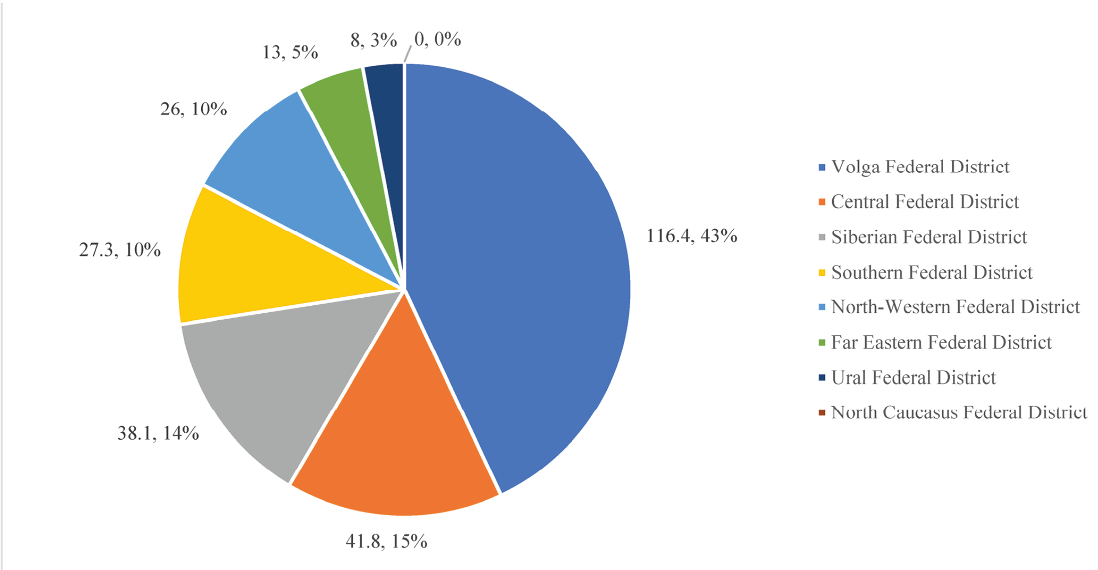


Figure 6. Grouping of the federal districts of the Russian Federation by volume of production of petroleum products, 2020.

The second region in terms of primary oil refining is the Central District, with a primary refining volume of 14.6%, in which three large oil refineries are located with a total refining volume of 40.9 million tons in 2020, which is 0.8 million tons less than the previous year, due to the overhaul of technological installations. The third region is the Siberian Federal District, with a market share of 14.2% and four large oil refineries, in which the volume of primary oil refining in 2020 amounted to 39.2 million tons, but decreased by 0.9 million tons compared to 2019.

The fourth region is the Southern Federal District, geographically closest to the export markets of petroleum products through ports on the Black and Caspian Seas. Eight large oil refineries are concentrated in the Southern District, and the largest of them is the Volgograd plant of LUKOIL with an installed capacity of 15.7 million tons of raw materials per year. In 2020, the volume of oil refining in the district amounted to 27.3 million tons, or 11.0% of the all-Russian indicator. In the North-Western District, 9.9% of Russian oil is processed, in which three large plants with a refining volume of 26.0 million tons operate. One of the largest Russian oil refineries, Kirishinefteorgsintez, is located in the district, with a volume of primary processing of raw materials of more than 18 million tons per year.

Our analysis has shown that the majority of Russian oil refineries are characterized by: the use of imperfect technologies, a low proportion of deepening processes; a fairly significant degree of depreciation of fixed assets; an insufficient level of conversion of crude oil into more valuable refined products. In addition, oil refining capacities are unevenly distributed throughout the country, which leads to the creation of prerequisites for the formation of regions that are excessive in production and regions that are "deficient" in the provision of petroleum products and an increase in the load on transport for its transportation. Almost all refineries are located in the interior of the country, away from the border and sea export terminals, which reduces the efficiency of exporting petroleum products by increasing transportation costs.

An important characteristic of the oil market of the Russian Federation is the dynamics of the utilization of refining capacities, which in 2020, amounted to 270 million tons, and the degree of utilization of primary oil refining units decreased to the lowest level since 2007, amounting to 82.3%. The overall reduction in the volume of primary processing of crude oil at Russian refineries was accompanied by a decrease in the production of all major types of petroleum products, namely, motor gasoline, diesel fuel, heating oil and aviation kerosene, which was largely due to the different dynamics of the reduction in external and internal demand for these fuels from consumers in the conditions of COVID-19. In addition, the dynamics of primary oil refining was influenced by legislative decisions in the field of taxation, which reduce the attractiveness of exports of dark petroleum products, as well as the process of state regulation of the domestic market of petroleum products.

An important value representing the technological efficiency of the industry is the depth of oil refining, which means the total yield as a percentage of all petroleum products, except for the non-converted residue used as boiler fuel. With shallow oil refining, the profit is 13.7 billion rubles, and with a deep chemical scheme, 41.9 billion rubles, i.e., the growth is more than 300%. In 2010, the refining depth of Russian refineries was 70.9%, in 2015, the indicator reached 74.2%, in 2017, the result was 81.3%, and in 2019, it was 83.1%. In 2020, the average depth of oil refining in the country increased by 1.3 percentage points to 84.4%. Despite the reconstruction and modernization of many enterprises and the improvement of the oil refining complex, the products were still more focused on domestic consumption, due to the low quality of oil refining. For comparison, in the USA, the average depth of oil refining is 90–95%, and at the most modern American refineries—up to 98%; in OPEC member countries, average depth is 85%, and in European countries, 85–90%. That is, we state that Russia is noticeably lagging behind in this indicator.

In 2020, Russian oil companies increased the depth of oil refining compared to the scale of 1.2–2.5%, and accordingly, the output of light oil products increased. Thus, the refineries of PJSC Lukoil had the greatest refining depth, 88.8%, which allowed them to increase the share of light products output from 69.3%, in 2018, to 73%, in 2020, respectively, reducing the share of fuel oil produced from 22%, in 2014, to 11%, in 2020. The greatest depths of oil refining were recorded in NOVATEK-Ust-Luga (99.9%), Antipinsky (99.5%), Novoshakhtinsky (99.1%), and Omsk (98.9%) refineries. However, a number of plants retain low refining depth indicators: Achinsk (65.6%), Tuapse (65.4%), Komsomolsk Refinery (63.1%). PJSC Rosneft, with the largest number of refineries, stood out for a relatively low level of refining depth of 74.4%. The analysis made it possible to note a significant differentiation of oil refineries by processing depth and to determine the average value for the federal districts, which in 2020, amounted to 79% in the North-Western District, 74% in the Siberian, 72% in the Volga, 70% in the Central, 62% in the South, 61% in the Far East, 55% in the Urals.

Thus, the conducted research showed that the state policy of Russia in the oil refining industry over the past few years has been aimed at increasing the level of oil refining depth and increasing the yield of light petroleum products. The main trends in the Russian oil refining industry in 2020 were the modernization of refineries, the renewal of equipment and technological capacities, the growth of production of high-octane gasoline that meets Euro-5 standards and higher, and the organization of "oil-free" production. As a result, the processing depth in comparison with 2014 increased by 15% in 2020 and amounted to 83.1%. Against the background of a reduction in the production of fuel oil by 42%, the share of the output of motor gasoline and diesel fuel increased, and a positive trend was observed in terms of the dynamics of production indicators. At the same time, the analysis of the oil refining sector market revealed a feature of the territorial structure of the refining sector, which is expressed in a higher level of dispersion across the country than the structure of its reserves and production.

Oil is the most important export commodity of the Russian Federation and provides more than 20% of cash receipts from foreign trade. According to the Federal Customs Service, in 2020, oil and petroleum products in monetary terms provided 35% of revenues to the budget of the Russian Federation from foreign trade. The dynamics of exports of oil and petroleum products from Russia for the period 2005–2020 is presented in Figure 7.

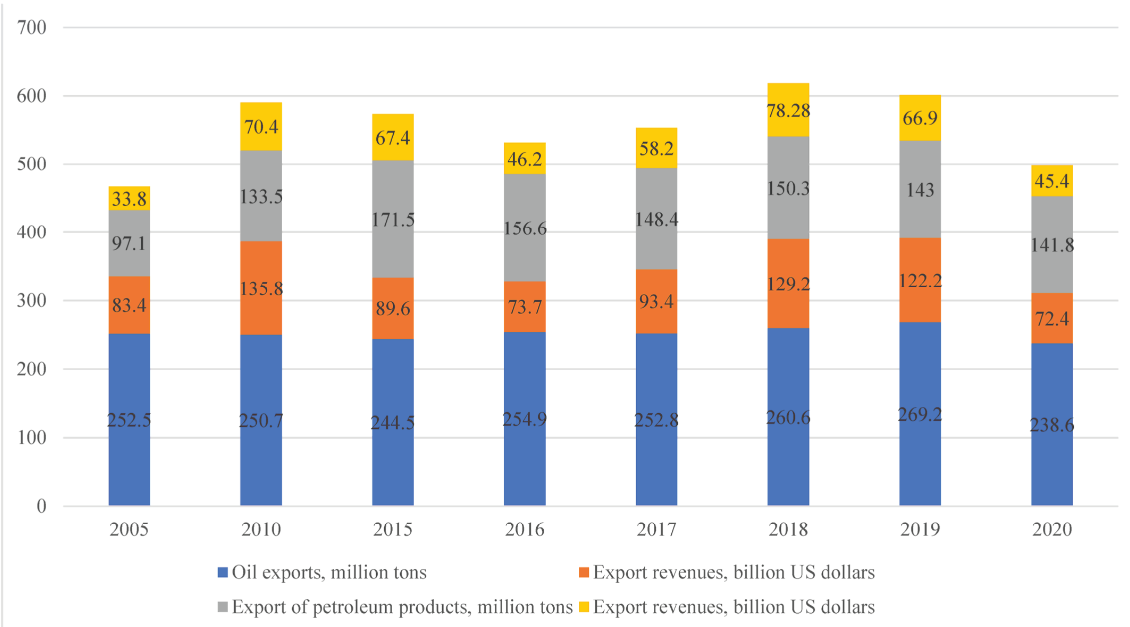


Figure 7. Dynamics of oil and petroleum products exports of the Russian Federation for 2005–2020. Compiled by the authors according to: The Central Bank of Russia [Electronic resource]. Access mode: https://cbr.ru/statistics/macro_itm/svs/export_energy/; http://global-finances.ru/eksport-nefti-iz-rossii-po-godam/ (accessed on 17 November 2021).

A study of the dynamics of the volume of exports of oil and petroleum products for 2005–2020 in Russia showed that on average, about 250 million tons were exported per year. In the period 2010–2014, there was a decrease in the volume of oil exports, and for the period 2015–2019, there was a steady increase in exports, and a record volume of 269.2 million tons was achieved in 2019. The growth compared to 2018 was 8.5 million tons or 3.3% [28]. However, in 2020, due to the complex of problems encountered, there was a decrease in exports by 11.3% to 238.6 million tons per year. Revenues from the export of oil and petroleum products for 2020 amounted to USD 141.7 billion, a decrease of 36.1% compared to the same period in 2019. Exports are mainly: crude oil and crude oil products to China (33%), the Netherlands (13%), and Germany (9%); and petroleum products to the Netherlands (15%), the USA (9%), and Turkey (5%). The analysis of the Russian oil market over the past ten years has revealed that as a result of rising world prices and an increase in oil supplies, the export revenue of Russian oil companies from oil sales has increased by more than 5 times (from USD 25 billion up to USD 135 billion), and revenue from oil products increased 7 times (from USD 10 billion to USD 70 billion).

One of the important indicators affecting GDP growth and the standard of living of the population is the volume of oil consumption, since the countries and regions that consume oil receive the maximum profit. There is a certain interdependence between the average per capita volume of oil consumption and the size of the gross domestic product (GDP) per capita: the higher the consumption, the higher the level of GDP per capita. Table 3 shows the volumes of oil consumption in the developed countries of the world.

Table 3. Oil consumption in developed countries in 2020.

	Country	Consumption Volume, Barrels per Day	Market Share, %		Country	Consumption Volume, Barrels per Day	Market Share, %
1.	USA	19,780,000	19.2	11.	Germany	2,281,000	2.28
2.	EU	15,000,000	15.0	12.	Iran	2,018,000	2.01
3.	China	14,225,000	14.2	13.	Mexico	1,733,000	1.7
4.	India	5,271,000	5.3	14.	Indonesia	1,628,000	1.6
5.	Japan	3,812,000	3.8	15.	France	1,530,000	1.5
6.	Saudi Arabia	3,788,000	3.7	16.	Singapore	1,339,000	1.3
7.	Russia	3,317,000	3.3	17.	Italy	1,262,000	1.2
8.	South Korea	2,760,000	2.7	18.	Spain	1,226,000	1.2
9.	Canada	2,403,000	2.4	19.	Great Britain	1,118,000	1.1
10.	Brazil	2,398,000	2.39	20.	Australia	1,046,000	1.0

Compiled by the authors according to: Organization of Petroleum Exporting Countries (OPEC). [electronic resource]. Access mode: https://www.opec.org/opec_web/en/index.htm (accessed on 13 October 2021).

The analysis of Table 3 shows that 78% of oil and petroleum products from the total volume of world consumption are consumed in the 20 leading countries of the world.

The largest consumer in the world is the USA, with a market share of 19.2%; the EU countries are in second place—15.0%; China is in third and fourth place—14.2%; and India has a share of 5.3%. It should be noted that in Russia, over the past decades, there has been a decrease in the consumption of oil and petroleum products from 223 million tons in 1995 to 146.9 million tons in 2020, and the country ranks 7th in terms of consumption. At the same time, the share of consumption per capita of the world volume is only 3.3% [13]. In the leading countries, in terms of oil consumption in 2020, the volume of consumption in the United States was 19.8 million barrels per day; in China—14.2 million barrels per day; in India—5.3 million barrels per day. Total global oil consumption, according to OPEC data for 2020, amounted to 90.8 million barrels per day, and according to experts' forecasts, this indicator will continue to grow to 96.9 million barrels per day.

Let us further consider the volume of consumption of one of the main petroleum products—motor gasoline in the Russian Federation—grouped by us by federal districts of the Russian Federation—Figure 8.

In the whole country, the total volume of gasoline consumption in 2020 amounted to 35.2 million tons. The leaders in the volume of consumption according to federal district were: Central—9.11 million tons (29.2%); Volga—5.98 million tons (19.2%); and Siberian—4.33 million tons (13.9%). This is followed by: the Southern district—3.24 million tons; Northwestern—3.2 million tons; Ural—2.8 million tons; North Caucasian—1.57 million tons; and Far Eastern—0.97 million tons; which complete the rating [29].

The revealed imbalances in gasoline consumption are due to several factors: the level of stability of the region, the degree of development of the economy and infrastructure, the standard of living of the population, geographical features, and the number of cars in the district. To a significant extent, the volume of consumption of petroleum products is directly dependent on oil prices. It should be noted that the current structure of the Russian oil market is due to the imperfection of domestic pricing, its dependence on the global pricing system for oil and petroleum products, as evidenced by the lack of a unified methodology for determining them, and the presence of many oil prices in the country. The competitive oil market, which should be the basis of pricing in Russia, is oligopolistic and controlled by several vertically integrated companies, which practically deprives this segment of a competitive environment.

A comparison of Russian domestic prices for petroleum products with export prices proves the existence of a clear relationship between the Russian and European markets, which causes an increase in domestic prices in the Russian Federation in proportion to their growth in the world markets. The lowest gasoline prices were formed in Venezuela, Kuwait, Iran, the UAE, and Saudi Arabia, and mainly high gasoline prices are noted in the European Union. Gasoline prices in countries may vary depending on the availability of raw materials, refineries, types of taxes, excise taxes and other costs. The dynamics of Russian prices for brands of motor gasoline and diesel fuel is shown in Figure 9.

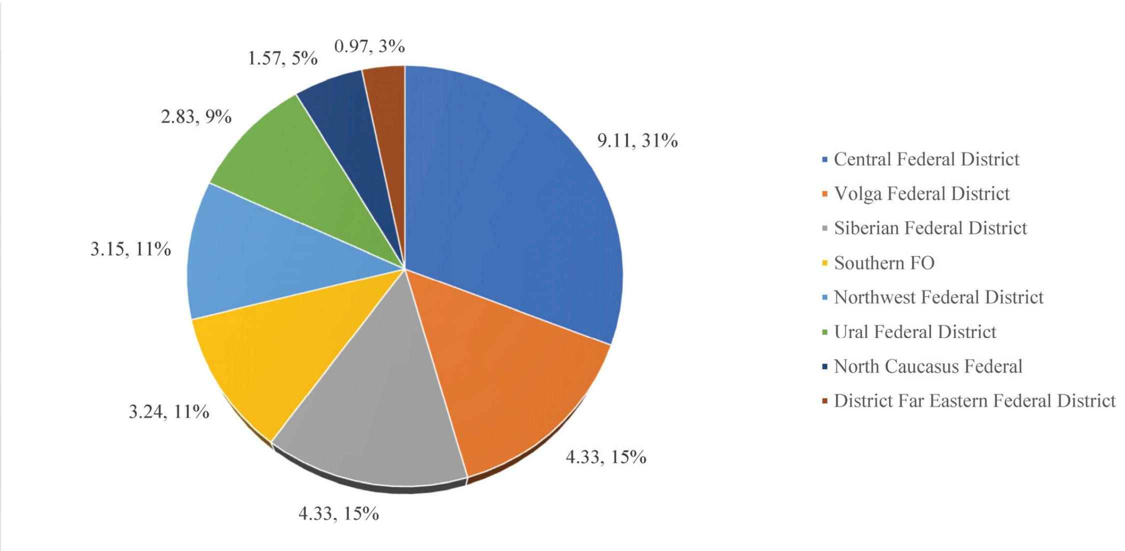


Figure 8. Grouping of federal districts of the Russian Federation by volume of gasoline consumption, 2020.

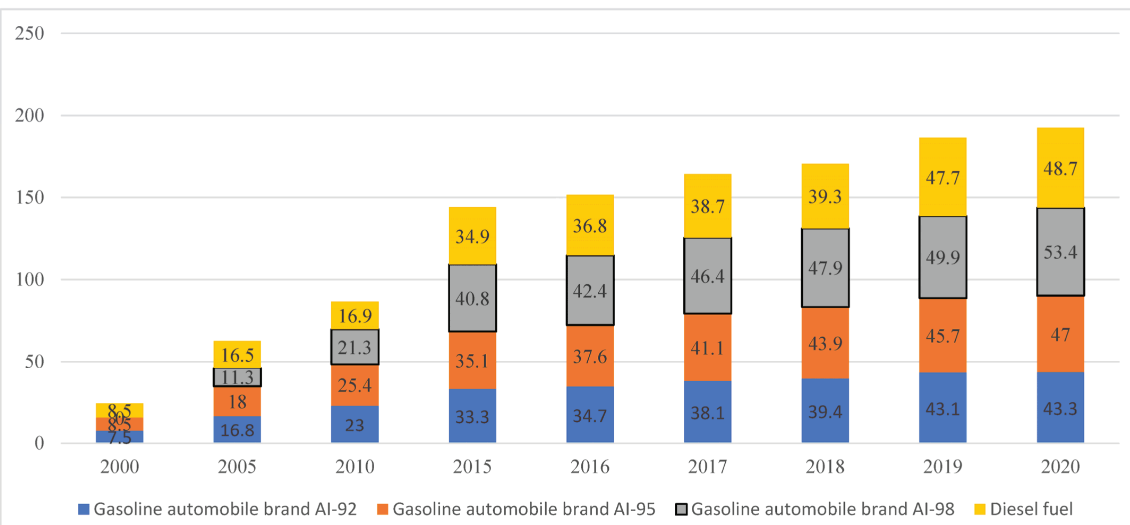


Figure 9. Dynamics of Russian prices for motor gasoline and diesel fuel for the period 2000–2020, rubles/liter. Compiled by the authors according to: https://www.gks.ru/bgd/free/B04_03/IssWWW.exe/Stg/d02/15.htm; Average consumer prices in the Russian Federation in 1992–2007. [electronic resource]. Access mode: https://www.gks.ru/free_doc/new_site/prices/potr/tab5-cen.htm (accessed on 10 October 2021).

The statistics given in Figure 9 allow us to conclude that over the past two decades, the increase in prices for automobile gasoline of various brands averaged 449% or 4.49 times for the AI-92 brand, and 441% or 4.41 times for the AI–95 brand. The average producer prices for automobile gasoline and diesel fuel in 2020 were: automobile gasoline—45.9 rubles; and diesel fuel—48.7 rubles.

To identify the factors of price growth, we will consider the pricing structure of motor gasoline in Russia based on the average cost of 1 L of motor gasoline in the Russian Federation and conduct a comparative analysis with the structure of the cost of gasoline in the United States—Table 4.

Table 4. The structure of the average cost of 1 L of gasoline in Russia and the USA, 2020.

Indicators	Russian Federation	USA
The cost of raw materials, %	12	54
Taxes and excise taxes, %	69	18
Production costs, %	6	5
Costs of delivery and sale of goods, %	8	17
Profit, %	5	6

Compiled by the authors according to: Rosstat, the Oil and Gas Information and Analytical Center (IACNG), EIA (Energy Information Administration), the US Federal Bureau of Labor Statistics (The Bureau of Labor Statistics, BLS). (accessed on 10 October 2021).

The analysis of Table 4 showed that: in Russia, in the final price of gasoline, the cost of raw materials is 12%, whereas in the USA, this cost is 54%; taxes and excise taxes in the Russian Federation (VAT, mineral extraction tax, income tax) reach almost 70%, whereas in the USA, the cost is 18%; and profit in Russia is 5%, where in the USA it is 6%.

3. Discussion and Conclusions

In the process of globalization of the oil and petroleum products market and its relationship with the economic development of the country, we have identified the problems of the current state of the Russian and regional markets and justified the determining influence of external and internal factors on its development.

1. The current state of the Russian oil market is characterized by the presence of problems that create real prerequisites for reducing the level of oil production and export volumes in the future. The probable instability is caused by a reduction in the growth of industrial oil reserves and the absence of a significant reserve of large deposits, due to a decrease in the pace of exploration in recent years.
2. Despite the significant increase in production observed in recent years, the issue of long-term sustainability of the achieved production volumes remains relevant. About 50% of oil production in Russia falls on fields put into operation before 2000, a level of production which is characterized by high rates of natural decline in production: 8–10% annually on the rolling stock of wells. Drilling of new wells makes it possible to slow down the reduction in production, but it is not possible to reverse the trend, as the water content of the fields increases. So, for the period from 2008–2020, oil production in Western Siberia decreased by 10%. To compensate for the natural decline in production at mature fields, it is necessary to actively introduce new reserves into development. Currently, in the structure of residual oil reserves, more than 2/3 are difficult to develop and require the use of technological innovations, which is associated with significant costs.
3. Oil production is characterized by an undeveloped material and technical base (only 14% of the oil equipment operated in Russia corresponds to the world level). The productivity of existing oil wells and the quality of the extracted oil continue to decrease, as well as the quality characteristics of the raw material base of the industry, which is manifested in the high depletion of exploited oil reserves. This makes it necessary to involve in the turnover of difficult-to-develop deposits that require significantly higher costs and the use of more complex technologies, which the industry currently does not have in sufficient volume.

4. Economic factors are functioning inefficiently; in particular, there is an underfunding of the industry due to the high level of taxation and insufficient motivation of oil companies to increase capital investments. Due to the need to increase the level of oil production to 530–600 million tons per year (in accordance with the "Energy Strategy of the Russian Federation until 2030"), the volume of oil production financing should be from USD 22 to USD 25 billion per year, while the volume of real capital investments is, on average, USD 7.8 billion per year. With such a volume of investment, it is impossible to achieve an innovative level of development of the industry that meets international standards.
5. In general, the domestic market is characterized by a high degree of consolidation and the virtually oligopolistic nature of the sphere of production (extraction and processing), low processing depth, weak competition in small wholesale and retail sales. The state has a dominant role in the hydrocarbon market due to its control of the largest oil producer PJSC Rosneft (40% share in production), the largest operator of the oil pipeline system PJSC Transneft, as well as control over tariffs and tax policy.
6. Problems are increasing due to insufficient state regulation of the oil market and an increase in the number of mothballed unprofitable wells. In the conditions of favorable conditions of world oil prices, Russian oil exporters do not receive incentives for technical and technological re-equipment, which leads to a lag in the industry.
7. Sectoral sanctions were imposed on Russian companies by the United States and the European Union countries, suggesting restrictions on cooperation between Russia and Western countries in the energy sector. In particular, sectoral sanctions have actually imposed a ban on the supply of equipment for production on the deep-water shelf, the implementation of projects on the Arctic shelf and the development of shale oil reserves. After the sanctions were imposed, almost all joint projects on the development of unconventional reserves and the development of offshore reserves in Russia were suspended.

However, it should be noted that the restrictions imposed are mainly aimed at reducing the long-term potential of Russian oil production and are not able to significantly affect the level of production in the coming years. In the longer term, the impact of sectoral sanctions on oil production in the country may be tangible. The success of the Russian oil industry will depend on the ability to create Russian technologies for offshore operations and the development of unconventional reserves. The increase in production in the last decade was associated with the start of production at new large projects, the implementation of which compensated for the natural decline in production at mature fields. According to our estimates, oil production at new fields will stabilize in the coming years.

The methodology of comprehensive improvement of the institutional structure of the Russian oil and petroleum products market, in our opinion, should be based on the following approaches:

- Development of new oil fields;
- An increase in the export share of products of the petrochemical and oil refining industries with high added value, rather than an increase in the volume of sales of raw materials of the Russian oil market;
- Conducting an active geographical diversification of the sales markets of Russian oil and petroleum products, and development of the countries of the Asian region and the USA;
- Improvement of the institutional structure of the Russian oil and petroleum products market;
- Improvement of the legislative framework, rental policy of the state, tax regime;
- Increasing the investment attractiveness of the domestic market of oil and petroleum products.

Currently, the geopolitical factor has become relevant and the functioning of the oil market is influenced by political factors in the conditions of the actual absence of a market mechanism. This is a further direction for ongoing research in the energy sector.

Author Contributions: Conceptualization, G.P.; methodology, A.B.; formal analysis, N.K.; writing—original draft preparation, I.I.; writing—review and editing, M.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Mamedov, Z.F.; Qurbanov, S.H.; Streltsova, E.; Borodin, A.; Yakovenko, I.; Aliev, A. Assessment of the potential for sustainable development of electric power enterprises: Approaches, models, technologies. *SOCAR Proc.* **2022**, *2*, 15–27. [CrossRef]
2. Borodin, A.; Zaitsev, V.; Mamedov, Z.F.; Panaedova, G.; Kulikov, A. Mechanisms for Tax Regulation of CO_2-Equivalent Emissions. *Energies* **2022**, *15*, 7111. [CrossRef]
3. Fedorova, E.; Lapshina, N.; Borodin, A.; Lazarev, M. Impact of information in press releases on the financial performance of Russian companies. *Ekon. Polit.* **2021**, *16*, 138–157. [CrossRef]
4. Mamedov, Z.F.; Qurbanov, S.H.; Streltsova, E.; Borodin, A.; Yakovenko, I.; Aliev, A. Mathematical models for assessing the investment attractiveness of oil companies. *SOCAR Proc.* **2021**, *4*, 102–114. [CrossRef]
5. Strielkowski, W.; Kulagovskaya, T.; Panaedova, G.; Kontsevaya, S.; Štreimikienė, D. Post-soviet economics in the context of international trade: Opportunities and threats from mutual cooperation. *Econ. Res.—Ekon. Istraz.* **2022**. [CrossRef]
6. Ilyina, I.E.; Klypin, A.V. Scientific and technological development of the Russian Federation: Current state and prospects. *Sci. Gov. Scientometr.* **2020**, *15*, 458–485. [CrossRef]
7. Guskov, A.E.; Karaush, A.S.; Menshchikov, I.E.; Shkolin, A.V.; Nedelskiy, V.O.; Sabirov, D.S.; Shchukin, T.N. National scientific and information infrastructure: Problems, tasks and prospects. *Sci. Gov. Scientometr.* **2020**, *17*, 380–407. [CrossRef]
8. EIA (Energy Information Administration). Available online: https://www.eia.gov/ (accessed on 2 November 2022).
9. BP Statistical Review of World Energy. 2021, p. 72. Available online: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-full-report.pdf (accessed on 5 November 2022).
10. OPEC Annual Statistical Bulletin 2020. 96. Fortune 500 Global Ranking. Annual Ranking of the Largest Corporations in the World. 2021. Available online: http://money.cnn.com/magazines/fortune/global500/2020/performers/industries/profits/asset.shtml (accessed on 4 November 2022).
11. The Bureau of Labor Statistics (BLS). Available online: http://www.bls.gov/ (accessed on 7 November 2022).
12. Regions of Russia. *The Main Characteristics of the Subjects of the Russian Federation*; Rosstat: Moscow, Russia, 2021; p. 766.
13. Energy Bulletin. *Adaptation of the Oil Market*; Analytical Center under the Government of the Russian Federation: Moscow, Russia, 2020; p. 19. Available online: https://ac.gov.ru/uploads/2-Publications/energo_dec_2020.pdf (accessed on 2 November 2022).
14. World Economic Outlook, January 2021. Available online: https://www.imf.org/en/Publications/WEO/Issues/2021/01/26/2021-world-economic-outlook-update (accessed on 5 November 2022).
15. Global Economic Prospects: Slow Growth, Policy Challenges World Economic Outlook, January 2020. Available online: https://www.worldbank.org/en/news/feature/2020/01/08/january-2020-global-economic-prospects-slow-growth-policy-challenges (accessed on 5 November 2022).
16. *State Report on the State and Use of Mineral Resources of the Russian Federation in 2020*; Ministry of Natural Resources and Ecology of the Russian Federation: Moscow, Russia, 2021; p. 572. Available online: https://www.rosnedra.gov.ru/data/Files/File/7992.pdf (accessed on 10 November 2022).
17. Regions of Russia. *Socio-Economic Indicators*; Rosstat: Moscow, Russia, 2011; p. 1112. Available online: https://rosstat.gov.ru/storage/mediabank/Region_Pokaz_2021.pdf (accessed on 9 November 2022).
18. Compiled According to the "Statistical Review of World Energy 2022", British Petroleum Bp Statistical Review of World Energy. 2022, p. 16. Available online: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf (accessed on 6 November 2022).
19. Filimonova, I.V.; Nemov, V.Y.; Nimble, I.V.; Shustry, I.; Mishin, M.; Komarova, A.; Zemnukhova, E.; Shumilova, S.; Kozhevin, V.; Nikiforenko, E.; et al. *Oil and Gas Complex of Russia—2020: Part 1. Oil Industry—2020: Long-Term Trends and Current State*; INGG SB RAS; Publishing House: Novosibirsk, Russia, 2021; p. 18.
20. Annual Report of PJSC Lukoil 2020. p. 224. Available online: https://lukoil.ru/FileSystem/9/553791.pdf (accessed on 5 October 2022).
21. Annual Report. PJSC NK "ROSNEFT". 2020, p. 444. Available online: https://www.rosneft.ru/upload/site1/document_file/a_report_2020.pdf (accessed on 12 October 2022).
22. Annual Report of PJSC Gazprom Neft 2020. p. 212. Available online: https://ir.gazprom-neft.ru/upload/iblock/69b/3.pdf (accessed on 5 November 2022).

23. Annual Report of PJSC Surgutneftegaz 2020. p. 48. Available online: https://www.surgutneftegas.ru/download.php?id=69614 (accessed on 5 September 2022).
24. Annual Report of PJSC Bashneft 2020. p. 48. Available online: http://www.bashneft.com/files/iblock/61.pdf (accessed on 5 October 2022).
25. Annual Report of PJSC Tatneft 2020. p. 48. Available online: https://www.tatneft.ru/uploads/publications/61725c8bbfaca243850193.pdf (accessed on 12 October 2022).
26. Review "The Main Trends in the Development of the World Oil Market Until 2030". M.: 88. Available online: https://lukoil.ru/FileSystem/PressCenter/84523.pdf (accessed on 5 October 2022).
27. The Russian Oil Industry in the Context of Global Challenges and Threats. Available online: https://burneft.ru/archive/issues/2018-11/3 (accessed on 5 October 2022).
28. Mastepanov, A.P. The Oil Sector of the World Economy in 2020: Forecasts and Expected Results. *Drill. Oil* **2020**, *1*, 33–39. Available online: https://burneft.ru/archive/issues/2021-01/33 (accessed on 15 October 2022).
29. lyaskina, N.I. Oil tax maneuver: Analysis of consequences and forecast of company development research. *Forecast. Probl.* **2022**, *4*, 33–44. [CrossRef]

energies

Article

Modeling the Business Environment of an Energy Holding in the Formation of a Financial Strategy

Alex Borodin [1,2,*], Galina Panaedova [3], Svetlana Frumina [4], Aidyn Kairbekuly [5] and Natalia Shchegolevatykh [6]

1 Department of Financial Management, Plekhanov Russian University of Economics, 117997 Moscow, Russia
2 Center for the Development of Forms of Integration of Science and Education, Russian Research Institute of Economics, Politics and Law in Science and Technology (RIEPL), 127254 Moscow, Russia
3 Department of Tax Policy and Customs Affairs, North-Caucasus Federal University, 355017S Stavropol, Russia; afina-02@rambler.ru
4 Department of Finance, Financial University under the Government of the Russian Federation, 105064 Moscow, Russia; frumina@mail.ru
5 Procurement Department, Nazarbaev Intellectual School of Physics and Mathematics in Semey, Semey 071411, Kazakhstan; kairbekuly@gmail.com
6 Department of Finance, SUEK JSC, 115054 Moscow, Russia; shchegolevatykh@sibgenco.ru
* Correspondence: aib-2004@yandex.ru

Citation: Borodin, A.; Panaedova, G.; Frumina, S.; Kairbekuly, A.; Shchegolevatykh, N. Modeling the Business Environment of an Energy Holding in the Formation of a Financial Strategy. *Energies* **2021**, *14*, 8107. https://doi.org/10.3390/en14238107

Academic Editor: Dimitrios Katsaprakakis

Received: 9 November 2021
Accepted: 29 November 2021
Published: 3 December 2021

Abstract: This article consists of the development of a set of methodological provisions concerning the identification of the features of the influence of the business environment on the effectiveness of the implementation of the company's financial strategy and the development of a system for its adaptation to the conditions of a dynamic external environment. The purpose of this article is to build an economic and mathematical model to identify the main elements of the business environment that affect the company's strategy, the formation of methods for evaluating the effectiveness of the implementation of a financial strategy taking into account such influence. The author's contribution consists in the development of an effective financial algorithmic strategy of the energy holding, considering the influence of the environmental factors. Hypothesis: the use of mathematical models of the business environment will increase the efficiency of energy holding management in the field of finance and investments. The scientific novelty of this article lies in the development of an algorithm that allows for obtaining an integral assessment of the impact of external and internal factors of the energy holding's business environment on its financial strategy using taxonomy methods, multidimensional statistical analysis and cluster and discriminant models. Results: the authors have developed a model of the influence of the energy holding's business space, which allows improving the interaction of financial flows within the holding and obtaining an optimal distribution of financial resources, taking into consideration the dynamic factors of the company's external environment.

Keywords: financial analysis; energy holdings; financial strategy; environment

1. Introduction

Modern conditions of the functioning and development of industrial complexes, in general, and production facilities and enterprises, in particular, are characterized by uncertainty and ambiguity of the influence of the external environment, increased competition, the emergence of new market participants and products, increased globalization processes and the formation of new requirements from consumers. A characteristic feature of the functioning of modern enterprises is that the orientation towards maximum efficiency has been replaced by an orientation towards economic development. Constantly changing working conditions caused by fluctuations in the external environment create an imbalance between existing production opportunities and possible alternatives to the economic development of the enterprise.

At the same time, it should be noted that the specifics of the interaction of an enterprise with its environment and business environment are not limited to direct relationships but are characterized by a significantly higher level of complexity and subordination. Thus, the activity of an industrial enterprise is significantly influenced by economic (economic policy of the state, taxation system, inflationary fluctuations, market conditions, development of market infrastructure, investment attractiveness of the country, etc.), political (stability of the government, development of the legislative framework, the nature of government–business relations, etc.), social (labor potential of the region, population dynamics, level and quality of education of potential employees, etc.) and technological (technical and technological development, the results of the introduction of scientific and technological progress, prospects for the production of domestic equipment, etc.) environmental factors.

The conditions of instability and uncertainty, the constant impact of the external environment and competition require the enterprise to create such a system of countering destabilizing factors that would ensure its effective functioning, the ability to resist not only the threat of destruction of the organizational structure and status but also obstacles in achieving key development goals.

Thus, these circumstances necessitate the development of a comprehensive adaptive mechanism that will ensure the response of the enterprise to the impact of external factors in terms of ensuring its competitiveness and sustainability as well as the adaptation of the financial strategy to the dynamism of the environment.

The financial strategy of the company is one of the main plans for business development in the future. The forecast of the development of the business environment is the basis for the formation of strategic plans and programs. The need to adapt the financial strategy of an enterprise to changes in the external environment necessitates the need to make certain adjustments to its internal systems and divisions in order to ensure that their functioning corresponds to the state of the business environment. There is no doubt that the introduction of appropriate changes should be carried out comprehensively and purposefully in a certain order using a systematic approach, which requires the organized management of this process.

The task of analyzing the impact of the business environment on the effectiveness of the implementation of the financial strategy of the enterprise and, accordingly, substantiating the directions for improving the mechanism of its adaptation to disturbances and turbulence of the external environment is especially relevant for domestic industrial holdings since they form a significant share of the economic potential of the country; however, as a result of the adverse impact of business environmental factors, the stability of their functioning is disrupted and financial stability and the level of competitiveness are reduced.

In this context, we note that the problem of research and the assessment of the impact of the business environment on the effectiveness of the company's financial strategy, as well as the organization of the adaptation process, management requires its own theoretical justification and practical solution, which, in general, determines the choice of the topic of the article, forms the conceptual basis of the research and determines the scientific tools of cognition.

Scientific research and analysis in the field of creating an effective financial strategy were carried out by foreign economists, which include [1–6].

Articles [7–10] were devoted to the analysis of individual elements of the company's financial strategy.

The analysis of the scientific and expert literature shows that the formation of a financial strategy of a business entity is the subject of active study by leading economists and scientists in different countries of the world. However, at the same time, it is necessary to pay attention to the fact that the study of the influence of business environmental factors is only an integral part of scientific works and today does not fully take into account the dynamism of markets, the peculiarities of the development of economic systems, especially in the context of digital transformations and the widespread introduction of information and communication technologies.

Given the volatility of the external environment, Russian companies are forced to quickly adapt to new conditions, using different methods to ensure the use of their strategic capabilities. The need for analysis in relation to assessing the effectiveness of the implementation of the financial strategy of Russian enterprises, depending on external factors, determined the choice of the strategy, its target orientation and the complexity of the tasks solved during the study.

2. Literature Foundations

The most difficult conditions for the energy holding from the point of view of strategic management of the financial situation are the conditions of the transnational environment, characterized by a combination of powerful pressure to standardize and the tangible influence of local forces.

In the process of implementing the new paradigm of managing business entities, world practice pays considerable attention to analytical tools that allow for justifying a financial strategy using flexible technologies for its adaptation to changes in the business environment. However, the key problems of using this tool are simplified ideas about the meaning and role of strategic analysis of the business environment in the management system, the use of rather primitive methods, criteria for choosing specific methods and approaches to their application.

The essential characteristics of the place and role of the financial strategy in the strategic program and plans of the enterprise are highlighted in Table 1.

Table 1. Key content characteristics of the energy holding's financial strategy.

Characteristics	Content and Essence of the Characteristics
One of the types of functional strategy of the holding company	The functional content of the financial strategy is that it covers only one of the activities of the industrial holding and its development is part of the key functions of financial management
The most important in the complex of functional strategies of the holding	The financial strategy provides the necessary resources for the implementation of all other functional strategies, thereby ensuring the coordination and integration of the efforts of all the holding's divisions in the process of achieving the set goals and key development targets.
It covers all the financial relations of the holding and the key areas of development of its financial activities	The development and justification of the financial strategy is part of the key tasks of strategic management. A comprehensive accounting of all possible forms of financial relations of the holding, as well as the prospects for the development of its financial activities, makes it possible to ensure the growth of its market value in the long term.
Forms specific financial goals for the long-term development of the holding	Taking into account the specifics of the financial activities of the holding, the financial strategy should contribute to the implementation of the mission and the achievement of the key benchmarks of its corporate strategy, on the one hand, and on the other, without contradicting, support the implementation of the tasks of the other functional strategies.
Promotes the selection of the most effective tools and methods for achieving the financial goals of the holding	The choice is ensured by selecting and evaluating more progressive and effective ways to solve the set tasks and finding and justifying optimal financial solutions and their appropriate gradation according to the criterion of maximizing the market value of the holding
Takes into account and adequately responds to changes in the external conditions of the holding's financial activities	The modern, progressive paradigm of developing and shaping the development strategy of the energy holding determines that the fundamental content of its strategic behavior is not in the clear implementation of the tasks provided for but in the ability to respond adequately to changes in the external environment without delay, with the appropriate adjustment of the tasks set.
Provides adaptability to changes	This characteristic allows us to implement, first of all, a change in the approaches and methods of accumulating and using the financial resources of the holding. Adaptive financial potential management is an effective tool for making adjustments to the ways and forms of achieving the holding's strategic goals

Generalization of the authors' [11–17] research allows us to conclude that the strategic analysis of the business environment of market economic entities is carried out using various methods of assessing and predicting the state of their external and internal environment, which have specific applications and are characterized by certain advantages and disadvantages.

Thus, the financial strategy is the unifying factor of the financial and strategic aspects of the management of the energy holding, which determines the financial goals for the long term and the means to achieve them.

Mathematically, the structure of the set of business environmental conditions that affect the financial strategy of a business entity can be represented as follows:

$$W(t) = \left\{W^E(t), W^I(t)\right\} \quad (1)$$

where $W(t)$ is the general set of operating conditions; $W^E(t)$ is a subset of external operating conditions; $W^I(t)$ is a subset of internal operating conditions.

At the same time, despite the widespread practice of analyzing the business environment, insufficient attention is paid to the coverage of quantitative and qualitative methods of its implementation. In addition, for domestic business entities, one of the main problems is that the analysis of the business environment is considered as an ideology of doing business and not as a tool for strategic management. Practical experience indicates an incomplete understanding and incorrect application of business environmental analysis methods in the course of identifying market opportunities and justifying strategic priorities for the financial development of a business entity.

In the process of studying the features of assessing the state and degree of influence of the business environment on the implementation of the financial strategy of the Russian energy holding, three key problems can be identified:

- The formalization of the information necessary for the study of the business environment and the sources of its receipt;
- The specification and identification of environmental factors that affect the financial strategy;
- The selection and justification of the most flexible, appropriate and most optimal methods of analysis.

Let us consider in more detail the problem of forming an information base for assessing the state and degree of influence of the business environment on the implementation of the financial strategy of the Russian energy holding.

Based on the generalization of the information obtained from the analysis of scientific papers, it can be argued that there is a close relationship between the factors of the business environment and the energy holding, and the influence of each of them to a certain extent affects its financial strategy.

Considering the factors and conditions of the business environment that affect and determine the financial strategy of the energy holding, they can be grouped depending on the group influence with which they enter into a relationship, namely:

(1) Consumers (*Icn*);
(2) Competitors (*Icm*);
(3) Suppliers (*Is*);
(4) Intermediaries (*In*);
(5) Contact audiences (*Ica*).

Accordingly, the level of integral influence of business environmental factors on the financial strategy of the energy holding can be expressed as follows:

$$I_{BE} = f(I_{cn}, I_{cm}, I_s, I_n, I_{ca}) \quad (2)$$

The task of analyzing the macroenvironment is becoming increasingly important for the energy holding when forming its financial strategy in the context of globalization and tougher competition in international markets. This is primarily because the financial condition of any enterprise that operates in a transnational dimension and is essentially an open system, is completely dependent on the outside world in terms of consumer demand, supply of resources, energy and personnel [18].

Within the microenvironment, it is possible to distinguish the contour of the industry and the near environment of the energy holding. The first circuit can be characterized by the actual and potential size of the industry, its development prospects and the stages of the life cycle of products and services produced, the structure of industry expenditures, the scale of competition, the logistics and sales system used, and the trends in the development of industrial production within this industry [19]. The analysis of the industry features allows for the analysis to get an idea of the effectiveness of the planned activities provided for by the financial strategy of the holding.

The formed information base forms the foundation for assessing the impact of the business environment on the financial strategy of the energy holding and, accordingly, determines the need to choose specific methods and approaches that allow for fundamental analysis, within which it is possible to identify general trends, as well as to implement applied research detailing specific manifestations, spheres and factors of influence.

Table 2 outlines an approximate, conditional list of research works and typical tasks that can take place when conducting both fundamental analysis and applied research.

Table 2. Indicative list of research works in the process of assessing the state and degree of influence of the business environment on the implementation of the financial strategy of the Russian energy holding.

Types of Research Works	Typical Tasks
Assessment of financial market parameters	- study of the structure and profitability of financial instruments; - analysis of the dynamics of inflation; - research of positions of key currencies; - investment risk analysis; - evaluation of credit offers on the market; - analysis of the Central Bank's discount rate; - study of own debt load, capital adequacy, profitability and liquidity;
Quantitative research of consumers and competitors	- analysis of price expectations; - evaluation of brand indexes of the competitive environment; - building maps of the perception of competitors; - quantitative assessment of consumer choice motives; - determining the vectors of switching consumers to competitors' offers;
Expert analysis	- assessing threats and opportunities; - determining short-term trends in the market environment;
Analysis of the product range and sales volumes	- customer base assessment; - evaluation of the economic efficiency of assortment items (ABC analysis); - assessment of sales stability (XYZ analysis).

Next, we will specify the factors of the energy holding's business environment that affect both the choice of the financial strategy and the results of its implementation.

Among the key characteristics of the external environment is the interconnectedness of factors: complexity, uncertainty, mobility. These characteristics of the external environment indicate a significant dynamic and variable nature of the changes that occur in it.

In this context, according to the author, it is necessary to take into consideration two conceptual aspects:

(1) All components of the macroenvironment of the energy holding are in a state of interaction, that is, changes in one of the components necessarily lead to changes in the other components of the macroenvironment. Therefore, their analysis should be carried out in a comprehensive manner, tracking specific changes in individual components of the environment and assessing their impact on other components;
(2) The strength of the disturbing effects of individual components of the macroenvironment on different holdings is not the same. For example, the degree and intensity of influence have different expressions and forms of manifestation, which depend on the industry and territorial affiliation of the holding, the size of the holding, and so on. For this reason, when analyzing the macroenvironment, it is necessary to use a homomorphic model with the allocation of only those parameters that significantly affect the financial strategy of an industrial holding and can be measured with greater or lesser accuracy.

According to the author, considering the peculiarities of the development of modern markets, as well as taking into account the specifics of the work of energy holdings in Russia, the factors of the external environment's influence on the financial strategy can be grouped into four aggregated categories:

- Forming factors: the factors that determine the dynamics of a financial strategy;
- Regulatory factors: factors that influence the dynamics and changes in the forming factors, which accordingly determines the regulatory impact on the financial strategy;
- The market: this group consists of factors that have a multidirectional influence, they can initiate both the emergence of opportunities and the emergence of difficulties and threats to the financial strategy;
- Warning factors: the threshold values of these factors signal that the economic system is out of dynamic equilibrium, as a result, there is the possibility of crisis phenomena.

Typical internal threats include imperfection of the organization of the financial management system; inefficiency of investment activities; non-compliance with liquidity indicators; abuse and incompetence of managers (accounting fraud, falsification of expenses, misappropriation of income, etc.); weak marketing policy; an inefficient financial monitoring system; the presence of information leakage channels; low capitalization.

Having determined the sources of information and the factors of the business environment that affect the financial strategy of the energy holding, we focused on choosing and justifying the most flexible, appropriate and optimal methods of analysis.

To study the impact of business environmental factors on the activities of business entities, in general, and their financial strategies, in particular, various methods were used, most of which are based on expert assessments and the implementation of a certain sequence of stages: the selection of the object of analysis (enterprise, structural unit, etc.), the justification of criteria and the formation of a group of experts, the development of a form for analysis and filling out questionnaires, etc., the evaluation of results and the formulation of final conclusions [20].

The theory and practice of studying the business environment and its impact on market participants have developed and proven the effectiveness of using such methods of fundamental analysis as SWOT analysis, PEST (STEP) analysis, SLEEP analysis, STEEPLE analysis, ETOM analysis, QUEST analysis, etc. [21].

The essential features of economic processes in the Russian economy are the incompleteness and fragmentary nature of the initial data, the limited information (short samples), the unidentified nature and type of relationships between the output and input variables, and the absence of a normal distribution in the static sample. These features significantly limit the use of traditional methods of analysis, in particular, the ARIMA model and other univariate extrapolation regression models, and require the development of new non-traditional approaches and methods based on artificial intelligence. Accordingly, in this case, the most acceptable is the use of methods based on the Fuzzy Logic methodology.

In turn, the diversity and uncertainty of the external and internal environment conditions determine the objective need for a timely and rapid response of the energy holding's financial strategy management system to changes with minimal costs, so in this case, the most appropriate and effective was the use of neural network analysis technologies that allowed for not only the collection and analysis of information about the factors of the business environment, as well as to quantify and qualitatively measure them, but also to assess their overall impact on the main components of the financial strategy. Additionally, neural network control systems demonstrate high efficiency if there is no complete set of data, or in the case when a complex object is analyzed [22].

It should be noted that the boundaries between the different approaches are unclear. In addition, practice proves that the use of hybrid analysis technologies based on the combination of traditional management methods, Fuzzy Logic and Neural Network, allows for the creation of intelligent assessment and management systems that are effective in a wide range of situations.

The desire for structural knowledge of the factors that influence the business environment on the financial strategy of business entities and the need to level out uncertainty is a natural desire of any management. It was this fact that led to the emergence of a methodology for dividing the factors of influence into "hard" and "soft". The starting point of this approach is the recognition that the success or failure of a strategic decision in the financial sphere depends on the uncertainty of the initial conditions and possible changes in the conditions of its implementation under the influence of a changing environment [23].

However, a significant number of factors of the business environment are not subjected to such a precise and formalized analysis because they do not have clear and precise manifestations, are not amenable to mathematical evaluation, they are difficult to quantify, and, in addition, their impact and the consequences of such impact are unpredictable. Only predictions can be made. In this case, it is also difficult to choose the right strategic decision of the financial behavior of the business entity. This type of factor is classified as "soft". Therefore, some alternative approach is needed, which includes the absence of the answer checked by the conditions of the problem in advance [24–27].

This feature characterizes the difference between two types of opposite factors of the business environment of modern business entities (Table 3).

Table 3. Identification of "hard" and "soft" factors.

Hard Factors	Soft Factors
Unambiguous understanding of the factors and directions of their influence. The assessment, analysis and management tools are unambiguous. It is known what the factor is. You know what you need to know about it. The problem of factor influence is clearly structured.	There is no single approach to factor identification. It is not known what the influence factor and the tools of its influence are. The information that needs to be established is difficult to identify and formalize. The method of evaluation and analysis is not obvious. The clear limits of the influence of the factor are not clear.

Considering the strategic problems of managing e-holdings in the modern business environment, in the author's opinion, in most cases, the factors of its influence should be referred to as "soft". However, the question immediately arises of how to identify in time the actions (and what those actions are) to choose for a business entity in the event of the influence of "soft" factors, when it is not only impossible to build algorithms, but it is often difficult to clearly characterize the factor itself, not to mention building a sequence of actions to solve emerging problems.

In this case, the theory of fuzzy logic and fuzzy sets is indispensable, because it is one of the most promising areas of scientific research in the field of analysis, forecasting and modeling of uncertain and stochastic economic phenomena and processes [28–30].

It is obvious that after selecting specific methods and approaches of analysis, a separate refinement and formalization requires an algorithm for conducting evaluation and analytical procedures.

Let us consider the algorithm developed by the authors for assessing the state and degree of influence of the business environment on the implementation of the financial strategy of the energy holding (Figure 1).

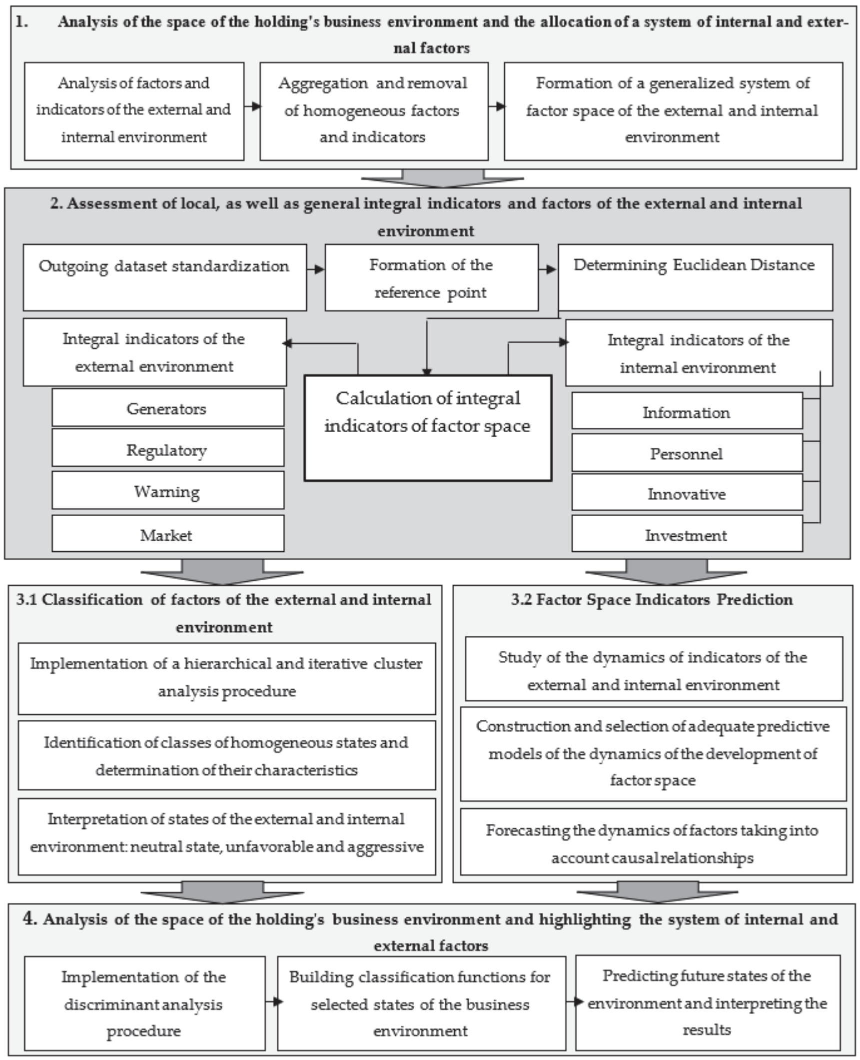


Figure 1. Algorithm for assessing the state and degree of influence of the business environment on the implementation of the financial strategy of a Russian energy holding.

Let us consider in more detail the features of using the proposed algorithm. The first step in assessing the factor space is to analyze and form a system of indicators of the external and internal business environment that affect the financial strategy of the energy holding. As mentioned earlier, when forming this system, the information base is the official publications of international organizations and rating agencies, information from public authorities, statistical reports, periodicals, official materials, etc.

The next step after the formation of the system of indicators of the factor space was the assessment of local and general integral indicators of the factors of the external and internal environment by the method of integral rating assessment.

The value of the integral indicator traditionally varies in the range from 0–1. The closer the value of the integrated assessment approaches 1, the more favorable the impact of this factor on the financial strategy of the energy holding and the results of its implementation. At the same time, it should be noted that all factors considered were divided into two groups based on the nature of the impact of each of them on the financial strategy, and depending on this, they can be stimulators and discouragers. In case of the negative influence of external and internal factors, it is important for the holding company to coordinate its activities in a timely manner, which will allow it to maintain financial stability. The positive influence of factors enables the implementation of promising areas to ensure financial stability.

At the third stage of the algorithm implementation, the classification and interpretation of the states of the factor space were carried out. To determine the types of the state of the external and internal environment, it is advisable to cluster factors using hierarchical (natural classification methods) and iterative (K—means method) methods. The obtained statistical characteristics were the basis for the interpretation of the states of the external and internal environment: neutral, unfavorable and aggressive.

Additionally, in the third stage, the indicators of the factor space of the external and internal environment of the energy holding were predicted to determine future development trends.

To predict the values of factors, according to the author, it is necessary to use the methods of dynamic econometrics, namely VAR analysis, since it takes into consideration the entire set of cause-and-effect lag relationships and is an adequate forecasting tool for several time series.

The last and fourth stage of the algorithm was the recognition of the future states of the factors of the external and internal environment, which is advisable to carry out on the basis of the use of methods of discriminant analysis and the construction of discriminant classification functions, which allowed for a forecast state of the factors to be made, and, as a result, the possible results of the implementation of the financial strategy of the energy holding.

We formalized the factors of the external and internal environment and compiled a list of information sources that allowed us to form a base for research. We conducted a critical analysis of various methods and tools for assessing the state and degree of influence of the business environment on the implementation of the financial strategy of the energy holding and considered, in practice, the features of using the recommendations, approaches and methods of action.

3. Results

Using the example of PJSC NOVATEK, using intelligent systems based on SWOT analysis and neural network modeling technologies, we assessed the state of the holding's financial strategy and determined the impact of the business environment on the results of its implementation.

First of all, we note that it is advisable to build and analyze neural network models using modern software packages that implement the appropriate technologies. Among them are the following: Neuro office, NeuroSolution, NeuroShell, STATISTICA Neural Networks, and others [31–33].

To assess the impact of business environmental factors on the financial strategy of PJSC NOVATEK, it is necessary to design neural networks and study their effectiveness in one of the above software packages.

The initial variable a of the neural network can be such indicators as the amount of profit from operating activities, the number of losses, the probability of break-even activities, the effectiveness of financial activities, the risk of liquidity and financial stability, the index of the ratio of debt and equity, and many other economic indicators of the financial activities of the holding.

The choice of the final indicator/output variable of the neural network determines the set of input variables. Therefore, they can be summarized as follows:

$P = \{P_p\},\ p = \overline{1,n}$ represents the set of factors of direct influence of the external environment, where the lower index $p = 1$, for example, characterizes the impact of factors initiated by suppliers, $p = 2$—financial institutions, $p = 3$—by consumers, $p = 4$—competitors, etc.

$P_{pj_p},\ p = \overline{1,m},\ j_p = \overline{1,J_p}$ represents the many factors of direct influence of the external environment of the lowest level of the hierarchy;

J_p is the number of factors of direct influence of the environment at the lowest level of the hierarchy in the p—the group of factors at the top level;

$K = \{K_k\},\ k = \overline{1,n}$ represents a set of factors directly affecting the internal environment, where the lower index $k = 1$ characterizes the influence of factors related, for example, to the professionalism of managers, $k = 2$—the presence of financial and other restrictions, $k = 3$—risky behavior in the financial market, $k = 4$—creditworthiness, etc.

$K_{kj_k},\ k = m,\ j_p = \overline{1,I_k}$ represents the many factors directly affecting the internal environment of the lowest level of the hierarchy;

I_k is the number of factors of direct influence of the internal environment of the lowest level of the hierarchy in the k-th group of factors of the upper level;

$Z_l, l = \overline{1,10}$ represents the artificial neurons of the first layer;

S represents the artificial neural network of the output layer.

For example, if a is interpreted as the probability of a successful launch by a division of PJSC NOVATEK of the development of a new field (in full, just in time), then the set of input variables is given as follows:

$P_1 = f(P_{11}, P_{12}, P_{13})$, where P_{11} is the price for the supply of spare parts for vehicles; P_{12} is the price of equipment and mechanisms; P_{13} is the terms of delivery of necessary consumables and the renewal of fixed assets of production;

$P_2 = f(P_{21}, P_{22})$ where, P_{21} is the salary of service personnel, P_{22} is the working conditions;

$P_3 = f(P_{31}, P_{32}, P_{33},\ P_{34})$, where P_{31} is the type and brand of extracted natural resources; P_{32} is the terms of delivery to customers; P_{33} is the distance and difficulty of the route, P_{34} is the demand for products;

$P_4 = f(P_{41}, P_{42}, P_{43})$, where P_{41} is the demand for competitors' products; P_{42} is the competitiveness of the holding company; P_{43} is the prices for a similar type of product from competitors;

$P_5 = f(P_{51}, P_{52})$, where P_{51} is the tightening of customs legislation; P_{52} is the tax burden on this type of operation;

$K_1 = f(K_{11}, K_{12})$, where K_{11} is the qualification of senior managers, K_{12} is the organization of financial management, requirements for continuous training and development of new analysis technologies;

$K_2 = f(K_{21}, K_{22},\ K_{23})$, where K_{21} is the presence of financial encumbrances on the property, K_{22} is the availability of outstanding loans, K_{23} is the presence of overdue debt;

$K_3 = f(K_{31}, K_{32})$, where K_{31} is the purchase of risky securities, K_{32} is investment in risky projects with an indefinite payback period.

All levels of the selected influence factors can be changed both quantitatively and qualitatively. For this purpose, it is necessary to define a linguistic variable "Level of parameter X", the carrier of which is a certain region of parameter X, and the term-set of values forms fuzzy subsets "very low level", "low level", "medium level", "high level", "very high level" [34–36].

Thus, an increase in the strength of the influence of one qualitative factor is accompanied by a corresponding decrease in the influence of the neighboring factor. At the point $\mu = 0.5$, the maximum degree of information uncertainty is reached, that is, in it, all neighboring qualitative characteristics have the same strength (identical). In the middle of the upper faces of the trapezoids of the classifier, there are nodal points that can be used as a system of weights in the process of aggregating vaguely defined data [37,38].

In practice, to analyze the impact of factors of the external business environment of PJSC NOVATEK on its financial strategy, the use of fuzzy set tools can have the following form.

Let us assume that the base factor (suppliers of equipment and spare parts), the influence of which is analyzed, has three component characteristics (pricing policy; reliability; image) with a weight of 0.6, 0.3 and 0.1, respectively. The level of each of them is estimated by the expert at 0.2, 0.6 and 0.5, respectively.

The functions of the membership of the carrier X to the corresponding fuzzy subset has the following form:

High factor level:

$$(X) = \begin{cases} 0,\ 0 \le X < 0.55 \\ 10(X - 0.55),\ 0.55 \le X < 0.65 \\ 1,\ 0.65 \le X < 0.75 \\ 10(0.85 - X),\ 0.75 \le X < 0.85 \\ 0,\ 0.85 \le X < 1 \end{cases}$$

Average factor level:

$$\mu(X) = \begin{cases} 0,\ 0 \le X < 0.35 \\ 10(X - 0.35),\ 0.35 \le X < 0.45 \\ 1,\ 0.45 \le X < 0.55 \\ 10(0.65 - X), 0.55 \le X < 0.65 \\ 0,\ 0.65 \le X < 1 \end{cases}$$

Low factor level:

$$\mu(X) = \begin{cases} 0,\ 0 \le X < 0.15 \\ 10(X - 0.15),\ 0.15 \le X < 0.25 \\ 1,\ 0.25 \le X < 0.35 \\ 10(0.45 - X), 0.35 \le X < 0.45 \\ 0,\ 0.45 \le X < 1 \end{cases}$$

Feature level recognition detects that the first one has a probability of 0.5 low or very low; the second one is unambiguously high; the third one has a probability of 0.5 medium or high. In order to assess the strength of the influence of the "suppliers" factor on the financial strategy of the holding, we constructed a matrix that made it possible to calculate the intensity of the impact of each of its characteristics separately (Table 4).

Table 4. Matrix required for conducting an integral assessment of the impact of the "suppliers" factor on the financial strategy of PJSC NOVATEK».

Factors	Weight Characteristics	Accessory Functions				
		Very Low	Low	Average	High	Very High
Pricing policy	0.6	0.5	0.5	0	0	0
Reliability	0.3	0	0	0	1	0
Image	0.1	0	0	0.5	0.5	0
Nodal points		0.075	0.3	0.5	0.7	0.925

In this case, the theory of fuzzy logic and fuzzy sets is indispensable because it is one of the most promising areas of scientific research in the field of analysis, forecasting and the modeling of uncertain and stochastic economic phenomena and processes [39].

Thus, the calculation based on the data in Table 4 looks like this:

$$SW = 0.6 \times (0.5 \times 0.75 + 0.5 \times 0.3) + 0.3 \times 1 \times 0.7 + 0.1 \times (0.5 \times 0.5 + 0.5 \times 0.7) \quad (3)$$

The calculation shows that the influence of the "suppliers" factor on the financial strategy of PJSC NOVATEK is determined by 80% as average and 20% as high. Similarly, matrix folding can be performed when switching from individual indicators of the strength/weakness of the influence of a certain factor of the holding's business environment to an integral indicator. To do this, the weight of the basic factors in the integral needs to be determined.

Furthermore, according to the authors, a significant interest in the process of assessing the state and degree of influence of the business environment on the implementation of the financial strategy of an industrial holding using intelligent technologies is the procedure for selecting a specific type of strategy, depending on the capabilities, resources, limitations, advantages and potential of the holding itself, i.e., on the characteristics of its internal environment.

Using neural network calculations, we assessed how the advantages and disadvantages of the internal organization of PJSC NOVATEK affected the choice of its financial strategy.

The holding company is faced with the task of choosing one alternative out of four possible options for financial strategies:

(1) The strategy of financial support for Accelerated Growth (A1);
(2) Strategy for Financial Support of Limited Growth (A2);
(3) Financial Security Support Strategy (A3);
(4) Individual Production Support Strategy (A4).

Each of these strategies has certain characteristics.

Strategy A1—it is focused on taking a leading position in the market. This goal can be achieved when the holding company has some advantage over its competitors and also has the potential to reduce the cost of production. At the same time, the implementation of this strategy provokes the emergence of price competition.

Strategy A2—the goal of this strategy is to increase the specialization and concentration of the holding's activities to meet the requirements of a specific segment of consumers. This strategy assumes the need for additional financial investments, but at the same time, it will take a leading place in technological development.

The A3 strategy does not provide for any radical changes; it is aimed at maintaining a stable financial position of the holding.

The A4 strategy requires additional investments directed to the readjustment of production lines, which will expand the product range. The implementation of this strategy allows for expanding the circle of consumers and contributing to the redistribution of the market between the participants.

To evaluate alternatives, we used the following criteria: C1, production costs; C2, sales costs; C3, costs of marketing activities and research; C4, product quality; C5, the availability of free cash from the holding; C6, the state of the market and the holding's position on it; C7, the risk of unpredictable losses.

The relative humidity was estimated using a linguistic variable.

W = {very important; important; important enough; not very important, practically not important}. The values of the reduced terms of the set were given by fuzzy numbers with a triangular form of membership functions.

The criteria were assigned the following linguistic ratings of relative importance: a = {a4 = not important; a3 = sufficiently important; a2 = important; a1 = very important}.

To evaluate alternatives by criteria, we used the linguistic variable S = "satisfaction" = {very low; low; medium; high; very high}. Figure 2 shows the membership functions of terms that have the form of triangles:

- extremely low = {1.0/0.0; 0.0/0.0};
- low = {0.0/0.0; 1.0/0.2; 0.0/0.4};

- average = {0.0/0.3; 1.0/0.5; 0.0/0.7};
- high = {0.0/0.6; 1.0/0.8; 0.0/1.0};
- very high = {0.0/0.8; 1.0/1.0}.

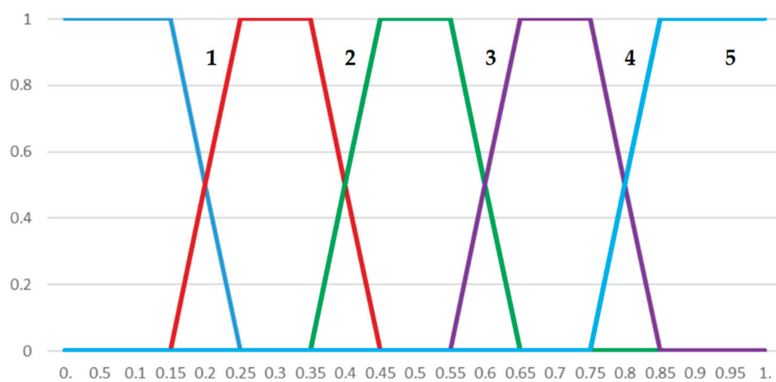


Figure 2. Membership functions for criteria importance terms. 1—extremely low, 2—low, 3—medium, 4—high, 5—very high.

Table 5 shows the grouped estimates of the selected alternatives obtained as a result of a survey of the heads of various divisions of PJSC NOVATEK.

Table 5. Evaluation of the quality of alternatives according to the selected criteria.

Criteria	Evaluating Alternatives			
	A1	**A2**	**A3**	**A4**
C1	very high	high	average	average
C2	very high	high	average	average
C3	very high	average	average	average
C4	high	high	average	low
C5	average	average	very high	average
C6	high	high	low	low
C7	very high	high	low	low

We calculated the weighted estimate of the *j*-th alternative by the formula:

$$R_j = \sum_{i=1}^{n} \alpha_j R_{ij}$$

where R_{ij} is a fuzzy number that represents the evaluation of the *j*-th alternative by the *i*-th criterion; α_j is the normalized coefficient.

The estimates for each strategy are presented in Table 6.

Table 6. Calculation of weighted estimates for each alternative.

Criteria	The Importance of the Criterion	A1		A2		A3		A4	
		Estimation	Weighted	Estimation	Weighted	Estimation	Weighted	Estimation	Weighted
C1	0.7	0.9	0.63	0.8	0.67	0.5	0.35	0.5	0.35
C2	0.5	0.9	0.43	0.8	0.43	0.5	0.41	0.5	0.41
C3	0.2	0.9	0.34	0.7	0.57	0.5	0.27	0.3	0.54
C4	0.7	0.8	0.2	0.5	0.37	0.6	0.56	0.6	0.28
C5	0.2	0.5	0.23	0.6	0.29	0.9	0.25	0.4	0.33
C6	0.5	0.8	0.67	0.8	0.64	0.2	0.64	0.5	0.46
C7	0.2	0.9	0.54	0.7	0.67	0.3	0.78	0.4	0.41
Weighted estimates Rj			2.95		2.68		1.47		1.18

Divide the resulting Rj by the maximum value. The generalizing criterion of the membership function (additive convolution μJ (j)) gives the following result: μJ (j) = {1.00/A1; 0.908/A2; 0.498/A3 0.4/A4}, which allows us to consider the strategy of taking a leading position in the A1 market as the best alternative.

The most acceptable strategy is A1, which assumes a leading position in the market and, accordingly, the choice of promising areas of activity.

In the process of choosing a financial strategy, the task is to choose one division from the available alternatives-NOVATEK-Kostroma (A1), NOVATEK-energo (A2), Arktikgaz (A3), Rostok LNG (A4).

To assess the creditworthiness of the borrowing units, we used their reporting data. Based on these data, we calculated the following credit ratios: absolute liquidity ratio (K1), intermediate coverage ratio (K2), total coverage ratio (K3), financial independence ratio (K4) and product profitability ratio (K5). The calculation results are shown in Table 7.

Table 7. Regulatory and actual levels of credit quality criteria for the divisions of PJSC NOVATEK».

Criteria	The Value of the Criterion for the Division				Normative Value
	A1	A2	A3	A4	
K1	0.964	1.133	1.128	1.265	0.1–0.25
K2	2.842	3.467	3.662	3.584	0.5–1.0
K3	3.57	4.3	4.608	4.368	1.0–2.5
K4	0.628	0.577	0.721	0.526	0.6
K5	0.157	0.167	0.17	0.156	The more, the better

An analysis of the regulatory and actual levels of criteria shows that all divisions can qualify for funding.

Sensitivity Analysis of the Model Using the Membership Function

The advantages of each division can be determined by constructing membership functions. We constructed membership functions that correspond to the concepts of "the most preferred absolute liquidity ratio", "the desired intermediate coverage ratio", "the best profitability ratio", etc.

We will determine the specific values of the membership functions according to the quality criteria K1, K2, K3, K4 and K5.

The fuzzy sets for the five criteria have the following form:

$$\mu K1(a) = 0.64 \div 0.964 + 0.66 \div 1.133 + 0.68 \div 1.128 + 088 \div 1.265$$

$$\mu K2(a) = 1.0 \div 2.842 + 1.0 \div 3.467 + 1.0 \div 3.662 + 1.0 \div 3.584$$

$$\mu K3(a) = 1.0 \div 3.57 + 1.0 \div 4.3 + 1.0 \div 4.608 + 1.0 \div 4.368$$

$$\mu K4(a) = 0.8 \div 0.628 + 0.74 \div 0.577 + 0.96 \div 0.72 + 0.71 \div 0.526$$

$$\mu K5(a) = 0.51 \div 0.157 + 0.58 \div 0.166 + 0.68 \div 0.17 + 0.53 \div 0.156$$

Let us perform a convolution of the received information. The set of optimal alternatives *C* is located at the intersection point of fuzzy sets that contain estimates of the selected alternatives according to the selection criteria. The operation of the intersection of fuzzy sets corresponds to the choice of the minimum value for the *j*-th alternative:

$$\mu_C(a_j) = min \mu_{K_i}(a_j)$$

The optimal alternative is the one that has the maximum value of the membership function for set C.

For the situation under study, the set of optimal alternatives is formed as follows:

C = {min {0.64; 1.0; 1.0; 0.8; 0.51}

min {0.66; 1.0; 1.0; 0.74; 0.58}

min {0.68; 1.0; 1.0; 0.96; 0.68}

min {0.88; 1.0; 1.0; 0.71; 0.53}}

The obtained data allow us to conclude that the optimal alternative is a3, which corresponds to a maximum value of 0.68. The second, third and fourth places are occupied by alternatives a2 → 0.58, a4 → 0.53 and 1 → 0.51, respectively. Most of the financial resources of the funds should be provided to the division of Arktikgaz.

Thus, the conducted neural network modeling allowed, taking into account the influence of factors of the internal business environment of PJSC NOVATEK, to choose the best financial strategy according to the specified criteria, which is focused on occupying the leading position of the holding in the market and, in addition, to justify the choice of a specific division, the development of which should be emphasized in the process of implementing the chosen strategy.

4. Discussion

Considering the above, the article structures a model of the mechanism of the relationship of factors of the business environment of an industrial holding, which allows us to establish that the key elements and conditions of the business environment that affect and determine its financial strategy can be classified depending on the influence groups with which the holding enters into relationships, namely, consumers, competitors, suppliers, intermediaries and contact audiences.

In addition, guided by the developed model, the author has identified a list of data necessary for analyzing the factors of the global macroenvironment and microenvironment of an industrial holding, as well as sources of information, which will allow the creation and maintenance of an up-to-date information system for monitoring the business environment. In addition, a conditional list of research work and typical tasks has been compiled that can be carried out in the process of conducting both fundamental analysis and applied research necessary to assess the environment of an industrial holding and identify key trends in its changes and areas of influence.

A critical analysis of the methods and tools for assessing the business environment directly allowed us to state a number of shortcomings and problems of using traditional approaches and methods in the context of globalization and the dynamic interaction of an industrial holding with its environment. In this regard, the expediency of using intelligent systems based on traditional methods and neural network modeling technologies is substantiated in the work.

The use of fuzzy set theory makes it possible to overcome the disadvantages of probabilistic and minimax approaches [40,41], as well as to coordinate various management decisions in the presence of fuzzy goals, constraints, coefficients and initial conditions. The approach used in the work to assess the state of the external business environment of PJSC NOVATEK is characterized by the function of belonging to the corresponding fuzzy number, which allowed us to form a full range of possible scenarios for the state of the holding. The advantage of combining a fuzzy output system with an analytical evaluation system is the possibility of using a single information space: source data for a fuzzy description and visualization results in the form of diagrams and data tables.

Moreover, using neural network computing, the work assessed how the advantages and disadvantages of the internal organization of PJSC NOVATEK affect the choice of its financial strategy. A significant advantage of the developed fuzzy model in comparison with known models is that the relationship between the input data and the output parameter is described using natural language concepts, which are objectively much "closer" to expert analysts than abstract mathematical concepts. This ensures a high level of adequacy of the formalization of expert knowledge about the impact of the indicators of the internal organization of the holding on its financial strategy.

5. Conclusions

Approbation of the use of fuzzy sets and SWOT analysis tools for the analysis of the external business environment was carried out on the example of PJSC NOVATEK.

To assess the state and degree of influence of the business environment on the implementation of the financial strategy of the Russian industrial holding, an algorithm was developed in the course of the study that enabled us to obtain an integral assessment of the impact of external and internal factors of the business environment of the industrial holding using taxonomy methods, multidimensional statistical analysis, cluster and discriminant models. The result of applying this algorithm in practice are econometric dynamic models of the causal interaction of factors of the external and internal environment, which make it possible to make a reasonable forecast of the financial condition of the holding and determine strategies for its further development.

Based on the obtained research results, this paper identifies the key factors of the internal and external business environment of an industrial holding that form the opportunities and threats of its effective development through the prism of the implementation of a financial strategy. In the system of factors of the external business environment, a group of formative factors, regulatory and warning factors are identified, which make it possible to assess the external competitive environment of an industrial holding and the economic situation in the country as a whole. The system of factors of the internal environment includes a group of information, investment, personnel and innovation factors, a comparative analysis of which will determine the internal reserves for the implementation of the financial strategy, as well as the possibilities of ensuring the stability and stability of the functioning of the industrial holding as a whole.

The perspective of the research is the development of a system of sub-indices for making important decisions on key areas of development of the energy holding. To do this, subordination will be introduced into the system of factors in the form of the formation of priority cereals and the aggregation of several indicators into one group. Based on the solution of such a question, the question of the optimal distribution of investments among the companies (divisions) of the holding will be raised. The economic effect will be a further increase in the holding's profit.

Author Contributions: Conceptualization, G.P.; methodology, N.S.; software, A.B.; formal analysis, A.K.; writing—original draft preparation, S.F.; writing—review and editing, S.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Belokrylova, O.; Belokrylov, K.; Tsygankov, S.; Syropyatov, V.; Streltsova, E. Public procurement quality assessment of a region: Regression analysis. *Int. J. Sociol. Soc. Policy* **2020**, *41*, 130–138. [CrossRef]
2. Bagirov, M.; Mateus, C. Oil prices, stock markets and firm performance: Evidence from Europe. *Int. Rev. Econ. Financ.* **2019**, *61*, 270–288. [CrossRef]
3. Alquist, R.; Kilian, L. What do we learn from the price of crude oil futures? *J. Appl. Econ.* **2010**, *25*, 539–573. [CrossRef]
4. Pukhov, E.; Volkov, E. Problems of capital structure management in an unfavorable business environment. *Manag. Issues* **2019**, *7*, 43.
5. Zabaznova, T. The essence of the business environment and the entrepreneurial environment in rural areas. *Terra Econ.* **2009**, *7*, 119.
6. Feoktistov, K. Features of the business environment of modern companies. *Quest. Theory Pract. Manag.* **2020**, *3*, 71.
7. Teplova, T.; Lysenko, V.; Sokolova, T. Shocks of supply and demand in the oil market, the equilibrium oil price and country responses of economic indicators. *Energy Syst.* **2019**, *10*, 843–869. [CrossRef]
8. Teplova, T.; Ruzanov, D. One Approach for Backtesting VaR Specifications in the Russian Stock Market. *Eng. Econ.* **2019**, *30*, 32–40. [CrossRef]
9. Leikin, D. *Corporate Center: Fundamentals of Holding Management*; Alpina Publisher: Moscow, Russia, 2017; p. 79.
10. Zavalishin, A. Intensity of corporate integration in the industry of the Russian Federation. *Issues Econ. Manag.* **2020**, *3*, 34.
11. Sudhir, R. Advancing Financial Strategies to Achieve Financial Well-being. *FIIB Bus. Rev.* **2020**, *9*, 73–74.
12. Hansell, D.; Rafi, B. Firm-Level Analysis Using the ABS' Business Longitudinal Analysis Data Environment (BLADE). *Aust. Econ. Rev.* **2018**, *51*, 132–138. [CrossRef]
13. Contribution to Management Science. *Strategic Priorities in Competitive Environments: Multidimensional Approaches for Business Success*; Dincer, H., Yüksel, S., Eds.; Springer: Cham, Switzerland, 2020; p. 356.
14. Contractor, F.J.; Dangol, R.; Nuruzzaman, N.; Raghunath, S. How do country regulations and business environment impact foreign direct investment (FDI) inflows? *Int. Bus. Rev.* **2020**, *29*, 101640. [CrossRef]
15. Borodin, A.; Mityushina, I.; Streltsova, E.; Kulikov, A.; Yakovenko, I.; Namitulina, A. Mathematical Modeling for Financial Analysis of an Enterprise: Motivating of Not Open Innovation. *J. Open Innov. Technol. Mark. Complex.* **2021**, *7*, 79. [CrossRef]
16. Timofeeva, N.Y. Forecasting the level of profitability of agricultural products of the Lipetsk region. *Mod. Econ. Probl. Solut.* **2017**, *7*, 129–135.
17. Borodin, A.; Mityushina, I. Evaluating the effectiveness of companies using the DEA method. *Nauk. Visnyk Natsionalnoho Hirnychoho Universytetu* **2020**, *6*, 193–197. [CrossRef]
18. Sudakov, V.A.; Titov, Y.P. Calculation of time to complete a task by a group of employees using fuzzy sets for the sustainable development of the enterprise. *Entrep. Sustain. Issues* **2020**, *8*, 1001–1011. [CrossRef]
19. Alti, A.; Titman, S. A Dynamic Model of Characteristic-Based Return Predictability. *SSRN Electron. J.* **2017**, *74*, 3187–3216. [CrossRef]
20. Addoum, J.M.; Delikouras, S.; Korniotis, G.M.; Kumar, A. Income Hedging, Dynamic Style Preferences, and Return Predictability. *J. Financ.* **2019**, *74*, 2055–2106. [CrossRef]
21. Bouchaud, J.; Krüger, P.; Landier, A.; Thesmar, D. Sticky Expectations and the Profitability Anomaly. *J. Financ.* **2018**, *74*, 639–674. [CrossRef]
22. Weisbrod, E. Stockholders' Unrealized Returns and the Market Reaction to Financial Disclosures. *J. Financ.* **2018**, *74*, 899–942. [CrossRef]
23. Chiang, C.; Dai, W.; Fan, J.; Hong, H.; Tu, J. Robust Measures of Earnings Surprises. *J. Financ.* **2018**, *74*, 943–983. [CrossRef]
24. Malloy, C.; Moskowitz, T.; Vissing-Jørgensen, A. Long-run stockholder consumption risk and asset returns. *J. Financ.* **2009**, *64*, 2427–2479. [CrossRef]
25. Pastor, L.; Stambaugh, R.F. Predictive Systems: Living with Imperfect Predictors. *SSRN Electron. J.* **2008**, *64*, 1583–1628. [CrossRef]
26. Andryeyeva, N.; Nikishyna, O.; Burkynskyi, B.; Khumarova, N.; Laiko, O.; Tiutiunnyk, H. Methodology of analysis of the influence of the economic policy of the state on the environment. *Insights Reg. Dev.* **2021**, *3*, 198–212. [CrossRef]
27. Grenčíková, A.; Navickas, V.; Kordoš, M.; Húževka, M. Slovak business environment development under the industry 4.0 and global pandemic outbreak issues. *Entrep. Sustain. Issues* **2021**, *8*, 164–179. [CrossRef]
28. Becheikh, N. Political stability and economic growth in developing economies: Lessons from Morocco, Tunisia and Egypt ten years after the Arab Spring. *Insights Reg. Dev.* **2021**, *3*, 229–251. [CrossRef]
29. Livdan, D.; Sapriza, H.; Zhang, L. Financially Constrained Stock Returns. *SSRN Electron. J.* **2006**, *64*, 1827–1862. [CrossRef]
30. Fama, E.; French, K. The corporate cost of capital and the return on corporate investment. *J. Financ.* **1999**, *54*, 1939–1967. [CrossRef]
31. Wierzbiński, M. Management accounting in the identification of opportunities and threats for business model in external environment of the company. *Pr. Nauk. Uniw. Ekon. We Wrocławiu* **2016**, *424*, 212–229.
32. IntechOpen. *Fuzzy Logic*; Volosencu, C., Ed.; IntechOpen: London, UK, 2020; p. 632.
33. Ivanyuk, V.; Abdikeev, N.; Pashchenko, F. Neural network model of multivariate analysis of the economic efficiency of the enterprise. *Sens. Syst.* **2019**, *10*, 9–17.
34. Afanasyev, D.O.; Fedorova, E.A.; Gilenko, E.V. The fundamental drivers of electricity price: A multi-scale adaptive regression analysis. *Empir. Econ.* **2021**, *60*, 1913–1938. [CrossRef]

35. Méndez-Suárez, M.; García-Fernández, F.; Gallardo, F. Artificial Intelligence Modelling Framework for Financial Automated Advising in the Copper Market. *J. Open Innov. Technol. Mark. Complex.* **2019**, *5*, 81. [CrossRef]
36. Hu, Y.-C.; Tseng, F.-M. Functional-link net with fuzzy integral for bankruptcy prediction. *Neurocomputing* **2007**, *70*, 2959–2968. [CrossRef]
37. Chiu, M.-C.; Chen, T.-C.T.; Hsu, K.-W. Modeling an Uncertain Productivity Learning Process Using an Interval Fuzzy Methodology. *Mathematics* **2020**, *8*, 998. [CrossRef]
38. Vasylieva, T.; Jurgilewicz, O.; Poliakh, S.; Tvaronavičienė, M.; Hydzik, P. Problems of measuring country's financial security. *J. Int. Stud.* **2020**, *13*, 329–346. [CrossRef]
39. Cui, J.; Liu, S.-F.; Zeng, B.; Xie, N.-M. A novel grey forecasting model and its optimization. *Appl. Math. Model.* **2013**, *37*, 4399–4406. [CrossRef]
40. Borodin, A.; Tvaronavičienė, M.; Vygodcyikova, I.; Kulikov, A.; Panaedova, G. Optimization of the Structure of the Investment Portfolio of High-Tech Companies Based on the Minimax Criterion. *Energies* **2021**, *14*, 4647. [CrossRef]
41. Borodin, A.; Tvaronavičienė, M.; Vygodcyikova, I.; Kulikov, A.; Skuratova, M.; Shchegolevatykh, N. Improving the Development Technology of an Oil and Gas Company Using the Minimax Optimality Criterion. *Energies* **2021**, *14*, 3177. [CrossRef]

energies

Article

Modeling Multivalued Dynamic Series of Financial Indexes on the Basis of Minimax Approximation

Zahid Mamedov [1], Irina Vygodchikova [2], Ayaz Aliev [3,*], Lira Gurieva [4] and Natalia Rud [5]

[1] Department of Finance and Financial Institutions, Azerbaijan State University of Economics, Baku 1001, Azerbaijan; prof.zahid.mamed@mail.ru
[2] Department of Differential Equations & Mathematic Economics, National Research Saratov State University Named after N. G. Chernyshevsky, 410012 Saratov, Russia; irinavigod@yandex.ru
[3] Department of Financial Management, Plekhanov Russian University of Economics, 117997 Moscow, Russia
[4] Department of Management, North Ossetian State University Named after K. L. Khetagurov, 362025 Vladikavkaz, Russia; 443879@mail.ru
[5] Department of World Economy and Customs, North-Caucasus Federal University, 357502 Pyatigorski, Russia; rud-td@yandex.ru
* Correspondence: aliev.aao@rea.ru

Abstract: In this article, the problem of modeling a time series using the Minimax method is considered. The expediency of using Minimax to identify points of change in trends and the range of changes in the graphical figures of technical analysis is justified. Spline approximation of the dynamic process with range constraints was performed to improve the quality of the model. Investors are advised to refrain from making hasty decisions in favor of holding reliable shares (such as PJSC Novatek shares), rather than selling them. The purchase of new shares should be carefully analyzed. Through an approximation of the dynamic number of the applicable optimization problem of minimizing the maximum Hausdorff distances between the ranges of the dynamic series and the values of the approximating function, the applied approach can provide reliable justification for signals to buy shares. Energy policy occupies the highest place in the list of progress ratings according to news analytics of businesses related to the energy sector of the economy. At the same time, statistical indicators and technologies of expert developments in this field, including intellectual analysis, can become an important basis for the development of a robotic knowledge program in the field under study, an organic addition to which is the authors' methodology of development in energy economics as in energy policy. This paper examines the model of approximation of the multivalued time series of PJSC Novatek, represented as a series of ranges of numerical values of the indicators of financial markets, with constraints on the approximating function. The authors consider it advisable for promising companies to apply this approach for successful long-term investment.

Keywords: Minimax; dynamic ranges; multivalued dynamic series; Hausdorff distances; approximation model; constraint; financial market

Citation: Mamedov, Z.; Vygodchikova, I.; Aliev, A.; Gurieva, L.; Rud, N. Modeling Multivalued Dynamic Series of Financial Indexes on the Basis of Minimax Approximation. *Energies* **2022**, *15*, 366. https://doi.org/10.3390/en15010366

Academic Editor: Periklis Gogas

Received: 3 December 2021
Accepted: 22 December 2021
Published: 5 January 2022

1. Introduction

The problem of multivalued dynamic series (in particular, interval data analysis) is the most important problem facing the modern e-business industry and technological development [1,2]. An industry company can and should take its rightful place if it has a high potential in terms of internal factors, external conditions and financial leverage [2–7]. Due to the recent avalanche-like growth [8] of the volume of information, both internal and external, well-known data processing methods, such as methods of adaptive time series forecasting, one-dimensional and multidimensional GARCH models, copula models, methods of wavelet analysis, neural networks, and many others [9–13], are no longer applicable. Moreover, with an increase in the volume of heterogeneous and unstable information, these methods can produce significant and uncritical results, while the use of filtering and smoothing of data leads to a decrease in the quality of the obtained model due to the loss of significant information about the analyzed process [14], so it cannot be used as the basis of the toolkit [15–17]. The problems of modeling a time series using various methods were studied by many authors, including, D.A. Dickey, W.A. Fuller [18]), C.A. Sims et al. [19], and Schumaker L.L. [20]. However, the question of mathematical modeling of the multivalued dynamic series regardless of the distribution law, with additional restrictions, has received little attention from researchers. In this paper, multivalued dynamic series is the term used to define a sequence ordered in time ranges of the numerical values of a given object. Current research does not consider the criterion of uniform approximation for use in multivalued mappings using the Hausdorff distance [21], including the restrictions on the approximating function. One of the effective methods for the analysis of unambiguous time series of different natures is the criterion of uniform approximation described by Chebyshev [22]. However, when considering the ranks of the specified ranges, there is a problem with the rationale behind the selection of the point inside the range, which makes it possible to achieve the most adequate model approximation. It is especially difficult [23] to resolve this issue if there is no information about the law distribution of the financial indexes within the range.

Reducing approximation errors makes it possible to produce a forecast using standard technical analysis indicators (MA, ROC, MACD, ETC.). However, the use of technical analysis indicators does not solve the problem of creating a noise-resistant decision-making model, with justification based on mathematical trend optimization. The trend in technical analysis is perceived so narrowly that it can be the result of an intuitive decision or the successful selection of a graphical scale, designed in terms of an interval or line chart. The high level of competition in the energy and oil and gas industries requires a model that allows the investor to apply a buy signal-oriented approach when they wish to buy new shares in the company of interest.

As an assumption, it is necessary to take into account the regular receipt of dividends and the desire to invest more money in the company in order to increase the well-being and the success of the company. This approach is not a form of technical analysis; on the contrary, it is part of fundamental analytics in terms of applying technical analysis signals to replenish the portfolio with new shares in the company of interest at a good price.

Of course, the sale is also possible if the investor needs money. Such decisions are rare; the main goal is confidence in stability. Stability can be achieved by a competent approximation, according to the key data identified in the complex analysis based on the Minimax criterion and the Hausdorff metric. This approach is fundamentally new and has not previously been considered in research. The fundamental basis of Minimax and algorithmization is laid down in [24–26]. Econometric analyses of robust (noise-resistant) estimates based on standard methods are presented in the works of many authors [27], but the criterion of noise filtering refers to the OLS zone or fuzzy logic; in this paper, we offer a reliable and balanced method and guarantee its high stability compared to standard methods, confirmed by practice. The new method can be safely applied in practice; there is not a single limitation, except for the presence of an algorithmic database and qualified programmers-analysts who are able to perform the data processing according to the author's methodology.

In [28], the emphasis is on econometric forecasts, taking into account the apparatus that existed earlier. The authors propose a fundamentally new apparatus that makes it possible to take into account non-stationary influences and noises (several of the most important), based on sound mathematical tools. The advantage of this approach is the ability to do without other tools; that is, integrity and self-sufficiency increase the accuracy of problem-solving. There are no contradictions with standard approaches; however, standard approaches do not always work, and our goal is to expand the fundamental base of analysis and evaluation and make a reasonable decision on forecasting.

In earlier works, we considered methods for modeling interval data and spline approximation models based on the Hausdorff distance and the Minimax criterion. We proposed a mathematical justification for a new method for modeling the estimated characteristics of time series using the Minimax criterion for a linear multiple regression model. The approach of modeling dynamic series of interval data in the Hausdorff metric is applied, differences are revealed in comparison with other works where distances between graphs are considered, and a uniform metric is adopted when the deviation of the segment (interval) from the value of the polynomial is taken point-by-point, after which the maximum of these values is calculated, which should be minimized by choosing the coefficients of the polynomial. The approach featured alternative properties, which include a far-reaching continuation of the properties of the Chebyshev model, by selecting a number of nodes that carry all the key information about the process, the number of which does not exceed the power of the polynomial by two. The fundamental difference was the construction of the so-called amplitude functions proposed by the author and the complete solution of the problem, even if it is ambiguous. This model already makes it possible to select the joining points of the splines. Further, the constraints made it possible not only to improve the model mathematically, but also to proceed to the approximation by combined splines with exact moments of joining. However, in this earlier paper, the restrictions on the joining of splines were precise, in contrast to the current study, in which the restrictions were reduced to ranges, thereby increasing the accuracy of the model. In addition, in contrast to previous studies, we propose a hierarchical procedure for finding the points of joining of splines. Each subsequent spline receives an improved mode of joining, which makes it possible to build a high-precision model suitable for identifying graphic shapes and forecasting. The novelty of this study lies in the use of the Hausdorff distance in the model, the improvement of the approximation model due to splines with dynamic (interval) constraints, and the iterative procedure for selecting the points of joining of splines.

We propose not only a method, but also a computerized system of the computational process and an algorithm for implementing the approach.

The statistical apparatus of interval data is developed in [29,30]. The proposed apparatus of mathematical statistics of interval data allowed us to create a mathematical basis for processing dynamic series of interval data. However, the methods of analysis, approximation, estimation, and forecasting contain a set of data regularization techniques, fuzzy logic principles, and probabilistic approaches that make it possible to obtain a solution to a particular problem by taking into account the interval setting of the parameters. The task becomes more complex, data processing slows down, and decision-making cannot contain clear recommendations. However, the solution to these problems is obtained in terms of the theory of fuzzy sets; it retains a high degree of uncertainty, and its reliability depends on the values of the argument. As an approximation criterion, we use a modified Minimax, which requires the introduction of weight coefficients for different points, the evaluation of which introduces an additional error into the resulting solution. When working with noisy data obtained as a result of superimposing a signal over different time periods, the problem of choosing an approximation criterion that is resistant to the type of noise arises. Traditionally, data are transformed to filter or smooth out noise effects, because it is believed that they create the maximum volatility. However, it is possible to lose useful information about the process, since the law governing the distribution of the indicator within different noise intervals may not be known or defined, which prevents the use of mixed probabilistic models. In such cases, it is advisable to use methods that are more resistant to the influence of local noise approximation methods. One of these is the Minimax criterion. When approximating a dynamic series of interval data, it is advisable to minimize the maximum distance from the approximating function to the far end of the range (that is, the maximum of the Hausdorff distances between the values of the function and the fixed ranges of the indicator).

The purpose of this article is to develop a methodology and tools for decision-making based on the use Minimax approximation multivalued [31,32] dynamic series of financial indexes in the Hausdorff metric.

The object of the study is the interval data obtained from the results of trading Novatec shares.

The subject of the research is instrumental tools in financial markets and mathematical programming of decisions, based on the Hausdorff metric.

The research hypothesis is as follows. The high level of uncertainty in stock market dynamics can be overcome by using the Hausdorff metric and Minimax approximation principle; the economic effect will be an increase in the investor's profit [33]. This model can be used for forecasting in isolation or in conjunction with other known methods of processing dynamic series.

Many works are devoted to the construction of financial and practical models in the field of financial management of large companies that create the oil and gas base of a given country. Such companies as PJSC Gazprom, PJSC Rosneft, PJSC Lukoil, PJSC Surgutneftegaz, and PJSC Novatek provide an opportunity to analyze the current level of the created energy structure and to understand the optimal form of managerial influence on the process in order to improve the development of promising companies. Many modern scientists are engaged in research in the field of financial monitoring and energy policy. Thus, in the work by Sun et al. (2021), an effective predictive model of risk factors associated with volatility was developed based on the statistical apparatus and modeling of an expert system based on neural network technology. However, the stability parameters of this model depend on the mode of forecasting oil price fluctuations caused by changes in both fundamental and transient risk factors. Achieving the disintegration of the multi-scale risk structure of the crude oil market using the decomposition of the variation mode is a very difficult task, even taking into account modern computerized systems; the solution must be repeatedly tested, and the statistical parameters may change, which is a separate problem. Other modeling approaches that serve as high-stability filters, such as the Minimax model, are needed. The Hausdorff metric makes it possible to take into account the noise-tolerant filter mode for constructing a multi-mode spline model in the interval data mode.

Aguirre and Ibikunle (2014) examined the factors influencing the growth of renewable energy sources at the level of raw material supplier countries, applying a sample analysis and evaluation of the backbone companies of the partner companies in the raw material structural complexes, including Brazil, Russia, India, China and South Africa. We use methods based on the far-reaching generalization and development of the least squares method (OLS) and its modifications, in terms of improving the FEVD model to PCSE, for sampling data on long and short ranges. However, these methods are not without the disadvantages inherent in all statistical estimates: strong dependence on changes in data, the complexity of diagnosing the key moments of trend changes to obtain a spline approximation, and low resistance to the interference associated with random errors and external factors. The use of interval data in the implementation of this model is not possible, which shows the feasibility of our approach.

A fundamentally new approach based on robust (noise-resistant) risk assessments is considered in [34]. Related models are based on the principles of Minimax optmimization over a non-smooth convex functional. These include, for example, a model based on the Chebyshev problem, a far-reaching generalization to interval data, which is our novel approach to the research problem of estimating, approximating, and modeling interval data, taking into account the constraints for both single-valued and multi-valued data. However, the problems associated with the complexity of modeling interval data in the spline approximation of stock market dynamics for an oil and gas company are not considered in this paper.

The authors of [35–38] diagnose the fact that in the Russian energy and gas complex, many system-forming companies and raw materials structures are unable to raise capital for the development of high technologies, and therefore are required to sell raw materials at the minimum market price. The pricing policy is also not significantly aimed at the development of high-tech exports, due to the fragmented valuation base. The authors touch upon the problems of the policy in the field of the energy complex, aimed at decentralization, efficiency, and economy. As for the oil industry, such problems are particularly acute. We need mathematical models that implement the solution to the problem in the optimization mode.

In the works of the mathematicians, Subbotin et al., the spline approximation is based on achieving an optimal function over the entire analytical segment [39–41]. Unlike similar works, the authors focus on econometric forecasts, taking into account their own Minimax methodology, which are localized and improved (due to limitations) when new data appear; it is the improvement of fragmentary dynamics, and not revision, that makes it possible to make optimal decisions. Our approach does not contradict the known methods; it is an independent theoretical and reliable method, worthy of existence on a par with other methods of approximation of dynamic processes. Practice shows that at present, our methodology works better than standard methods based on MNCs, approximation by trigonometric polynomials, wavelets, and fuzzy logic methods.

We indicate the need to introduce mathematical models, such as the wavelet analysis of dynamic series [42]. This method is advisable to use when evaluating dynamic series. The disadvantage is the high complexity of the model problem and the need to use unique software. The Minimax approach, like the wavelet analysis, allows us to evaluate problem situations and key points ("bursts" of changes), but it features a noise-resistant zone, the possibility of using interval data, the introduction of limiting conditions, and high-level algorithms with a highly efficient block of software calculations, which we mathematically justify.

2. Mathematical Model of Minimax

Designations: t_k—the number of the period when stock prices were fixed (trading days), from the minimum $y_{1,k}$ up to the maximum $y_{2,k}$. We have the multivalued dynamic series of financials (Hall and Lemer, 2010), market index (for example, price of share). For every point, t_k, we introduce into consideration the set of points (grid): $T = \{t_0 < \ldots t_k \ldots < t_N\}$. The following stock price values are recorded in each node of the grid T: $y_{2,k}$ is the top and $y_{1,k}$ the bottom bound of price, so the range (all boundaries included) is $[y_{1,k}; y_{2,k}]$, so $y_{1,k} \leq y_{2,k}$, k = 0, . . . ,N.

A mathematical model of multivalued time series (interval time series) is represented as algebraic polynomial of n degree with coefficients as components of vector A (unknown variables in the problem):

$$p_n(A, t_k) = a_0 + a_1 t_k + \ldots + a_n {t_k}^n /$$

Therefore, we need to determine [35] the coefficients of the polynomial

$$A = (a_0, a_1, \ldots, a_n) \in R^{n+1}$$

Consider at each point (node) of the discrete grid T the Hausdorff distance between the price range and the value of the polynomial (the coefficients of which should be calculated). Given that the value of the polynomial is a single point, this distance can be written as:

$$f(A, k) = \max\{y_{2,k} - p_n(A, t_k); p_n(A, t_k) - y_{1,k}\},\ k = 0, \ldots, N.$$

In our approach, the polynomial coefficients are found based on the problem of minimizing the maximum of the Hausdorff distance for a given discrete time series [43].

Next, we select the maximum of such distances and obtain the objective function $\rho(A)$, which should be minimized:

$$\rho(A) = \max_{k=0,\ldots,N} f(A, k) \to \min_{A \in R^{n+1}} \quad (1)$$

In expression (1), the minimum is the objective function containing the maximum of their components, each of which expresses the maximum deviation of the value of the approximating function from the upper bound of the approximated range, and is the main criterion (Minimax).

Note that prior research did not consider the application of the criterion of uniform approximation for multivalued mappings using the Hausdorff distance.

In [44], solving the problem without constraints does not satisfy the required constraints; that is, the constraints are significant.

Problem (1) belongs to the field of non-smooth convex analysis, but the solution is achieved using our approach, which is a far-reaching generalization of the problem of approximating a single-valued discrete function by an algebraic polynomial of fixed degree.

The purpose of the further analysis was to develop a method of approximation for ranges that would be more successful than the one obtained using the method of least squares.

To this end, as the approximation criterion we use the distance (metric) Hausdorff. Hausdorff distance for some discrete values t_k equals the maximum of the difference between the highest value of the index $y_{2,k}$ and the value of the algebraic polynomial, and the difference between the value of algebraic polynomial and the lowest value of the index $y_{1,k}$.

The use of the least squares method does not always lead to success, since the indicator prediction is aimed at the latest data, which is used to verify the significance of the process. However, the data could be fundamentally larger and the level of significance and the forecast change after each new event, which we perceive as a projection of the data sample on the real picture of the dynamic series. The subsequent errors are high, and the key points of changing dynamics have to be found among the nodes of the revision of the trend indicators of the technical analysis.

We conducted a series of experiments aimed at developing the Minimax approach (the Nausdorff metric) and improving it for predicting dynamic series of interval data with limiting conditions and modified data ranges, aimed at the accurate joining of splines.

It should be noted that the Minimax method for interval data and "range" type constraints was tested in practice (ten solid companies were identified, in terms of financial condition, with market indicators worthy of investors' attention (the opportunity to buy shares in an open sale)).

Currency markets, due to the restrictions adopted in 2020, were not considered in this study.

Thus, important companies were filtered out and experiments were performed. The highest level of success was demonstrated by the company PJSC Novatek, which showed a growth in the indicators used in the fundamental analysis (rating, financial integral index, return on equity). At the same time, the ratio of borrowed sources of financing of PJSC Novatek to its own sources of financing, as an indicator of risk, was lower than that of the leading companies of competing industries (PJSC Gazprom is certainly better in all the indicators; however, this is not a struggle for a place in the oil and gas industry, on the contrary, orientation towards the market leader makes it possible to create a healthy position in the industry for each company and turn competitors into friendly developing parties to the overall process of knowledge-intensive technological development for leading Russian industries).

3. Methodology

3.1. Constraints of Type Equality

In order to obtain a significant approximation and identify key points, the general trend, and significant trend breaks, as well as to obtain a long-term forecast, we propose to use a combined methodology based on the search for key events for the moments of coupling of the saplines and the choice of the optimal mode of coupling within the range of constraints, assuming the dynamic inclusion of the coupling moment from the bottom to the upper limit of the range of constraints. We substantiate the essential role of the bounds that allow us to find the n solution in a finite number of iterations of the method.

The internal points of the docking ranges do not significantly affect the solution of the problem, as in the "interrupted range" alternance. We introduced the term to interpret the phenomenon of alternation in the maximum deviation from the lower (upper) boundaries of the initial dynamic series, taking into account changes in each subsequent node; the interruption of the alternation is caused by a constraint and depends on the nature of the deviation in the last node.

The introduction of modifications related to additional constraints requires the introduction of a new algorithmic solution to problem (1).

Such a solution to the problem of approximation modeling of a nonstationary noisy process is obtained in the work of [45]. This article proposes a methodology for predicting the stabilization level of a chaotically developing system based on Minimax estimates of the model quality and our indicators of the instantaneous elasticity of the process, which allow us to judge the dynamics of the global trend.

The system of formation of spline forecasting on the last segment of the analysis using the Minimax approach is developed, the joining of splines for conditional approximation occurs according to a mathematically based algorithm.

Such a solution to the problem of approximation modeling of a nonstationary noisy process is obtained in the work of [46]. The resulting solution is tested for evaluating the parameters of economic functions, for making informed decisions in the field of financial management, and for approximating non-standard, noisy and stepwise developing dynamic processes (demography, financial markets, medicine, mechanics, communications and telecommunications.

In [46], we propose a methodology for predicting the stabilization level of a chaotically developing system based on Minimax estimates of the model quality and the author's indicators of the instantaneous elasticity of the process, which allow us to judge the dynamics of the global trend.

In [47], analytical experiments were performed for the company PJSC ROSSETI. The "Rosseti" experiments provided real data; the aim of investigation was the development of a system for the formation of spline forecasting in the last segment of the analysis using the Minimax approach. The joining of splines for conditional approximation occurs according to a mathematically based algorithm.

The proposed methods are based on splines (n-polynomial, n-1,2 at maximum, at combination) in the Minimax approach to optimal prognozation. We attempted to prove these theoretical propositions, so we created numerical methods of data analysis and approximation of data through complex decisions, but with several splines, which we developed the basis of Minimax approach and its application. The suggested method makes it possible to detect trends in the stock market at an early stage of analysis and to create reasonable trading strategies for shareholders and investors, as well as a procedure for predicting the stability loss and transition into chaos of a network of oscillators lying on a curve, where each of the oscillators can move in two perpendicular directions. The dynamics of the coupled oscillators are governed by the sixth-order PDE, which is directly derived using the classical hypotheses of a curvilinear flexible beam movement theory [48]. Was applied the FDM (Finite Difference Method) to reduce PDEs into ODEs, and reach an optimal number of calculation studies and algorithm steps, as well as to obtain spatial coordination of a number oscillators that were involved in the approximating methodology due to the dynamics of our continuous structural member, as important key positions, with the overall aim of achieving stability.

The new methodology and procedure offer many advantages over the classical approaches, and make it possible to approach the connection of splices using complex algorithms and the Minimax approach, presiding in real time over key moments (connection points). The new methodology is illustrated and discussed through a fundamental analysis of the company PJSC Novatek.

Consider the criterion (1), for example, for the limits associated with the condition of a fixed location of a point in an algebraic polynomial at a grid node, $t_s \in T$: $p_n(A, t_s) = y_s$ [49]:

$$\rho(A) = \max_{k=0,\dots,N} f(A,k) \to \min_{A \in D},$$
$$D = \left\{ A \in R^{n+1} : p_n(A, t_s) = y_s \right\},\ t_s \in T \tag{2}$$

Give algorithm for the situation when $y_{2,s} = y_{1,s} := y_s$. In [50] it is proven that this is the only decision. The solution to the problem (2) consists of two main stages: (1) the problem (1) is solved if the solution belongs to the set D, then the process is completed; the case when such a condition is not fulfilled is fundamentally interesting.

Let us introduce the notation. The basis is an ordered set of (n + 2) points of the form

$$\sigma = \left\{ t_{j_0} < \dots < t_{j_{n+1}} \right\} \subset T.$$

We consider the bases for which $t_s \in T$.

With the amplitude on the basis of σ, we call the functions $\phi_{1-i,k}(\sigma)$ defined by the formulas:

$$\varphi_{1-i,k}(\sigma) = \begin{cases} iy_{2,j_k} + (1-i)y_{1,j_k}, k - even, \\ iy_{1,j_k} + (1-i)y_{2,j_k},\ k\ -\ odd, \end{cases}$$
$$k = 0, \dots, (n+1), i = 0\ or\ i = 1. \tag{3}$$

We formulate discrete Chebyshev problems for amplitude functions [51]:

$$\rho_i(A, \sigma) = \max_{k=\overline{0,n+1}} \left| \varphi_{i,k}(\sigma) - p_n(A, t_{j_k}) \right| \to \min_{A \in R^{n+1}},$$
$$i = 0, 1.$$

By the criterion of solving a discrete Chebyshev problem, the numbers for problems (3) are uniquely determined $h_0(\sigma)$ and $h_1(\sigma)$, satisfying the equalities (for $i = 0$ or $i = 1$):

$$h_i(\sigma) = \begin{cases} y_{2,j_k} - p_n(A_i(\sigma),\ t_{j_k}), (k+i) - even, \\ -y_{1,j_k} + p_n(A_i(\sigma),\ t_{j_k}), (k+i) - odd, \end{cases}$$
$$\rho_i(A, \sigma) = h_i(\sigma),$$
$$k = \overline{0, n+1}.$$

Next, as follows from [52], problem (2) features an unambiguous solution. A subtask of the problem (2) is considered on each basis. To find the coefficients of the approximating polynomial in problem (2) it is necessary to carry out the iterative solution of systems of linear equations (to avoid redundancy in characters, the argument (σ) by $\varphi_{i\ ,\ k}(\sigma), h_i(\sigma)$ omit, use $\varphi_{i\ ,\ k}$ and h_i):

$$\phi_{0,j_k} - p_n(A_0, t_{j_k}) = (-1)^k h_0,\ k = \overline{0, n+1} \backslash \{r\}$$
$$,\ p_n(A, t_{j_r}) = y_s,$$

or

$$\phi_{1,j_k} - p_n(A_1, t_{j_k}) = (-1)^k h_1,\ k = \overline{0, n+1} \backslash \{r\}$$
$$,\ p_n(A, t_{j_r}) = y_s, t_s = t_{j_r}$$

The solution will be polynomial coefficients A_i, for which turned out $\rho(A) = h_i$ for i = 0 or i = 1.

From the original multivalued time series, (n + 2) selector corresponding to a discrete ascending points in time t_{j_k}, $k = 0, \dots, n+1$ is selected arbitrarily; the knot t_s must necessarily be present among these nodes.

Were considered two variants of the choices from among the tops and bottoms of the ranges.

Each time alternates the upper, the lower bound of the range, as before, by considering the two choices of bound of the range directly left and right of the point constraints: the first option is taken from the upper bounds of the ranges, and, in the second embodiment, from the lower bounds of the ranges. The procedure for changing the basis is optimized [53].

3.2. Splines by Range Constraints

Considering the criterion (1), the next constraints are used [54], so we receive the following problem:

$$\rho(A) = \max_{k=1,\ldots,N} f(A,k) \to \min_{A \in DD} \quad (4)$$

where

$$DD = \left\{ A \in R^{n+1} : u_{1,s_j} \le p_n(A, t_{s_j}) \le u_{2,s_j} \right\}, \\ u_{1,s_j} < u_{2,s_j},\ t_{s_j} \in T, s_j \in \{0, \ldots, N\} \quad (5)$$

The polynomial at (4)–(5) in the all points t_{s_j} must be included in the ranges $[u_{1,s_j}; u_{2,s_j}]$.

From the original multivalued time series $(n + 2)$ selector corresponding to a discrete ascending points in time t_{j_k}, $k = 0, \ldots, n+1$ is selected arbitrarily; the knot all t_{s_j} must necessarily be among these nodes necessarily.

The choice of the selector of a multivalued mapping from (n + 2) is similar to paragraph 2. When we consider the top bound of the constraint "from left and from right", we use the top bounds of the ranges, but when considering the lower bound of constraint "from left and from right", we use the lower ends of the ranges.

In [55] it is proven that to obtain the coefficients of the approximating polynomial at (4)–(5), it is necessary to carry out the iterative solution of systems of linear equations. The iterative process is finite and leads to a decision that is proven through the optimal provided analysis of financial data.

4. Computational Experiments Splines, DSS (Decision Support System)

Spline approximation includes three stages (the decision support system, DSS, presented in Figure 1):

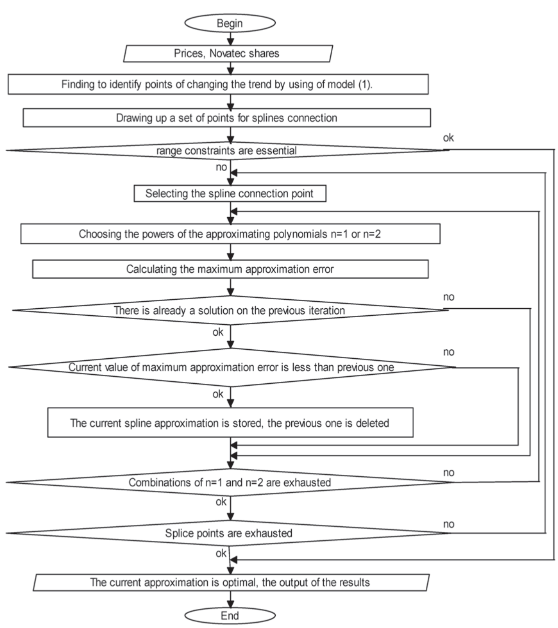


Figure 1. DSS. Justification for using Minimax presented in Figures 5–7 and Table 1.

Stage 1. Selection of spline joining points.

1.1 Finding points of change in the trend by using of model (1).
1.2 First approximation by model (2).

Stage 2. Improving the approximative properties of splines using range constraints.

2.1 Identification of ranges of changing graphical figures of technical analysis is justified [56].
2.2 Improving the approximative properties of splines by using model (3).

Stage 3. Forecast by last period.

3.1 Finding signal to buy shares.
3.2 Justification of signal.

Consider PJSC Novatek's stock trading history. The following prices are used: minimum and maximum for each day of trading as y_1 and y_2, respectively.

Stage 1. Selection of spline joining point, Figure 2.

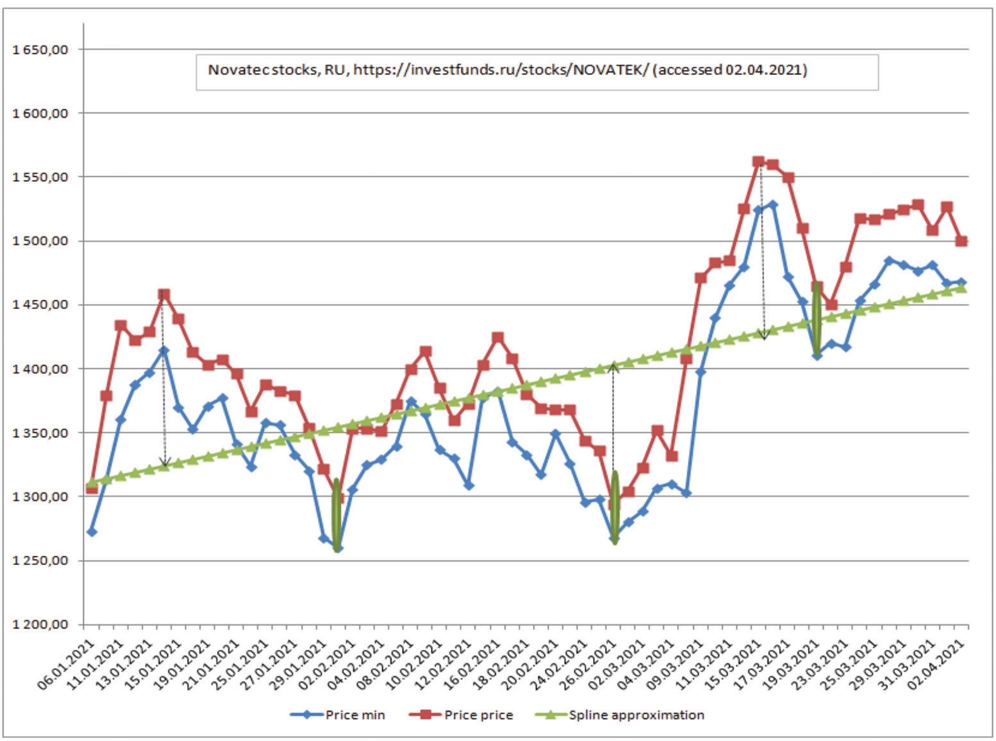


Figure 2. Spline joining points, selection (approximation error 10%).

Explaining this procedure, it is necessary to note the presence of five important conditional operators that are in the mode of hierarchical data analysis. At each stage, a full assessment of the basic solutions is performed, key points are found, and general data processing is performed, taking into account the specific interpretation of the constraints. The specificity makes it possible to remove unnecessary noise influence already at the second stage of data processing. The undoubted advantage of the model is the determination of the key process parameters to which the forecasting model is tied, and its stability at each stage, since the calculations performed are workable and involve the development in the implementation mode of spline coupling with optimal limiting parameters that preserve the integrity of the model.

5. Results

Since the approximation of the ranges PJSC Novatek was the most effective, it was used in the subsequent computation experiments.

Stage 2. Improving the approximative properties of splines using range constraints, Figures 3 and 4.

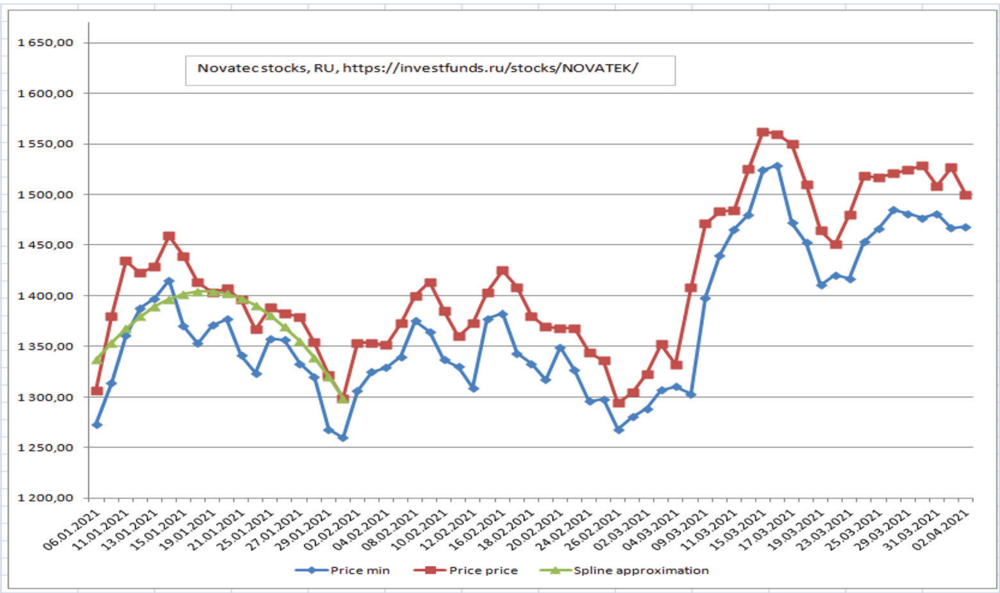


Figure 3. First approximation by model (2), approximation error 5%.

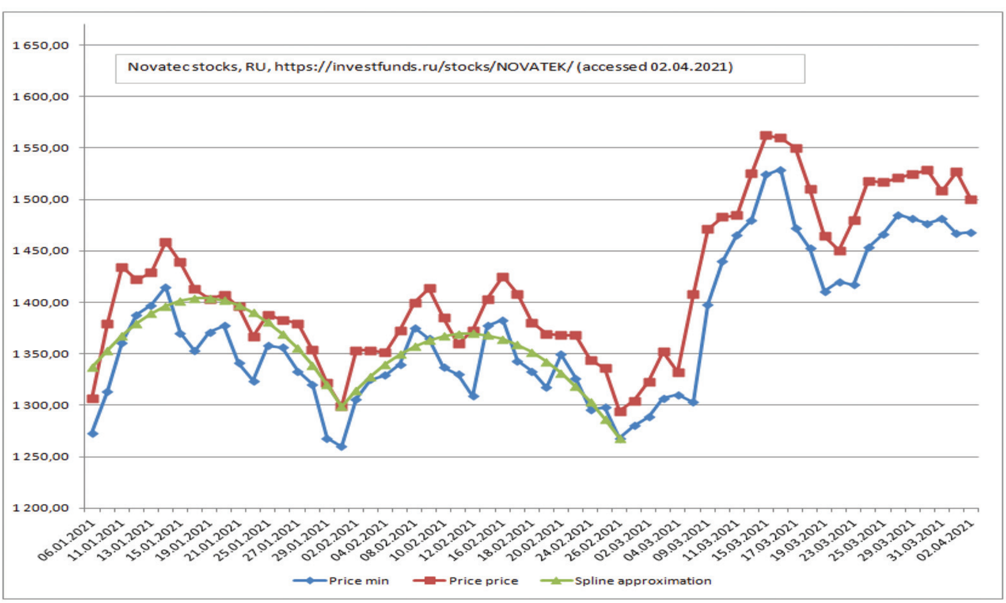


Figure 4. Second approximation by model (2), approximation error 5%.

Stage 3. Forecast by last period, stage by stage, to finish.

To justify the signal, until the end of the formation of the figure at the last stage, the investor should follow the current signals. Therefore, the investor should refrain from buying PJSC Novatek shares. If the round top is completed, the stock price will decline within 10 days, after which the investor should consider buying. If the stock price rises, investors should wait for the end of the formation of the "Head and Shoulders" figure, about a month or two; when they receive a stable signal, they should buy shares.

Furthermore, according to the last calculations, if Ordinary Least Squares, OLS, is applied with constraints, for time series, composed of the midpoints of the ranges, we obtain the following results. Assessments of the adequacy of the approximation models obtained using the three methods, for model illustration (PJSC Novatek), are presented in Figures 5–7 and Table 1.

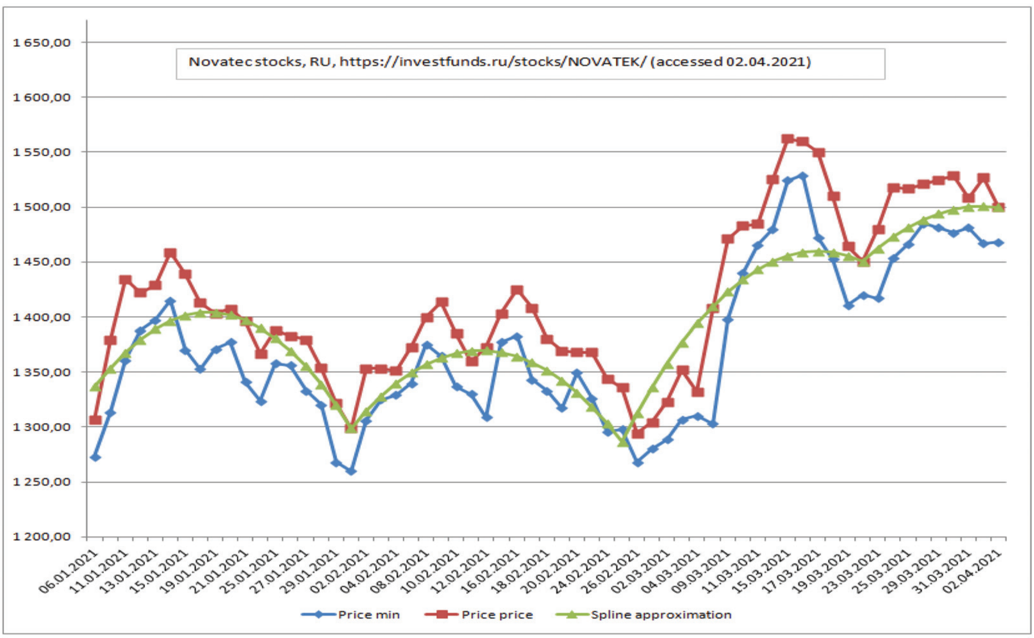


Figure 5. Improving the approximative properties of splines by using model (3), approximation error 3–6%, 3% at last period.

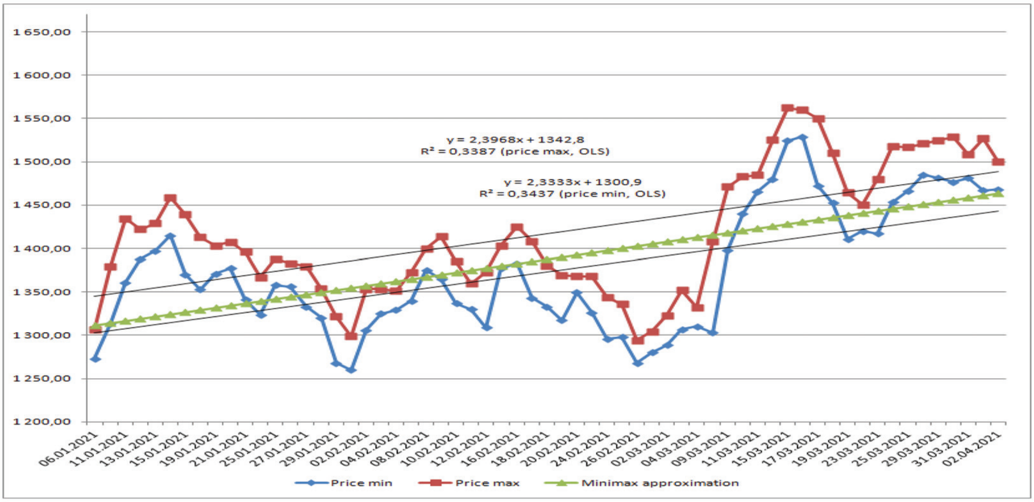


Figure 6. Minimax and OLS approximation (n = 1, line).

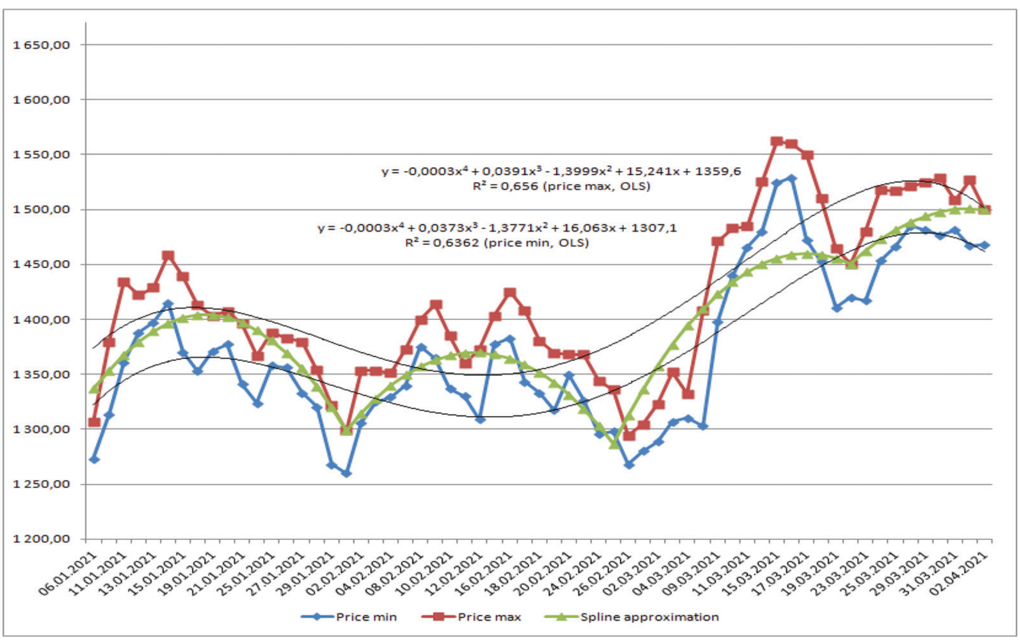


Figure 7. Spline (n = 2) and OLS approximation (n = 4).

Table 1. Analysis of the significance of models for approximation for model illustration.

Significance of the Correlation Coefficient According to the Student's *t*-Test						
	Approximation of Ranges (Original, Linear Polynomial), Figure 2	**Approximation by Minimum Points (OLS, Linear Polynomial), Figure 6**	**Approximation by Maximum Points (OLS, Linear Polynomial), Figure 6**	**Approximation by Minimum Points (OLS, Polynomial of Degree 4), Figure 7**	**Approximation by Maximum Points (OLS, Polynomial of Degree 4), Figure 7**	**Approximation of Ranges (Splines, Maximum Degree of Polynomial Spline 2), Figures 5 and 7**
Correlation coefficient	0.59	0.58	0.59	0.8	0.71	0.90
$t_{набл.}$	5.61	5.47	5.61	10.24	7.74	16.08
$t_{кр}$	2.00	2.00	2.00	2.00	2.00	2.00
Significance	significant	significant	significant	significant	significant	significant

6. Discussion

Our approach to solving the problem of approximation in a dynamic series is fundamentally different in the form of an objective function, an independent solution to the problem, a new algorithm, which is a significant development of standard techniques.

In this article, we propose a fundamentally new apparatus that makes it possible to take into account non-stationary influences and noises (several of the most important), based on sound mathematical tools.

The advantage of the approach is the ability to work without other tools; that is, the integrity and self-sufficiency of solving the problem of data analysis and forecasting.

Note that there are no contradictions with standard approaches, but standard approaches do not always work, because the noise effect obscures data analysis and in some cases, the forecast is not possible due to high and rare outliers in the data. In this context of problems related to the energy sector of the economy, our strategic goal is to expand the fundamental base of analysis and evaluation to make an informed decision on forecasting.

Expert systems (tree-like, neural network, logical, rules-oriented "what-if" productions, etc.) rarely include the developed algorithm; usually the rules are executed on a heuristic basis and multiple approximations. Therefore, fundamental methods, especially in the field of financial analytics, where the value of a solution is lost by the minute, are not significantly developed in scientific practice. The energy market requires clear, reasonable, and quick decisions that do not need to be changed during a period of stability (at least a month, preferably six months). We developed exactly such a device, which is reflected in the presented examples in our methodology.

A number of experiments have shown a high continuity with our approach to the well-known methodology of econometric analysis and forecasting. Our approach is not an addition to these othr approaches; it makes it possible to solve the problem and describe the process without using standard approaches, completely independently. A significant advantage is the focus on reducing errors from significant deviations in the data and on the ability to exclude a number of events without losing the quality of the forecast. The only drawback compared to methods based on MNCs is the complexity of solving problems (we solved this problem), as well as the lack of requirements for the stability of the process as a basis (Gauss–Markov theorem), although such conditions are rarely observed. The analysis was performed, a dynamic picture of the process was constructed, and a high-quality approximation was obtained. The process can develop in fragments; the method is appropriate for a wide range of applications in practice.

It is advisable to implement the methodology in the field of energy policy and resource conservation, at all levels of Russian practice, from the center, across the leading regions of Russia. We reasonably believe (according to the experiments performed) that the economic effect of the introduction of the mathematical apparatus will increase yearly profits by at least 40%, on the basis of the rational distribution of investments, as well as the fact that the decision is made by a financial analyst (group leader). We do not consider it right to accord the final decision-making to a robotic system; we believe that a key figure in the management of a financial service at any level (state, region, bank, holding, or company), qualified and able to correctly interpret the recommendations of the program block, is the key to the prosperity of the energy economy of Russia.

7. Conclusions

(1) This article presented a dynamic energy system based on the Minimax criterion of optimality.

(2) We optimally designed a structure in accordance with energy and financial policy.

Our approach can be used as a fully fledged independent resource to assess and forecast the development of companies. As a result of the application of our methodology, a purposeful political strategy was developed, which should include certain risk assessment parameters, predictive models, and algorithmized structures based on program packages.

(3) We considered a model of approximation of price ranges by algebraic polynomial.

The model is based on the far-reaching generalization of the Minimax criterion of Chebyshev. We took into account the possibility of applying the approximation of data represented by ranges, as well as additional restrictions on the approximating function. We developed a methodology to solve optimization problems, allowing us to obtain high-quality approximations. The algorithm was developed for solving discrete problems of the best uniform approximation of multivalued mapping within specified ranges, as well as algebraic polynomial with constraints on the value of the approximating polynomial on the top and bottom in several nodes of the grid. Our computational experiments showed the high quality of the suggested method of approximation. We fulfilled a three-stage approximation with polynomial splines, connected within ranges for improving the model, for PJSC Novatek stocks.

Despite numerous works on the statistical study of interval data required by such approaches, the complexity of the model, useful in engineering and technology, has not been extended to economics, where it is necessary to accurately determine a reasonable and reliable path of action. Noise-resistant filters, tuned to the Chebyshev model and its far-reaching generalizations, created a high resonance in society. Questions arose as to why the method produces similar results to the standard Minimax, why the key points created a zone of noise immunity, and why there are no such tools in statistical analysis programs, but only robust estimates based on the type of rounding of data due to the enlargement of modified structures. The answers are very simple: Minimax is based on the procedure for analyzing data using the traditional optimization method (partial derivatives, the possibility of using convex analysis and constraints, ready-made formulas); and Minimax requires a non-smooth approximation, subdifferential calculus problems are set, the apparatus of non-strict analysis from the point of view of mathematics is fundamentally complex.

In this article we proposed methods of constraints on Minimax using hierarchal decision making. In contrast to the classical models, we use volatility as a parameter for solving the optimization problem and producing a forecast based on a multi-stage hierarchical evaluation of data and a theoretically based problem of non-smooth analysis, which allows us to achieve the research goal in an optimal way, by saving time on the procedures of multiple data processing and the revision of the solution. The stability of the solution for the average period of the analytical procedure is an undoubted advantage of the analytical core. The problem of complex analysis, evaluation, and modeling of decision-making in the oil and gas industry forces us to look for a solution in an optimal way, taking into account the highest-quality forecast.

The authors of the work created and tested a multi-stage decision-making system in the field of financial and political dynamic structures. The company under study (PJSC Novatek) received a very high status according to the estimates of world experts according to the following criteria: basis of production, image policy, prospect of financial development, and improvement of financial policy in the field of the Russian oil and gas complex.

We used Minimax and the Hausdorff metric as the focus of the policy decision on innovation in view of the successful prediction of the modeled data structure. This paper presents a comprehensive analysis of situational approaches. Thus, the state could, but does not always have time to place emphasis on financial policy for high-tech industries. The Minimax approach will save significant time for making important investment decisions.

To attract an investor aiming to develop the status and technology of a company, it is necessary to clearly indicate the graphical figure of the analysis background and provide high-level estimates of the trend dynamics with key positions, which is an optimal approximation of the process and serves as a basis for decision-making. This was performed in this article.

Author Contributions: Conceptualization, A.A.; methodology, I.V.; software, I.V.; formal analysis, N.R.; writing—original draft preparation, L.G.; writing—review and editing, Z.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Crosbie, P.J.; Bohn, J.R. Modelling default risk. In *World Scientific Reference on Contingent Claims Analysis in Corporate Finance*; The Hebrew University of Jerusalem: Jerusalem, Israel, 2019; pp. 471–506. [CrossRef]
2. Duchin, R.; Ozbas, O.; Sebsoy, B. Costly external finance, corporate investment, and the subprime mortgage credit crisis. *J. Financ. Econ.* **2010**, *97*, 418–435. [CrossRef]
3. Campbell, J.Y.; Hilscher, J.; Szilagyi, J. In search of distress risk. *J. Financ.* **2008**, *63*, 2899–2939. [CrossRef]
4. Kulmaganbetova, A.; Dubina, I.; Rakhmetulina, Z.; Tlessova, E.; Tulegenova, Z. Innovative potential of small and medium business. *Entrep. Sustain. Issues* **2020**, *8*, 1286–1304. [CrossRef]
5. Bulińska-Stangrecka, H.; Bagieńska, A. Intangible resources for an organization's sustainability potential. *Entrep. Sustain. Issues* **2020**, *8*, 741–761. [CrossRef]
6. Skuratovych, I.; Lytvyn, N.; Panova, I.; Ovcharenko, I.; Hryhorevska, O. Efficiency of using the potential of small business in ensuring sustainable economic growth. *Entrep. Sustain. Issues* **2021**, *8*, 742–756. [CrossRef]
7. Mura, L.; Hajduová, Z. Small and medium enterprises in regions—Empirical and quantitative approach. *Insights Into Reg. Dev.* **2021**, *3*, 252–266. [CrossRef]
8. Fizaine, F.; Court, V. Energy expenditure, economic growth, and the minimum EROI of society. *Energy Pol.* **2016**, *95*, 172–186. [CrossRef]
9. Eberhart, A.C.; Maxwell, W.F.; Siddique, A.R. A reexamination of the tradeoff between the future benefit and riskiness of R & D increases. *J. Account. Res.* **2007**, *46*, 27–52. [CrossRef]
10. Ericson, R.; Pakes, A. Markov-perfect industry dynamics: A framework for empirical work. *Rev. Econ. Stud.* **1995**, *62*, 53–82. [CrossRef]
11. Gomariz, M.C.F.; Ballesta, J.P.S. Financial reporting quality, debt maturity and investment efficiency. *J. Bank. Financ.* **2014**, *40*, 494–506. [CrossRef]
12. Zhang, W. R & D investment and distress risk. *J. Empir. Financ.* **2015**, *32*, 94–114. [CrossRef]
13. Salamat, S.; Lixia, N.; Naseem, S.; Mohsin, M.; Zia-ur-Rehman, M.; Baig, S.A. Modeling cryptocurrencies volatility using Garch models: A comparison based on Normal and Student's T-Error distribution. *Entrep. Sustain. Issues* **2020**, *7*, 1580–1596. [CrossRef]
14. Fumo, N.; Rafe Biswas, M.A. Regression analysis for prediction of residential energy consumption. *Sustain. Energy Rev.* **2015**, *47*, 332–343. [CrossRef]
15. Fama, E.F.; French, K.R. The cross-section of expected stock returns. *J. Financ.* **1992**, *47*, 427–465. [CrossRef]
16. Fernandes, A.M.; Paunov, C. The risks of innovation: Are innovating firms less likely to die? *Rev. Econ. Stat.* **2015**, *97*, 638–653. [CrossRef]
17. Fung, M. R & D, knowledge spillovers and stock volatility. *Account. Financ.* **2006**, *46*, 107–124. [CrossRef]

18. Aghion, P.; Bloom, N.; Blundell, R.; Griffith, R.; Howitt, P. Competition and innovation: An inverted-U relationship. *Q. J. Econ.* **2005**, *120*, 701–728. [CrossRef]
19. Aghion, P.; Blundell, R.; Griffith, R.; Howitt, P.; Prantl, S. The effects of entry on incumbent innovation and productivity. *Rev. Econ. Stat.* **2009**, *91*, 20–32. [CrossRef]
20. Aghion, P.; Akcigit, U.; Howitt, P. What do we learn from Schumpeterian growth theory? In *Handbook of Economic Growth*; Aghion, P., Durlauf, S., Eds.; Elsevier: Amsterdam, The Netherlands, 2014; Volume 2, pp. 515–563. [CrossRef]
21. Berger, A.N.; Rosen, R.J.; Udell, G.F. Does market size structure affect competition? The case of small business lending. *J. Bank. Financ.* **2007**, *31*, 11–33. [CrossRef]
22. Bharath, S.T.; Shumway, T. Forecasting default with the Merton distance to default model. *Rev. Financ. Stud.* **2008**, *21*, 1339–1369. [CrossRef]
23. Gilbert, R. Looking for Mr. Schumpeter: Where are we in the competition-innovation debate? *Innov. Policy Econ.* **2006**, *6*, 159–215. [CrossRef]
24. Vygodchikova, I. On approximation of multivalued mapping by algebraic polynomial with constraints. *Russ. Math.* **2015**, *59*, 25–28. [CrossRef]
25. Demyanov, V.; Malozemov, V. *Introduction to Minimax*; Nauka, M., Ed.; Dover Publication: Mineola, NY, USA, 1972; p. 368.
26. Sendov, B.K. *Hausdorff Approximations*; Bulgarian Academy of Sciences: Sofia, Bulgaria, 1979; p. 372.
27. H'uber, P.J. *Robust Statistics*; John Wiley & Sons, Inc.: New York, NY, USA, 1981; p. 320.
28. Hadad, Y.; Keren, B.; Gurevich, G. Improving demand forecasting using change point analysis. *Int. J. Bus. Forecast. Mark. Intell.* **2017**, *3*, 130–151. [CrossRef]
29. Nedosekin, A. Alternative methods of investing in basic sectors of the Russian economy. *Notes Min. Inst.* **2016**, *219*, 482–489.
30. Nedosekin, A.; Abdoulaeva, Z.; Konnikov, E.; Zhuk, A. Fuzzy set models for economic resilience estimation. *Mathematics* **2020**, *8*, 1516. [CrossRef]
31. Gu, L. Product market competition, R & D investment and stock returns. *J. Financ. Econ.* **2016**, *119*, 441–455. [CrossRef]
32. Hall, B.; Lerner, J. Financing R & D and innovation. In *Handbook of the Economics of Innovation*; Hall, B.H., Rosenberg, N., Eds.; Elsevier: Amsterdam, The Netherlands, 2010; pp. 609–639. [CrossRef]
33. Alhassan, A.; Naka, A. Corporate future investments and stock liquidity: Evidence from emerging markets. *Int. Rev. Econ. Financ.* **2020**, *65*, 69–83. [CrossRef]
34. Yue, S.; Lu, R.; Shen, Y.; Chen, H. How does financial development affect energy consumption? Evidence from 21 transitional countries. *Energy Policy* **2019**, *130*, 253–262. [CrossRef]
35. Talipova, A.; Parsegov, S.; Tukpetov, P. Russian gas exchange: A new indicator of market efficiency and competition or the instrument of monopolist? *Energy Policy* **2019**, *135*, 111012. [CrossRef]
36. Shair, J.; Xie, X.; Wang, L.; Liu, W.; He, J.; Liu, H. Overview of emerging subsynchronous oscillations in practical wind power systems. *Renew. Sustain. Energy Rev.* **2019**, *99*, 159–168. [CrossRef]
37. Domnikov, A.; Khodorovsky, M.; Domnikova, L. Competitive development of energy cogeneration systems in conditions of economic imbalances. *Int. J. Energy Prod. Manag.* **2020**, *5*, 342–354. [CrossRef]
38. Ahlberg, J.; Nilson, E.; Walsh, J. *The Theory of Splines and Their Applications: Mathematics in Science and Engineering: A Series of Monographs and Textbooks*; Academic Press: Cambridge, MA, USA, 1967; Volume 38, p. 443.
39. Subbotin, Y.; Chernykh, N. Interpolation wavelets in boundary value problems. *Proc. Steklov Inst. Math.* **2018**, *300*, 172–183. [CrossRef]
40. Subbotin, Y.; Shevaldin, V. On one method of constructing local parabolic splines with additional nodes. *Proc. Inst. Math. Mech. Ural. Branch Russ. Acad. Sci.* **2019**, *25*, 205–219.
41. Afanasyev, D.; Fedorova, E. The long-term trends on the electricity markets: Comparison of empirical mode and wavelet decompositions. *Energy Econ.* **2016**, *56*, 432–442. [CrossRef]
42. Bourcet, C. Empirical determinants of renewable energy deployment: A systematic literature review. *Energy Econ.* **2020**, *85*, 104563. [CrossRef]
43. Hulshof, D.; van der Maat, J.P.; Mulder, M. Market fundamentals, competition and natural-gas prices. *Energy Pol.* **2016**, *94*, 480–491. [CrossRef]
44. Biddle, G.C.; Hilary, G.; Verdi, R.S. How does financial reporting quality relate to investment efficiency? *J. Account. Econ.* **2009**, *48*, 112–131. [CrossRef]
45. Borodin, A.; Natocheeva, N.; Khominich, I.; Kulikov, A.; Shchegolevatykh, N. The Impact of the Business Environment on the Effectiveness of the Implementation of the Financial Strategy of the Oil and Gas Company. *Int. J. Energy Econ. Policy* **2021**, *11*, 13–21. [CrossRef]
46. Awrejcewicz, J.; Krysko, V.A.; Kutepov, I.E.; Vygodchikova, I.Y. Quantifying chaos of curvilinear beam via exponents. *Commun. Non-Linear Sci. Numer. Simul.* **2015**, *27*, 81–92. [CrossRef]
47. Borodin, A.; Tvaronavičienė, M.; Vygodcyikova, I.; Kulikov, A.; Panaedova, G. Optimization of the Structure of the Investment Portfolio of High-Tech Companies Based on the Minimax Criterion. *Energies* **2021**, *14*, 4647. [CrossRef]
48. Aliev, A.A.; Bondarenko, T.G.; Keri, I.T.; Soltakhanov, A.U.; Vetshinina, A.A. Predicting levels of innovation-led development as exemplified by state-owned oil company. *J. Appl. Econ. Sci.* **2018**, *13*, 1902–1907.

49. Campbell, J.; Dhaliwal, D.; Schwartz, W. Financing constraints and the cost of capital: Evidence from the funding of corporate pension plants. *Rev. Financ. Stud.* **2012**, *25*, 868–912. [CrossRef]
50. McFadden, D. The measurement of urban travel demand. *J. Publ. Econ.* **1974**, *3*, 303–328. [CrossRef]
51. Demyanov, V.; Vasilev, L. *Non-Differential Optimization*; Nauka, M., Ed.; Nauka Publishing House: Moscow, Russia, 1981; p. 384.
52. Demyanov, V.; Rubinov, A. *Fundamentals of Nonsmooth Analysis and Calculus Quasi-Differentiable*; Nauka, M., Ed.; Nauka Publishing House: Moscow, Russia, 1990; p. 432.
53. Ilyasov, R. Phase cycling analysis in oil export prices dynamics. *Humanit. Soc.-Econ. Sci.* **2017**, *1*, 131–136.
54. Seo, K. *Managerial Economics*; Translation from English; INFRA-M: Moscow, Russia, 2000; p. 671.
55. Sidorov, S.P.; Revutskiy, A.; Faizliev, A.; Korobov, E.; Balash, V. Garch model with jumps: Testing the impact of news intensity on stock volatility. In Lecture Notes in Engineering and Computer Science. In Proceedings of the World Congress on Engineering, WCE, London, UK, 2–4 July 2014; pp. 110–115.
56. Kostikova, A.V.; Tereliansky, P.V.; Shuvaev, A.V.; Parakhina, V.N.; Timoshenko, P.N. Expert fuzzy modeling of dynamic properties of complex systems. *ARPN J. Eng. Appl. Sci.* **2016**, *11*, 222–230.

energies

MDPI

Article

Assessment and Integral Indexing of the Main Indicators of Oil and Gas Companies by Circular Convolution

Irina Vygodchikova [1], Mikhail Gordienko [2,*], Natalia Natocheeva [3], Natalia Rud [4] and Anzhela Namitulina [5]

1 Department of Differential Equations & Mathematic Economics, National Research Saratov State University, 410012 Saratov, Russia; irinavigod@yandex.ru
2 Department of Financial Management, Plekhanov Russian University of Economics, 117997 Moscow, Russia
3 Department of Financial Markets, Plekhanov Russian University of Economics, 117997 Moscow, Russia; natocheeva12@yandex.ru
4 Department of World Economy and Customs, North-Caucasus Federal University, 357500 Pyatigorsk, Russia; rud-td@yandex.ru
5 Department of Finance, Financial University under the Government of the Russian Federation, 105064 Moscow, Russia; z.anzhela@bk.ru
* Correspondence: gordienkomikhail@yandex.ru

Citation: Vygodchikova, I.; Gordienko, M.; Natocheeva, N.; Rud, N.; Namitulina, A. Assessment and Integral Indexing of the Main Indicators of Oil and Gas Companies by Circular Convolution. *Energies* **2022**, *15*, 877. https://doi.org/10.3390/en15030877

Academic Editor: David Borge-Diez

Received: 24 November 2021
Accepted: 21 January 2022
Published: 25 January 2022

Abstract: In the oil and gas industry, which is the basis of the Russian energy market, a significant and urgent question arises: How to distribute companies according to their investment attractiveness? Accordingly, quantitative indicators are needed. Lacking extensive experience in the practical implementation of fundamental rating tools, work is needed to develop methodologies of weighting coefficients and lists, built on the experience of the "big three" rating agencies. The article proposes an algorithm for forming an integral rating of companies based on financial reporting indicators and the author's rules of fuzzy logic based on the principle of "circular convolution", from the best to the slave, deepening the analysis to the center, when all companies are exhausted and places in the rating are distributed. The problem of assessing and integrally indexing the indicators of large companies in leading sectors of the economy (e.g., oil and gas, banks, electricity) is becoming manifest, while it is obvious that there is competition between large companies of the country's leading industries for state investment resources. The nature of the leading industries is such that it is necessary to assess the quality of the company's functioning based on the formation of rating groups. Based on the rating, investments are distributed among the companies under consideration. The author has developed a portfolio model that is analogous to the Harry Max Markowitz model, which does not contradict this model but allows consideration of a broader range of risk assessments used in the model (for example, the rating of companies). The optimal portfolio is built, taking into account the resulting index and the initial grouping in the hierarchical data correction mode. The logically sequential method of circular convolution of four important indicators to an integral index and a mathematically substantiated method for optimizing the minimax portfolio presented in the work will allow the investor to develop optimal (from the point of view of the transparency of the apparatus used, mathematical feasibility and time spent on the implementation of the software package) tools for investing and enlarging his capital.

Keywords: integral index; competitive advantage; investments; share distribution; optimization model; minimax; hierarchical analysis; circular convolution

1. Introduction

The relevance of the problem of integrated assessment of companies and the compilation of an investor's portfolio is beyond doubt, being the central problem of investing in high-tech companies in Russia. In the first instance, the task arises of building a rating of investment attractiveness of companies using an algorithmic procedure. The authors propose the use of a new methodology, namely, a model of a minimax approach and hierarchical data analysis. In the context of modern digital data processing systems, the problem of integral ranking of important targeted financing indicators of financial, economic, intermediary, and marketing activities of companies in Russia's leading industries comes to the fore. The business–economy–society relationship influences important values of public welfare. A consequence of the introduction of integral indexing technologies is the development of a mathematical apparatus for cost optimization, which is facilitated by the minimax optimization approach, allowing use of new risk assessments of a company's sub-portfolio in a circular convolution mode.

Considering oil and gas companies in Russia, several problems should be noted that stand in the way of using standard methods of integral indexing and portfolio investment. With integral indexing, it is necessary to consider the whole range of financial indicators of important groups, such as liquidity, financial stability and risk, business activity, and profitability. At the same time, investors can often "hide" behind technical analysis tools using only the dynamics of market indicators. The development of the company depends on the investor being interested in the growth of the company's capitalization and successful activities, from which it is possible to receive dividends; therefore, the investor chooses the capital investment sector and forms (revises) their portfolio no more than 2–6 times a year. To do this, it is necessary to perform a calculation taking into account the parameters of the portfolio of interest.

The existing methods applied for the integral assessment of the financial indicators of the state and sustainable development of the company have, as a rule, a drawback associated with the incomparability of indicators in terms of the degree of influence on the level of development of the company in the group.

The use of optimization of the portfolio structure for the inclusion of promising companies based on the construction of an integral rating based on the results of hierarchical analysis enables avoidance of the disadvantages of other methods. The approach proposed in this article has not been previously considered in the literature.

The main parameter of the risk assessment investment model is a company's rating. At the moment, the methodological tools for the rating assessment of Russian companies are at an early stage of development, although such studies across the world have provided a good foundation, thanks to leading rating agencies that have their own sound methodologies for rating companies. Until mid-2017, when developing investment strategies for the development of Russian industry giants, the opinions of the "big three" international rating agencies, Standard and Poor's, Fitch Ratings or Moody's and Forbes magazine experts, were taken into account. However, due to the reduction in foreign expertise in Russia, it became necessary to develop and implement its own rating methodology for assessing the investment attractiveness of companies. The current rating approach (e.g., through accredited agencies, such as Expert RA, NRA, NKR, ACRA), needs a new and mathematically sound approach to building a rating that optimizes the investment process of the most important high-tech projects by taking into account the priority of indicators and circular convolution into a single index. An important feature of the developed method is the use of a mathematical apparatus, which includes a hierarchical analysis of the ranked indicators of financial and economic activity of companies, considering their priority, and the use of a minimax approach to obtain a rating assessment of companies by circular convolution. The algorithmic base follows from the priority of indicators, then groups are formed, with the highest and lowest priority in the list of companies identified. The boundary groups are then removed from the analytical base and the "internal" groups are subjected to the same method, in a circle of analytical refinement of the rating. This approach has not been considered in the literature. Further, a significant development of the research topic is carried out, the mode of "convolution of indicators in a circle" into an integral index is justified, and the prospects for development are indicated. The purpose of the article is to develop a procedure for the integral indexing of financial indicators in a circular convolution mode using a minimax model to optimize the investor's portfolio in order to increase the investment attractiveness and competitiveness of the business.

The subject of the study is financial quantitative indicators, optimization and hierarchical models of companies' activities. The objects of the research are the leading companies in the oil and gas industry of the Russian economy.

2. Literature Foundations

A comprehensive assessment of the competitive advantages of the world giants of the leading economic sectors in the oil and gas industry requires a systematic analysis and ranking of investment criteria for the effectiveness of the companies in question.

There are a variety of approaches to assessing the competitive advantages of oil companies. For example, the experience of reforming the management system and introducing innovative practices in PetroChina [1] is based on the development of six elements: balancing between the existing reserves and new developments, the state dynamic distribution of rights for the extraction and reservation of minerals, the assessment of new territories, the management of benefits, the assessment of the value of the company's reserves, and the expansion of cooperation.

Another competitive advantage is digitalization, or rather the introduction of blockchain technology and smart contracts in Iraq [2]. The article assesses the impact of this technology from the point of individual, environmental and organizational factors of competitiveness. The data is analyzed using structural equation modeling (PLS). The results indicate that introduction of the technology increases the stability of work, grows the organizational culture and the long-term development goals of oil companies are achieved more effectively.

The Malaysian experience in assessing and ranking competitiveness is based on the application of innovation opportunity scaling [3]. The main opportunities for increasing competitiveness are assessed from the standpoint of greening and the application of eco-innovations. The authors present a three-dimensional structure of innovation policy with nine detailed elements. It is noted that the design of eco-innovations is seen in product service management, pollution prevention, and commitment to sustainable development. As part of another study of oil and gas companies in Malaysia [4], a hierarchical model is built by prioritizing core competencies in relation to the financial performance of companies. The authors used an analytical hierarchical process (AHP) and a mathematical model approach, which were synthesized using the Super Decisions software. The proposed toolkit can be used as a benchmark for prioritizing core competencies in relation to the competitive advantages of a company in the analyzed sector of the economy. As part of increasing the competitiveness of Thai companies, a formal industrial commercialization model is also being developed, which is suitable for the commercialization of inventions in the field of oil industry products and processes [5].

Evidently, the specifics of the industry-based assessment of companies differ significantly according to the scale of their activities. According to the author, it is necessary to introduce a complex ABC-criteria (assets, revenue, equity) data ranking methodology, which is presented in this paper for the first time. The consonance of the indicators is accidental; it is possibly an intuitive coincidence that was not planned by the author and can be revised if there are strong arguments in favor of other indicators.

The author's methodology allows for the selection of "leaders" by ABC criteria, as well as companies whose ABC indicators in the considered group are significantly lower than average (the study uses the term "closing group"). The average group of companies is subject to further analysis according to the author's methodology (if there are more than 10 companies), or final ranking by D criteria (net profit). After ranking by indicator D, companies of the middle group are "embedded" in the environment from leaders to the closing group (they are also ranked by D taking into account the subordination of the circular convolution of groups).

It should be noted that ABC analysis has not been used in such studies in this way. Alternative approaches, which were not ultimately applied in the framework of this study, are represented by the following scientific studies described. One of the approaches is based on integral ranking using decision-making methods, analytical network process (ANP), DEMATEL and analytical hierarchical process (AHP), as well as a combination of methods that the authors [6] termed hybrid fuzzy ANP-DEMATEL-AHP. The approach assumed the use of 7 main criteria and 39 sub-criteria as indicators of rating and multi-ranking of data. Other studies [7–9] have approached the issue from the standpoint of ranking investment performance criteria. This approach uses capital rationing metrics and impact analysis for IOR/EOR projects. The various combinations of oil companies' investment portfolios, as well as the experience of the Norwegian oil sector taxation system's impact on restrictions and reductions in the marginality of IOR/EOR projects, are studied. Finally, another approach considered [10] is based on a comparative methodology by AHP and fuzzy TOPSIS criteria. AHP is used to determine the criteria weights and the fuzzy TOPSIS method is used to obtain the final rating.

The feasibility of the author's methodological approach to the circular ranking of companies, which was used, for example, to select a supplier in the petrochemical industry [11–13] is based on several theses.

Firstly, most of the indicators used are subject to high volatility of the internal state of industry parity, so it is advisable to use several indicators responsible for the main financial data flows within the company [14,15].

Secondly, the indicators are considered as static parameters in the high volatility model; therefore, it is necessary to use fundamental analytics, taking into account the quality of the audit and the peculiarities of profit management in the oil and gas industry [16]. The main sources of reliable information are the balance sheet and financial results report, but not the market price of the company's shares [17–19].

Thirdly, the risk associated with the volatility of technical analysis indicators must be stabilized to the level of real balance sheet indicators. Therefore, it is necessary to apply the portfolio approach [20,21]; the portfolio will be built according to the indicators specified by investors, adjusted to the level of the company's rating in the given group of competing companies. The paper considers the oil and gas industry as the basis for the formation of a competitive investor portfolio [22,23].

Data rating and multi-ranking are gaining particular popularity [24–26], while an important goal is a comprehensive assessment of portfolio investments [27]. Complex strategic and financial analysis, in terms of multi-ranking and hierarchical assessment of development indexes in groups, is gaining particular popularity [28,29]. For a full-fledged analysis, it becomes necessary to take into account many important indicators of the financial and economic activities of companies and to scale them up to perform a comprehensive assessment.

It is necessary to conduct a financial analysis based on evaluating the ratio standards (e.g., liquidity, financial stability, profitability, business activity); as a result, it can be concluded that the business is reliable and promising, having competitive strength and the potential for innovative developments [30,31].

3. Materials and Methods

3.1. Methodology for Constructing an Integral Rating of the Competitiveness of Russian Companies

The construction of the integral index is implemented in a multi-stage system, which includes at least five stages:

(1) formation and systematization of indicators of financial and economic activity used in assessment models for analysis and optimization of capital investments in oil and gas companies in Russia;
(2) normalization of the values of indicators, taking into account linear scaling and ranking of data, and calculation of aggregates (sub-indexing) according to the original or scaled indicators;
(3) formation of company groups according to the adopted aggregate or quantitative indicators in a circular convolution mode;
(4) integral ranking by groups taking into account the adopted circular classification of data;

(5) decision on the structure of the investment portfolio and the minimax criterion of optimality.

System analysis is carried out based on evaluation, quantitative indexes modeling up to sub-indexing level within the groups of companies obtained by circular convolution, after which the system of aggregation indexes is defined using multi-ranking, hierarchical analysis, and a new data filtering algorithm (in the circular convolution of business competitiveness indicators).

The feasibility of the hierarchical procedure is contained in the mathematical system of a circular convolution of financial business competitiveness indicators, among which certain indicators are primary.

This approach essentially and fundamentally differs from the existing methods of analyzing hierarchies, since the rules of fuzzy logic of decision-making "what-if" are replaced by a justified subordination of ranked financial indicators (sub-indexes) and ranking in a circular convolution mode.

3.2. Theory

At the first stage of analyzing the business competitiveness, quantitative volumetric business development indicators are used (e.g., balance sheet assets, revenue, equity).

At the second stage, the capital investments assessment is optimized. For this, the relative profitability and risk indicators, the return on equity (the ratio of net profit to equity) and financial leverage (the ratio of borrowed funds to equity) are applied.

The groups of leaders and closing companies (in this sample) are selected considering three ABC indicators. The remaining regions are combined into a new subgroup, among which leaders and closing groups are distinguished, or a linear ranking is performed by indicator D.

At each new stage, new groups are ranked after excluding the leaders and closing groups, switching the rating mode to the "center of the circular convolution of data", the procedure-stopping mode—the presence of one or two groups of leaders and the closing groups without the possibility of selecting the middle group.

A company-rating model is based on circular convolution and hierarchical data analysis. In building groups at each stage of hierarchical analysis and circular convolution, the article uses the following important indicators of the company's performance: assets (A), revenue (B), and equity (C). In the construction of the integral index based on the results of the grouping, the ranking is made by net profit indicator (D), taking into account the subordination of the groups: the best indexes for the group of leaders (at the beginning, the first stage and until the last, after the middle group is ranked, then the companies of the closing groups from the last (internal) closing group to the first closing one (boundary)).

N—the total number of analyzed companies.

Ranking the indicators, A, B, C, D for companies through a, b, c, d, respectively, taking into account indexes, so a_i is the rank of indicator A for company i. It is clear that:

$$\bar{c} = \bar{a} = \bar{b} = \bar{d} = \frac{1}{N}\sum_{i=1}^{N} a_i \tag{1}$$

3.3. Minimax Optimality Criterion

Let us assume that the investor's capital is distributed for n companies (oil and gas).

where

V_i—financial leverage ratio of i company,

$\eta 1, \ldots, \eta n$—the return on equity of these companies (oil and gas industry),

θ_i—is the investment share of i company.

To calculate the investment shares of companies in the portfolio, the following problem is solved

$$\Psi(\theta) = \max_{i=\overline{1,n}} V_i\theta_i \to \min_{\theta \in D}, \tag{2}$$

where

$$D = \{\theta = (\theta_1, \ldots, \theta_n) \in R^n : \sum_{i=1}^{n} \theta_i = 1\} .$$

For the solution, the following formulas are applied

$$\theta_i = 1/\left(V_i \sum_{k=1}^{n} V_k{}^{-1}\right),\ i = 1, \ldots, n \quad (3)$$

Next, share Corrections (3) are applied, the return on equity is used

$$\theta_i{}^* = \eta_i \theta_i / \left(\sum_{k=1}^{n} \eta_k \theta_k\right),\ i = 1, \ldots, n \quad (4)$$

To obtain the optimal investment shares, the final revision of Shares (4) is performed according to the integral rating method (marked by IR), Formula (5).

$$\theta_i{}^{**} = \theta_i{}^* / \left(IR_i \cdot \sum_{k=1}^{n} (IR_k)^{-1} \theta_k\right),\ i = 1, \ldots, n \quad (5)$$

As a result, the optimal solution for the portfolio will be achieved using the author's circular assessment approach by grouping, rating and hierarchical data assessment.

The method of circular convolution of large companies contains two main stages, with the first stage proceeding in a hierarchical mode.

At the first stage, two groups are identified: leaders (ABC indicators are above average) and closing group (ABC is below average).

The rest of the companies form a middle-ranking group, which is subject to further ranking according to the principle: from the borders to the center of the circle, when a signal to stop the process is received, the presence of one or two groups of leaders and closing group without the possibility of identifying the middle group.

At the second stage, an *integral rating* is built. The indicator D is first applied for all leading groups, from the first to the last, then in the central group based on the results of the hierarchical analysis, and then, for the closing groups, from the last to the first (boundary) (Figure 1):

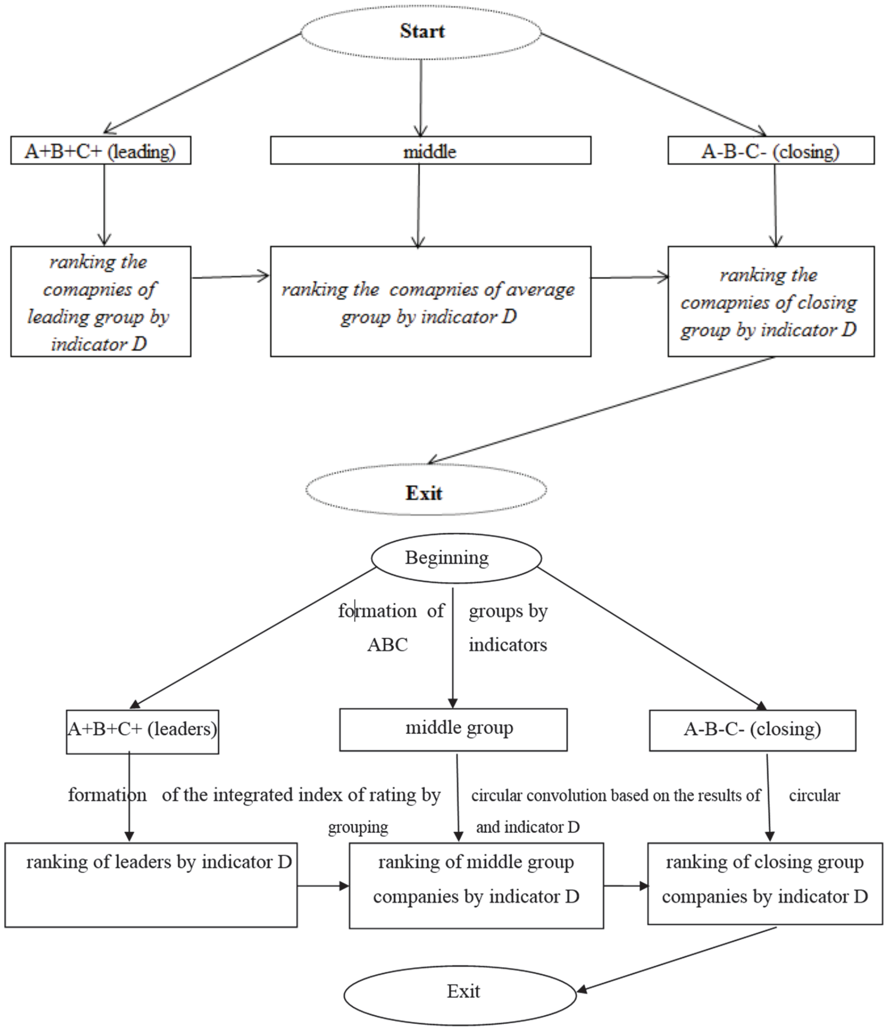


Figure 1. Scheme of information flows of integrated rating by circular convolution (RCC).

4. Results

Computational experiment: an integral rating of the companies' competitiveness. The seven largest oil and gas companies in Russia (2019) participated in the experiments in terms of assets. The reliability assessment was carried out according to the recommendations from [32], the correlations of the ABC group indicators are not contradictory and indicate significant differences (estimates of the pair correlation coefficients within the group for the indicated indicators were at least 0.23, on average 0.37, with a maximum of 0.8, which is consistent with the standard). Initial data and analysis of average values for all indicators are presented in Table 1; the integral rating for each year is shown in Table 2.

It should be noted that Gazprom is a stable leader in the oil and gas industry in Russia followed by Surgutneftegaz taking into account the strong growth of its funds and balance sheet assets [33,34].

Next, according to the rating, the 3rd place is taken by Rosneft (the largest company that solidly strengthened its positions due to the purchase of Bashneft shares in 2018); Bashneft is consistently ranked 7th in the top ten oil and gas companies.

Table 1. Initial data and analysis of average values for the selected indicators.

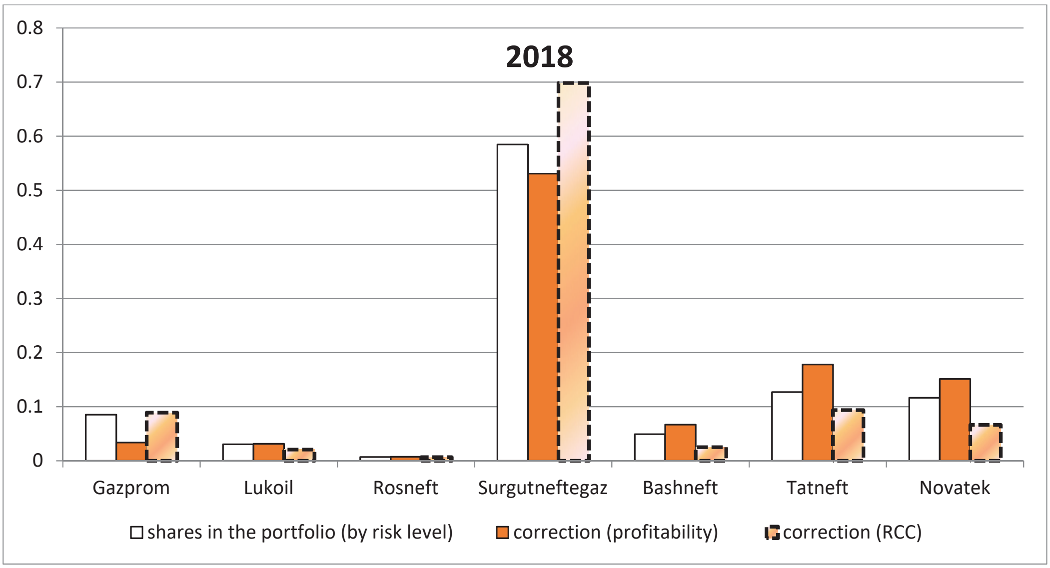
Company	Year	Net Profit, Thousand Rubles (Indicator D)	Equity Capital, Thousand Rubles (Indicator C)	Revenue, Thousand Rubles (Indicator B)	Assets, Thousand Rubles (Indicator A)	Debt Capital, Thousand Rubles	Risk (Debt/Equity, Financial Leverage), Shares (%)	Profitability (Net Profit to Equity), Shares (%)
Gazprom	2018	934398300	11067247169	5179549285	15736141582	4668894413	42.19	8.44
	2019	651124114	11334679889	4758711459	15916355497	4581675608	40.42	5.74
Lukoil	2018	219484106	995563401	264355247	2170214155	1174650754	117.99	22.05
	2019	405759769	957169199	444471354	2209166567	1251997368	130.80	42.39
Rosneft	2018	460784009	2026470417	6968248044	12308717819	10282247402	507.40	22.74
	2019	396526209	2261771078	6827526407	12323497743	10061726665	444.86	17.53
Surgutneftegaz	2018	827641293	4281345701	1524947700	4544846340	263500639	6.15	19.33
	2019	105478643	4303834579	1555622592	4553686428	249851849	5.81	2.45
Bashneft	2018	101833004	351 330 815	755 435 433	608 331 214	257000399	73.15	28.98
	2019	49 159 699	372 317 094	703 150 528	632 954 361	260637267	70.00	13.20
Tatneft	2018	192765634	645652579	793237174	828555115	182902536	28.33	29.86
	2019	156046046	572756678	827026695	816544112	243787434	42.56	27.24
Novatek	2018	159184828	575580380	560647664	753371467	177791087	30.89	27.66
	2019	237224510	718557978	528544385	899787613	181229635	25.22	33.01
TOTAL (average)	2018		2849027209	2292345792	5278596813	2429569604	115.16	22.72
	2019		2931583785	2235007631	5335998903	2404415118	108.53	20.23

Table 2. Integrated rating 2018–2019.

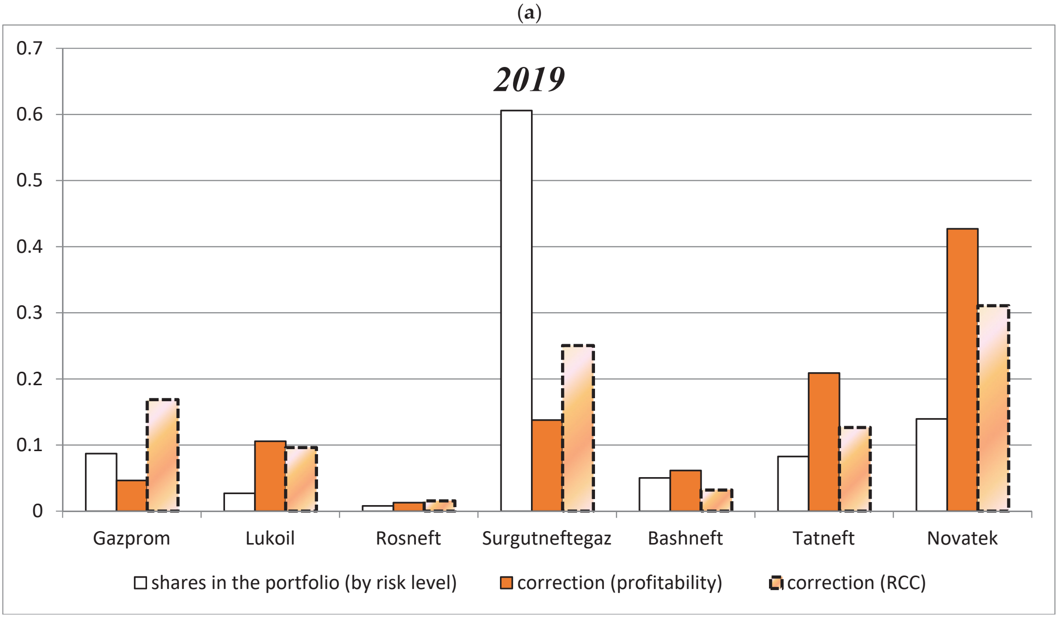
Company	Year	IR (Integral Rating, Two-Stage Convolution in a Circle), 1-Leader (Taking into Account Net Profit)	Share Fraction in the Portfolio (by Risk Level)	Correction (Profitability)	Correction (RCC)
Gazprom	2018	1	8.53%	3.38%	8.90%
	2019	1	8.70%	4.64%	16.86%
Lukoil	2018	4	3.05%	3.16%	2.08%
	2019	4	2.69%	10.57%	9.61%
Rosneft	2018	3	0.71%	0.76%	0.66%
	2019	3	0.79%	1.29%	1.56%
Surgutneftegaz	2018	2	58.45%	53.07%	69.83%
	2019	2	60.59%	13.77%	25.05%
Bashneft	2018	7	4.92%	6.70%	2.52%
	2019	7	5.02%	6.15%	3.20%
Tatneft	2018	5	12.70%	17.81%	9.37%
	2019	6	8.26%	20.88%	12.66%
Novatek	2018	6	11.65%	15.13%	6.64%
	2019	5	13.95%	42.70%	31.06%

Changes affected Novatek and Tatneft, the latter company yielding 5th place to Novatek in 2019 (Table 2).

Computational experiment: the formation of an investor's portfolio according to the optimal model. Taking into account the circular convolution and hierarchical assessment of important indicators, the structure of the investor's portfolio was assessed (Figure 2), considering Formula (3).



(**a**)



(**b**)

Figure 2. The structure of investments is based on the integral rating of competitiveness in dynamics, 2018 (**a**) and 2019 (**b**).

The IR rating made it possible to develop a portfolio rating of the RCC obtained using the minimax model in correction mode by the level of profitability (Table 3) and rating (Figure 3).

Table 3. Integral rating RCC 2019.

Company	RCC (Final)
Gazprom	17%
Lukoil	9.5%
Rosneft	1.5%
Surgutneftegaz	25%
Bashneft	3%
Tatneft	13%
Novatek	31%

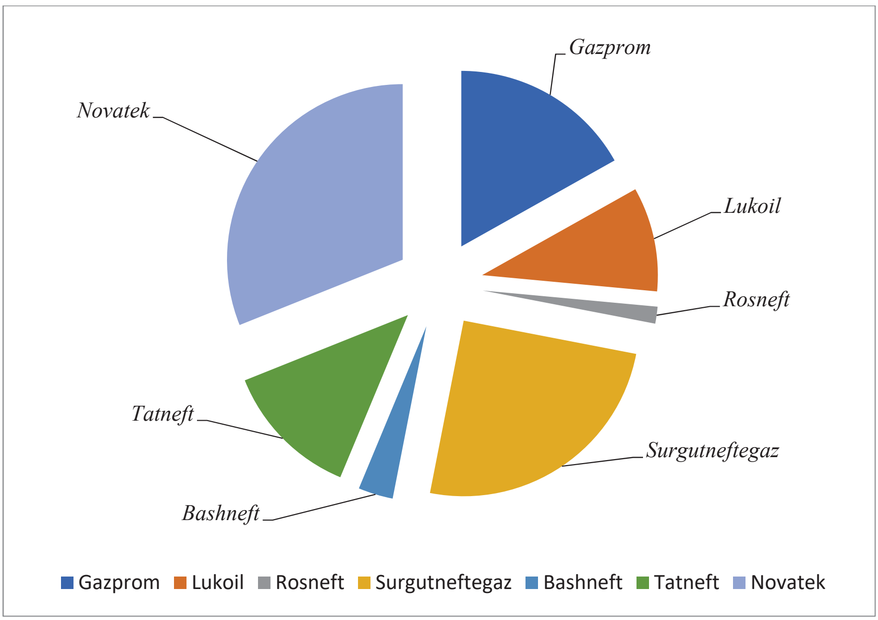


Figure 3. Structure of investments 2019 (optimal distribution in the structure of the investor's portfolio on the basis of integral ranking on competitiveness in dynamics.

The use of the integral rating values as mathematical model parameters (1) allows optimization of the share structure of investment, and this approach is advisable to use in investment analysis to preserve and systematically increase the capital of the most competitive, successfully developing companies in the leading sectors of the country's economy.

5. Discussion

Investors, creditors, and owners need to agree on rational ways to establish a company. For a small business, such a question can be solved by the CFO together with the management, but for the most important industry companies, such as Neftegaz, which occupy leading positions in ensuring the material and strategic security of Russia, to fulfil the requirement for timely and impeccable provision of services, a comprehensive study of the problem is necessary. To make a decision, investors, creditors, owners, and government agencies need a reliable quantitative base, based on which the dynamics in the group of companies and for each of them will be monitored and analyzed. The oil and gas industry is characterized by the joint influence of decision makers in building the rating. At the same time, there are factors complicating the analysis, e.g., the choice of indicators, correlations, and the presence of undisputed leaders according to the selected analysis criteria. All these shortcomings were overcome in the study by introducing an integral ranking of data by priorities applying a "top-down" and "bottom-up" approach, considering "leader-slave" groups. Large companies are taken into account and the leadership regime in the group may change, which the methodology addresses. The methodology is universal in nature; the procedures of rating and portfolio modeling are carried out taking into account the correction coefficients for the level of profitability and investment risks. Recommendations for optimal investment of companies in the selected group were obtained. The integral rating enables evaluation of the contribution of each company to high-tech development, compared to other companies. The author provides reasons for the need to use important financial indicators when considering placement in a group of companies according to an algorithm that is not swallowed up by the principles of fuzzy logic, including "leader", "middle group", "closing group", with further ranking according to the net profit indicator. The main functional purpose of the proposal is investment analysis with balanced risks. It can be used for targeted financing of large-scale state projects with significant differences in the scale of financing (the methodology then has clear advantages over others due to the absence of required weights in the weight convolution, and due to correction of the investment object (i.e., qualitative or quantitative indicator)). The problem of financing oil and gas companies becomes a strategic and rationally oriented (e.g., profit, production volume, profit priority), rather than a politically oriented task. The authors successfully achieved a solution to the problem, performing an assessment of quantitative indicators, identification of priorities, selection of the indexing and ranking mode of data, and calculation of derived indicators, using the ABC method in "circular convolution" mode. As a result, a model of convolution of derived indicators into an integral rating for the companies in question was obtained and tested in practice, providing a visual representation of the result. The authors obtained an optimal ranking, which is important for investors of all levels by zones of responsible implementation and use. When building a portfolio based on the optimization principle, the paper proposes a new method of portfolio investment, which is of interest to a rational investor aimed at stable receipt of dividends as guarantees of maintaining a high standard of living. Therefore, when forming an investment portfolio, it is advisable to consider the investor's interest in the company's dividends, and, consequently, in the amount of its profit. At the same time, the use of models based on minimizing the risk associated with the volatility of company stocks requires knowledge of the covariance matrix of stock returns (i.e., the Markowitz model and its development). A problem arises with collecting and regularly updating the source data. Therefore, when making investment decisions, the authors apply an integrated approach developed by them, based on the construction of an integral rating of investment attractiveness by circular convolution and a portfolio of uniform risk distribution of investing funds, in which the rating points obtained are used as risk assessments. The authors assume that the methodology will be implemented in the practice of Russian investment activity until July 2022.

6. Conclusions

We have developed a method of integral indexing of large Russian companies by cyclical convolution of financial indicators into an integral index. This approach is a development of the rating school and can be applied in practice in rating agencies in Russia.

Limiting conditions include that it is necessary to prioritize indicators. In the development of the methodology, indicators of interest to the investor, lender, owner can be considered, depending on their goals. In terms of the specifics of the methodology, circular convolution is needed when evaluating large companies in various industries. Their indicators (e.g., intersectoral differences) immediately create business prospects in this industry and leading industries and closing ones in the group arise; therefore, this rating is multidimensional and allows identification of leaders at the level of corporate and industry data analysis. Cyclical ranking is carried out at the level of using ranked data on four groups of ABCD indicators (i.e., assets, revenue, equity and net profit) in the optimization model of investment analysis based on the minimax criterion.

The article presents a methodology based on quantitative assessment, hierarchical analysis and ranking of financial stability and risk indicators of the largest companies in the Russian oil and gas industry, which allows building of an integral rating and obtaining a share structure. Investment capital is considered, in which the competitiveness of the investor's portfolio remains on the average period of data analysis (as a rule, the decision should be reviewed annually). The feasibility of practical application of the methodology for building a rating of investment attractiveness of large Russian companies in energy-intensive industries is substantiated.

The integral rating obtained as a result of the author's approach is compared with the ratings of leading rating agencies. In contrast to existing approaches, the author's approach enables a detailed and objective rating assessment of the current state and prospects of business development to be obtained without the need to bring the initial indicators to a comparable form, and without conducting additional research to assess the weight of the coefficients used in the analysis. The proposed approach makes it possible to build a rating based on a hierarchical procedure and an algorithm for ranking companies according to three indicators of financial and economic activity, which, according to the author, it is advisable to use when making investment decisions relating to assessment of the prospects for the development of the most important sectors of the country's energy economy, and programs for managing the competitiveness of the energy business.

Author Contributions: Conceptualization, M.G.; methodology, I.V.; software, I.V.; formal analysis, N.R.; writing—original draft preparation, A.N.; writing—review and editing, N.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Li, G.; He, H.; Liang, K.; Wu, P.; Xu, X. China's oil and gas resource management reform and innovative practice of PetroChina. *China Pet. Explor.* **2021**, *26*, 45–54. [CrossRef]
2. Younus, A.M.; Raju, V. Resilient Features of Organizational Culture in Implementation of Smart Contract Technology Blockchain in Iraqi Gas and Oil Companies. *Int. J. Qual. Res.* **2021**, *15*, 435–450. [CrossRef]
3. Munodawafa, R.T.; Johl, S.K. Measurement development for eco-innovation capabilities of Malaysian oil and gas firms. *Int. J. Product. Perform. Manag.* **2021**, ahead-of-print. 1–23. [CrossRef]
4. Krishnan, D.; Islam, R.; Sarif, S.M. A hierarchical model to enhance financial and strategic performance of an oil and gas company in Malaysia. *Int. J. Energy Sect. Manag.* **2020**, *14*, 482–503. [CrossRef]
5. Ngamcachonkulkid, S.; Chutima, P.; Chuaykoblap, S. Developing a commercialisation model for innovative products and processes in a petroleum firm. *Int. J. Process Manag. Benchmarking* **2020**, *10*, 439–461. [CrossRef]
6. Baradaran, V.; Shahmohammad, H.; Gedaali, H. Identifying and ranking criteria for selection of the knowledge-based plans using hybrid fuzzy ANP-DEMATEL method. *Adv. Environ. Biol.* **2013**, *7*, 1979–1987.
7. Osmundsen, P.O. Capital rationing by metrics—Implications for IOR/EOR-projects. In Proceedings of the IOR NORWAY 2017—19th European Symposium on Improved Oil Recovery: Sustainable IOR in a Low Oil Price World, Stavanger, Norway, 24–27 April 2017. [CrossRef]
8. Boyer, M.M.; Filion, D. Common and fundamental factors in stock returns of Canadian oil and gas companies. *Energy Econ.* **2007**, *29*, 428–453. [CrossRef]
9. Repina, E.; Shiryaeva, L.; Fedorova, E. The Study of Dependence Structure between Small Business Development and Microfinance Security of Russian Regions. *Ekon. Mat. Metod.* **2019**, *55*, 41–57. [CrossRef]

10. Amiri, M.P. Project selection for oil-fields development by using the AHP and fuzzy TOPSIS methods. *Expert Syst. Appl.* **2010**, *37*, 6218–6224. [CrossRef]
11. Mina, H.; Kannan, D.; Gholami-Zanjani, S.M.; Biuki, M. Transition towards circular supplier selection in petrochemical industry: A hybrid approach to achieve sustainable development goals. *J. Clean. Prod.* **2021**, *286*, 125273. [CrossRef]
12. Mokhova, N.; Zinecker, M.; Meluzín, T. Internal factors influencing the cost of equity capital. *Entrep. Sustain. Issues* **2018**, *5*, 827–845. [CrossRef]
13. Ogiugo, H.U.; Adesuyi, I.; Ogbeide, S.O. Empirical test of capital asset pricing model on securities return of listed firms in Nigeria. *Insights Reg. Dev.* **2020**, *4*, 825–836. [CrossRef]
14. Shapchits, A.A. Kreditosposobnost' sistemoobrazuyushchikh predpriyatii rossii: Likvidnost' i finansovaya ustoichivost'. Credit status of backbone enterprises of Russia: Liquidity and financial stability. *Financ. Anal. Sci. Exp.* **2012**, *35*, 44–57.
15. Mnif, Y.; Ben Hamouda, A. Audit quality and the trade-off between real and accrual earnings management in the oil and gas industry: The GCC evidence. *J. Appl. Account. Res.* **2021**, *22*, 223–251. [CrossRef]
16. Plenkina, V.; Andronova, I.; Deberdieva, E.; Lenkova, O.; Osinovskaya, I. Specifics of strategic managerial decisions-making in Russian oil companies. *Entrep. Sustain. Issues* **2018**, *5*, 858–874. [CrossRef]
17. Vygodchikova, I.Y. Compiling Investment Attractiveness Rating of the Largest Russian Companies Using Minimax Approach. *Stat. Econ.* **2020**, *17*, 82–93. [CrossRef]
18. Volokobinsky, I.Y.; Pekarskaya, O.A.; Razy, D.A. Prinyatie reshenii na osnove metoda analiza ierarkhii. Decision-making based on the hierarchy analysis method. *Vestn. Finans. Univ.* **2016**, *20*, 33–42.
19. Voronov, D.S. Evaluation of the competitiveness of the largest Russian companies by the end of 2015. *Sovrem. Konkur.* **2016**, *10*, 118–143.
20. Zhigach, S.A.; Yudina, E.N. Multi-objective optimization as a tool for scenario modeling of a company's portfolio. In Proceedings of the Society of Petroleum Engineers—SPE Russian Petroleum Technology Conference 2020, RPTC 2020, Moscow, Russia, 12–14 October 2020.
21. Vygodchikova, I.Y. Estimation of Bond Risks using Minimax. *J. Adv. Res. Law Econ.* **2016**, *7*, 1899–1907. [CrossRef]
22. Masood, O.; Tvaronavičienė, M.; Javaria, K. Impact of oil prices on stock return: Evidence from G7 countries. *Insights Reg. Dev.* **2019**, *1*, 129–137. [CrossRef]
23. Karminsky, A.M.; Peresetsky, A.A. Modeli reitingov mezhdunarodnykh agentstv. *Models Banks Ratings. Appl. Econom.* **2007**, *1*, 3–19.
24. Kosorukova, I.V.; Prokimnov, N.N. Enterprise value and enterprise price: Concepts and derivability of financial indicators. *J. Appl. Inform.* **2013**, *5*, 45–57.
25. Svetunkov, S.G.; Smolkin, V.P. Approach to the assessment of the industrial enterprise sustainable development. *Actual Probl. Econ. Law* **2014**, *2*, 89–94.
26. Khalikov, M.A.; Maksimov, D.A. Multistage optimization of a non-institutional investor's assents portfolio. *Putevod. Predprin.* **2017**, *33*, 211–219.
27. Khalin, V.G.; Chernova, G.V.; Yurkov, A.V. Methodological aspects of the establishment and operation of decision support systems. *Econ. Anal. Theory Pract.* **2015**, *7*, 20–33.
28. Vygodchikova, I. Construction the rating of competitiveness the Russian companies. *J. Mod. Compet.* **2018**, *12*, 5–17.
29. Karminsky, A.M.; Peresetsky, A.A.; Petrov, A.E. *Reitingi v Ekonomike: Metodologiya i Praktika. Ratings in Economy: Methodology and Practice*; Finans. I Stat.: Moscow, Russia, 2005; pp. 235–240.
30. Vygodchikova, I.Y. Toolkit of decisions making about investment of large Russian companies using hierarchical procedure of ranking and minimax approach. *J. Appl. Inform.* **2019**, *14*, 123–137.
31. Burkynskyi, B.; Iermakova, O.; Laiko, O. Strategic directions for increasing the gross value added of the high-tech sector (on the example of the Ukrainian economy). *Entrep. Sustain. Issues* **2021**, *8*, 508–523. [CrossRef]
32. Borodin, A.; Tvaronavičienė, M.; Vygodcyikova, I.; Kulikov, A.; Skuratova, M.; Shchegolevatykh, N. Improving the Development Technology of an Oil and Gas Company Using the Minimax Optimality Criterion. *Energies* **2021**, *14*, 3177. [CrossRef]
33. Borodin, A.; Tvaronavičienė, M.; Vygodcyikova, I.; Kulikov, A.; Panaedova, G. Optimization of the Structure of the Investment Portfolio of High-Tech Companies Based on the Minimax Criterion. *Energies* **2021**, *14*, 4647. [CrossRef]
34. Borodin, A.; Natocheeva, N.; Khominich, I.; Kulikov, A.; Shchegolevatykh, N. The Impact of the Business Environment on the Effectiveness of the Implementation of the Financial Strategy of the Oil and Gas Company. *Int. J. Energy Econ. Policy* **2021**, *11*, 13–21. [CrossRef]

energies

MDPI

Article

Tailored Blockchain Applications for the Natural Gas Industry: The Case Study of SOCAR

Cemal Zehir [1,2], Melike Zehir [2,3], Alex Borodin [2,4,*], Zahid Farrukh Mamedov [2] and Sadiq Qurbanov [2]

1 Department of Business Administration, Yildiz Technical University, Istanbul 34220, Turkey
2 Center for Islamic Finance, Azerbaijan State University of Economics (UNEC), Baku AZ 1001, Azerbaijan
3 Graduate School of Social Sciences, Yildiz Technical University, Istanbul 34220, Turkey
4 Department of Finance of Sustainable Development, Plekhanov Russian University of Economics, 117997 Moscow, Russia
* Correspondence: aib-2004@yandex.ru

Abstract: Blockchain technology has emerging areas of deployment in diverse sectors and use cases. In this study, several potential application areas of blockchain with promising benefits have been identified in the natural gas industry. There is no single solution that can address different challenges and meet disparate requirements. Therefore, it is important to understand the needs of the natural gas industry and propose appropriate blockchain solutions. Moreover, in the literature, there is a lack of detailed case studies involving industrial experts from the natural gas sector. Expert opinion can be useful for prioritizing the most needed or expected blockchain application areas among several options. By considering privacy, authentication, speed, security, energy consumption, and costs, suitable blockchain types and consensus mechanisms can be determined. This study presents one of the first detailed case studies for tailored applications of blockchain in the natural gas industry. Through a two-staged semi-structured interview with executives from SOCAR Azerbaijan, the most important blockchain application areas and operational requirements were identified. Furthermore, the most suitable blockchain solutions that can address application-specific conditions and needs were determined. This study both, develops a replicable and reliable methodology to conduct detailed blockchain implementation case studies in the natural gas industry and various other sectors, and provides detailed insights into the primary application areas, operational expectations–requirements, and implementation challenges specific to each application.

Keywords: blockchain; case study; internet of things (IoT); natural gas; engineering

Citation: Zehir, C.; Zehir, M.; Borodin, A.; Mamedov, Z.F.; Qurbanov, S. Tailored Blockchain Applications for the Natural Gas Industry: The Case Study of SOCAR. *Energies* **2022**, *15*, 6010. https://doi.org/10.3390/en15166010

Academic Editor: Wen-Hsien Tsai

Received: 17 June 2022
Accepted: 14 August 2022
Published: 19 August 2022

1. Introduction

Natural gas is one of the major sources meeting world energy consumption and it is the only fossil-based source that has consistently increased its share among the other sources in the last half-century. Global natural gas production has steadily increased in the last decade, with an annual growth rate around 2.5%, except for minor drops encountered in 2009 by 2.6% and in 2020 by 2.5% [1]. The share of natural gas in the world total energy supply reached 23.2% of 606 EJ (exajoule, 10^{18} joules) in 2019, a considerable growth compared to 16.1% of 254 EJ in 1973. In OECD countries, despite the decline in the share of coal (from 22.5% in 1973 to 13.2% in 2019) and oil (from 52.6% in 1973 to 34% in 2019) of total energy supply by source, the share of natural gas has significantly increased, from 18.9% to 30.6%. In world gross electricity production, natural gas is the second largest source, with a 23.5% share, following the leader coal with a 36.7% share, ahead of all the other sources [2]. In OECD countries, it was the only source with a steadily increasing share in gross electricity production up to the beginning of the 2000s, and from around 2007 to today, it has continued to grow together with emerging renewable energy technologies (Figure 1) [2].

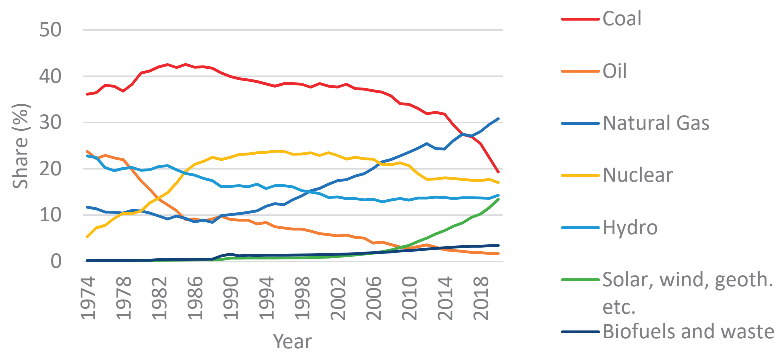


Figure 1. The share of OECD gross electricity production from 1974 to 2000 [2].

There are a number of major problems in the natural gas industry [3]. Obsolete infrastructure can be listed as one of the major issues. Outdated natural gas pipelines, a centralized structure, and cascaded software systems are not suitable for handling a massive number of devices and users. The unreliability of transactions due to third party inclusion is another point of concern. Gas orders are prepared and supervised by third parties and this does not guarantee the transparency, fairness, and traceability of transactions. The third problem is price fluctuations due to dynamic changes in natural gas resources. It is an important challenge for users to foresee reliable sales information, due to uncertainties related to fluctuations. Gas data inaccuracies are the fourth major problem. Delays being encountered in data collection from gas meters in the field trigger energy supply failures. The last major problem is user information security. The information provided by users during transactions, comprising personal information, gas consumption, and other details, is mainly stored in centralized databases, with the risk of being compromised, deleted, or modified. Similar concerns are listed in IBM's whitepaper in [4], defining the current business transactions as inefficient, expensive, and vulnerable due to the involvement of multiple stakeholders with individual ledgers compliant with their specific policies and procedures. Vulnerabilities are further detailed in terms of time, cost, and risk. Many transactions are stated as sensitive to time, as requiring considerable time to settle and reconcile, and prone to delays. From a cost perspective, high overhead costs due to inclusion of various companies and operating units, high costs of management and execution, and detailed documentation needs are listed. The related risks are ambiguity and not being able to verify, being open to errors and tampering, and lack of a single source of truth.

Sector experts agree on the possible benefits of wider automation and digitalization, to increase profitability [5]. Oil and gas companies are willing to adopt and implement new digital technologies and change their operating practices [6]. The World Economic Forum, in a whitepaper, stated that USD 2.5 trillion value could be derived from the digitalization of the oil and gas sector, including a 108,000 barrel reduction in pipeline spills, 120,000 barrel reduction in spills in upstream operations, a 370 million tonne reduction in CO_2 emissions, a 800 million gallon reduction in water consumption, a 16% reduction in accidents and injuries, by utlizing enhanced automation and remote operation, predictive maintenance, operation optimization, data analytics and modelling, field staff connections, supply/demand balancing, digital customer services, and others [7].

Blockchain is one of the emerging technologies that can offer promising potential applications, with prospective benefits in several sectors, ranging from finance [8] to supply chains [9,10], health to mobility [11], public governance to cybersecurity [12], and infrastructure to energy [13]. A blockchain is a distributed and shared ledger that enables immutable transaction records [14], asset tracking, and common trust between several stakeholders and parties [15]. It combines cryptography, data management, networking, and incentive mechanisms to aid the verification, execution, and recording of transactions between parties [16]. A distributed ledger is an addition-only storage method of transactions distributed between many participating nodes. Blockchain represents a connected list of blocks. Each block stores an ordered set of transactions. Each transaction is recorded as a block of data, representing the movement of a tangible (product) or intangible (intellectual) asset. The data block can store the relevant information (sides, content, quantity, time, place, condition, and others) that is needed about the related transaction. Each new block is added to a chain of blocks and is connected to the blocks before and after it. Since the records have a specific time and sequence, any attempts to insert additional blocks between the existing blocks or to modify former blocks can be detected and prevented. None of the transactions can be changed or tampered with once they are recorded in the shared ledger. In case a record includes an error, a new transaction has to be added to reverse the error and both records will be visible. Smart contracts contain a number of rules determined to trigger and perform their related actions and transactions autonomously. A consensus protocol, algorithm, or methodology determines how a new block can be added to the network, resolving competing new blocks [16]. Smart contracts are used to perform autonomous actions based on predetermined rules, triggered by specific conditions. Smart contracts allow peer to peer transactions without any intermediaries, utilizing consensus protocols and software-based verification methodologies [17].

Blockchain technology can enhance data management [18], reduce transaction costs [19], avoid error and fraud [20], and improve system performance with enhanced monitoring and maintenance [21].

Blockchain is not a one-size-fits-all solution or a silver bullet with a single type of implementation that will be beneficial in all cases, applications, and conditions. It has several types and design varieties (characteristics, consensus mechanisms, and others), which are explained in detail in Section 2 of this paper, and which could be suitable or may not fit, based on the considered context of adoption. Moreover, it is a major challenge for industrial players and corporate executives to evaluate and decide on the most suitable blockchain type and design that will fit the targeted sectoral applications, among several potential integration options. Due to this difficulty, industry actors have formed non-profit organizations (such as the OOC Oil & Gas Blockchain Consortium [22], which later changed its name to Blockchain for Energy [23]) to explore the potential areas of use and determine the best solutions collaboratively. Additionally, blockchain brings together some inevitable risks and costs that should be carefully considered in potential applications [24].

Several studies have identified similar potential application areas of blockchain for the natural gas industry. The potential areas of use range from leakage detection in gas pipeline networks to the tracking and tracing of natural gas shipment; automation of gas exploration and production processes to gas asset life-cycle management; billing and payment simplification to operational and compliance auditing; and well abandonment and restoration tracing to waste collection and disposal [4,25–28]. The natural gas supply chain facilities that are considered for potential implementation of blockchain solutions are shown in Figure 2. A new concept of a micro ecosystem with blockchain and edge computing is explored in [29]. Integrated use of blockchain with AI and IoT is investigated from architectural and design perspectives in [3] and in gas prediction and transaction in the smart city context in [30]. A novel solution, aiming natural gas resource finance and sustainability, is presented in [31]. Ref. [32] implemented business process modelling, to investigate the implementation of blockchain in the midstream LNG supply chain. The existing studies have mainly explored the potential areas of use and prospective benefits of blockchain in the natural gas sector, without sufficiently detailing the suitable blockchain types (private, consortium, or public), consensus mechanisms (Proof of Work (PoW), Proof of Stake (PoS), Delegated Proof of Stake (DPoS), Proof of Authority (PoA), Practical Byzantine Fault Tolerance (PBFT), and Proof of Elapsed Time (PoET)) and related risks specific to application areas. Moreover, there is a need for case studies that actively involve industry experts in prioritizing applications, identifying requirements, and tailoring solutions.

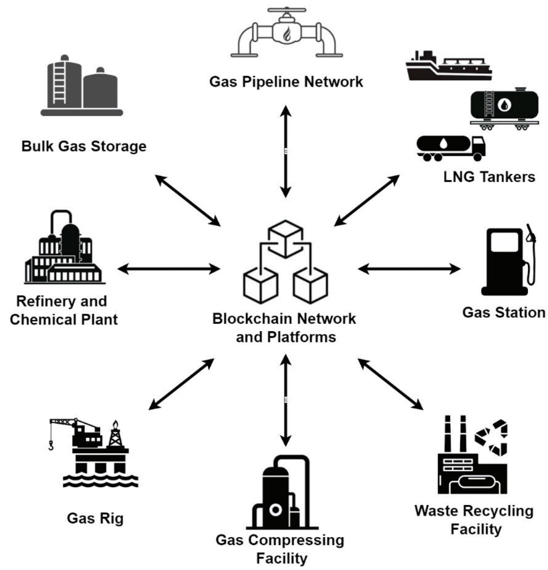


Figure 2. The natural gas supply chain facilities that considered for potential blockchain solution implementation [25].

Issues in the natural gas industry include

- conventional infrastructure challenges and limitations in monitoring, operating, and maintaining a large number of assets,
- gas price volatilities,
- gas stock tracking issues,
- dependency on third parties for financial transactions and gas exploration.

The two problems to be solved within the scope of this study are

- prioritization of application areas of blockchain, based on the requirements or desires of The State Oil Company of the Azerbaijan Republic (SOCAR) operations,
- the lack of clarity regarding the suitable blockchain solutions that would best fit natural gas sector applications.

This paper presents one of the first detailed case studies of the application of blockchain in the natural gas sector. Through a two-stage semi-structured interview conducted with the executives of SOCAR Azerbaijan, one of the top companies in the natural gas industry globally, the prominent application areas of blockchain for SOCAR were prioritized, the requirements for each use case were identified, and suitable blockchain types and consensus mechanisms were tailored, specific to each application, and considering the operational performance, costs, and risks. Section 2 describes the blockchain types and consensus mechanisms, risks of blockchain applications, and the potential areas of use, as well as the benefits of blockchain in natural gas procedures and processes. Section 3 explains the methodology used in the case study. Section 4 presents the results of the interviews and tailors the suitable blockchain solutions that can address the most prominent use cases and operational requirements. Section 5 discusses the findings of the study and provides directions for future research.

2. Literature Review

2.1. Blockchain Types, Consensus Mechanisms, Risks, and Natural Gas Industry Applications

This section explains the blockchain types, consensus mechanisms, associated risks, and potential applications in the natural gas sector under different subsections. The information presented in this section formed the basis for the semi-structured interview explained in Section 3.

2.1.1. Blockchain Types

There are four main types of blockchain, namely, private, consortium, public, and hybrid. A private (permissioned) blockchain provides access only to known participants, providing them with the ability to read and/or write data. A system provider, a single authority, is in charge of evaluating new applicants that request to join the network and giving them permission to access the data. The system provider also has the ability to roll back and reverse some processes. Private blockchains are faster in terms of speed and have lower costs compared to the other blockchain types. On the other hand, all the participants are known, the devices are authenticated, and dependence on a single authority has the risk of failure in case of being compromised through cyberattacks. Usually, Proof of Stake (PoS), Proof of Authority (PoA), and Practical Byzantine Fault Tolerance (PBFT) consensus mechanisms are used in private blockchains.

A consortium blockchain is another permissioned type of blockchain. Unlike private blockchains, a consortium blockchain is controlled by a group, rather than a single authority. It has a semi-decentralized structure [33]. Only trusted and verified participants can validate blocks. It is a mid-solution between private and public blockchains, with an intermediate energy consumption, cost, and transaction speed. Although it is more secure compared to a single authority-dependent private blockchain, the consortium formation process still has the risk of intrusion of undesired parties and entities. Personal information needs to be known, as in private blockchains. Proof of Work (PoW), PoS, and PoA are generally preferred as the consortium mechanisms.

A public (permissionless) blockchain is accessible to anyone [34]. The participants have random IDs and do not need to disclose their personal information (pseudonymity). It is the blockchain type used in Bitcoin and most of the Ethereum networks. There is no central entity that evaluates new applications or manages, the ongoing traffic. In this blockchain type, unknown devices can participate without any initial checks for trustworthiness. A large number of participants and highly decentralized structure provide more security, while decreasing transaction speed and increasing energy consumption and system costs. Usually, PoW and PoS consortium mechanisms are used.

A hybrid blockchain is a customizable solution, where the members can determine which participants can join the network and which transactions will be open to public. It aims to combine the desirable parts of public and private blockchains: freedom and controlled access [35]. It is positioned between the consortium and public blockchains, in terms of security, speed, and costs.

2.1.2. Consensus Mechanisms

There are over 30 mainstream consensus algorithms, six of which are commonly used in prominent applications [25]. This subsection describes the six most used consensus algorithms comparatively.

Proof of Work (PoW) allows every miner to validate new data blocks. Nodes can remain anonymous, and any willing participant can join mining. It requires extensive computation, which should also be verified by other nodes [36].

Proof of Stake (PoS) allows stakeholders owning coins or smart contracts to participate. The ones with high stakes are chosen to validate new blocks. "Minters" reserve some of their coins as a security deposit, to become a validator. A mistaken validation causes the validator to lose their staked tokens. This approach financially rewards the validators for acting fairly.

Delegated Proof of Stake (DPoS) is a considerably modified version of PoS, in which, token holders vote for a group to be responsible for validation of transactions [37]. This approach strengthens the decentralized aspect of the blockchain, as the network participants decide together who will validate transactions, while the actual validation is performed by a smaller delegated group, with improved speed.

Proof of Authority (PoA) is based on the validation of transactions by specifically authorized nodes. The authorized nodes have recognized organizational identities, which are subject to penalties based on external regulations outside the blockchain platform. It has a lower energy consumption and higher transaction speed compared to other consensus mechanisms [38]. It is a suitable mechanism for some private blockchain applications.

Practical Byzantine Fault Tolerance (PBFT) is implemented by authorization of a network of trusted validators (secondary nodes) by a single authority (primary node). This approach can provide reliable transactions as long as less than one third of the nodes are compromised [39]. The consensus is reached by voting.

Proof of Elapsed Time (PoET) randomly generates time delays, the reliability of which is checked at the hardware level. The nodes are allowed to stay idle or perform some other work for their randomly determined period, increasing the network efficiency. Random time determination allows every participating node an equal chance of winning the reward [40].

2.1.3. Risks

Blockchain applications have a number of risks that need to be considered during decision making and solution design. Deloitte lists the risks under three categories: standard risk considerations, value transfer risk considerations, and smart contract risk considerations [41].

There are eight standard risk considerations. Strategic risk is a firm's decision to either adopt technology at an early stage of development or wait until it matures. It is also related to deciding on the network to take part in and the platform to utilize. Business continuity risk is associated with network service interruption due to cyberattacks or operational issues. It requires the development and adoption of methods that can provide fast incident response and short recovery time. Reputational risk is related to compliance with legacy infrastructure. Information security risk is based on the vulnerability of participant account or wallet and the security of transactions in private blockchains. Regulator risk represents compliance with diverse regulatory requirements, particularly in international transactions. Operational and IT risks are concerned with the speed, scalability, and interoperability with legacy systems of implementations. Contractual risk is the need for service-level agreements between the participating nodes and the network administrator. Supplier risks are related to risks associated with third-party technology providers.

Value transfer risk considerations have four subtypes. Consensus protocol risk considers the disadvantages of the adopted consensus mechanisms and their vulnerabilities to cyberattacks or operational issues during deployment. Another risk is key management, which concerns the irreversible transfer of assets in cases of a hijacked account. The deployment component provides a complete working container infrastructure for the considered business application [14]. Continuous integration, delivery, and deployment approaches can help minimize related risks [42]. Continuous integration is the frequent integration and merging of work between the team members. This method reduces the release cycle, enhances software quality, and increases development team productivity. Continuous delivery aims to ensure that an application can be instantly deployed in the relevant environment. Continuous deployment autonomously and continuously deploys the applications for production or customer use cases. Data confidentiality risk concerns metadata leakage of participant transaction metadata to unauthorized network participants. Liquidity risk is related to resolving disputes in transactions, relying on pre-determined regulations.

There are four smart contract risk considerations. Business and regulatory risks are about the business, economic, and legal arrangements used in determination of smart contracts. Contract enforcement is the compliance with legal limitations and financial arrangements. Legal liability is the risk of fraudulent or mistaken use of smart contracts. Information security risks are related to cyberattacks that may target the access, modification, or deletion of information.

Similar risks can be found in another recent study [43]. Seven risks are identified, without any subcategories. Legal risk is related to the regulatory, legal liability, and business and regulatory risks explained in the above paragraphs. Technical risk is partially the same as operational and IT risks and part of strategic risk. Protocol risk is related to consensus protocol risk and partially to operational and IT risks. Cyber risk is similar to key management and information security risks. Privacy risk is related to data confidentiality risk. Validation risk is partially similar to legal liability. Finally, market risk is identical with strategic risk and reputational risk. The interrelations between the risks identified in the two mentioned studies are shown in Figure 2. The determination of very similar risks in two independent, prominent studies shows that these risks are highly likely to be encountered in future field applications and that it is of critical importance to consider them when tailoring blockchain solutions to a specific use case in an industry. In this paper, as part of the interviews conducted in the case study, the risks were mentioned to the executives and taken into account when identifying the most suitable blockchain solutions specific to each potential application.

2.1.4. Potential Applications in the Natural Gas Industry

The natural gas industry value chain consists of three main sections: upstream, midstream, and downstream. Upstream covers gas exploration, production, and processing (including gasification), while midstream is related to transport and LNG shipping, and downstream encompasses regasification, storage, and sale [28,32]. This subsection describes possible areas of use of blockchain in the natural gas industry.

One of the primary areas of use could be the monitoring of natural gas network pipelines. Leakage detection, theft, physical attack-intervention detection, and notification of system operators, with use of real-time monitoring systems operating with blockchains to ensure secure operation and timely maintenance of the critical infrastructure.

Compared to conventional centralized monitoring and storage of data collected from sensors in the field, which are vulnerable to physical and cyberattacks, blockchain can be used to authorize sensors to secure the source of data, and smart contracts can allow autonomous detection of leakages and abnormalities, notifying the related departments and staff instantly. Moreover, records related to maintenance and repairs can be stored in blockchain platforms, allowing traceability and auditing by other staff and entities in future related activities.

Monitoring systems can also be used for natural gas shipments by LNG carrier ships, trucks, and railroad tank cars. Logistic activities can be traced and tracked, ensuring compliance with regulations. Current location and followed route information can be obtained, estimating arrival times and providing notifications in case of any updates. Immutable shipment records enhance security and prevent fraud during shipping. The purity of the product can be verified and recorded at certain points of shipment, providing a traceable trail, to identify the time and place that impurities are added to gas and responsible parties. Similar to pipeline monitoring, LNG carriers' temperature, humidity, pressure, volume, and other parameters representing the state of health can be monitored.

Gas exploration and production is another potential area for implementation of blockchain solutions. Exploration, based on seismic techniques for identifying reserve locations, drilling of wells and testing of the quality and volume of reserve, generates big data, which can be collected, stored, and protected, for use in post-processing. Problems in the collected data can be identified through smart contracts. The related data can be shared with the stakeholders that participate in the exploration and production. Exploration and extraction automation systems are conventionally based on centralized solutions, which may have errors and data corruption issues. Furthermore, stakeholders mostly rent equipment from third party organizations. Blockchain can allow information sharing and payments among the stakeholders.

Gas asset life-cycle management is also listed among the primary potential areas for the application of blockchains. The procurement, shipment, installation, establishment, and repair activities of gas assets involve different subcontractors, requiring compliance with safety regulations. Asset inventory records need to be kept up-to-date. Even purchase and sale request can be processed over blockchain platforms, based on equipment supplier scores representing their reputation. Blockchain can allow the detection and prevention of fabricated, uncertified, or insufficiently performing equipment that does not meet standards. In this way, equipment costs, field staff safety issues, and service interruptions can be minimized.

There is potential for blockchain applications in the billing and payment processes as well. The current payment procedure in the gas industry is to give the stakeholders up to 90 days to complete a payment. The determination of such a long time window is due to the use of centralized systems that are vulnerable to cyberattacks, manual settlement, and non-transparent operations. The conventional systems are also not suitable for a high number of microtransactions. Blockchains can be used for verification of payment provision, receival, and updates, ensuring compliance with the related trading agreements and eliminating the need for intermediaries. It can also be utilized for joint billing in joint ventures.

In the area of regulatory compliance and auditing, the compliance of stakeholders with related state, regional, and international laws, as well as standards and regulations, can be checked. License cancellation, financial losses, or penalties related to non-compliance can be performed over blockchain too. Compliance with field staff safety precautions can be tracked and guaranteed over blockchain as well. The use of dangerous and forbidden chemicals can be prevented as part of the same process.

Well abandonment and restoration can be traced using blockchain solutions. Temporary or permanent abandonment of wells can be verified. Information, including date of abandonment, the reason for abandonment, and type of abandonment, can be stored in a blockchain and could be used at the restoration stage.

Gas waste disposal and recycling is the eighth identified potential area of use of blockchain in the natural gas sector. Compliance with waste treatment regulations, waste tracking, and stages such as gathering, processing, shipping, treating, recycling, and landfilling can be monitored. Successful delivery of waste to a determined recycling plant can be ensured, minimizing illegal dumping and shipments. In such applications, smart contracts can be used to manage delays, fraud and data forgery, and documentation. The amount of waste lost during disposal and recycling can be closely tracked.

2.2. Related Work

Blockchain integration into the natural gas industry is usually considered together with the oil industry [28,43]. The current studies mainly provide an industry-wide perspective about potential areas of use, without the prioritization of use cases and without conducting in-depth case studies involving participants or direct data from major industrial players. Some pilot projects and challenges are briefly introduced from such studies.

In application-specific studies, deterministically-decided single solutions are usually selected and investigated, usually combining IoT and AI [3,30,44]. Such studies usually focus on the design stage and do not employ a holistic approach, to foresee operational challenges.

The majority of the studies in this area have been conducted by Chinese researchers.

There are inspiring approaches from different sectors. One study considered a wide range of use cases in electric power and the energy industry, ranging from microgrids to wholesale electricity markets, green certificate trading to e-mobility charging infrastructure, and asset management to grid services [34]. Conducting interviews and identifying the critical criteria, such as transaction speed, transaction cost, transparency, integrity, confidentiality, suitable blockchain types, and consensus mechanisms, are specified. Such a methodology has not been conducted in an up-to-date manner in the natural gas sector.

The majority of the studies emphasized the advantages of blockchain applications, while a few studies looked into the details of the associated risks [41–43]. These risks also need to be taken into account when determining the most suitable blockchain solution for a use case in a selected sector. A combination of the methodology provided in [34] with the risks specified in [41–43] could progress blockchain adoption efforts further, highlighting the promising options. The inclusion of sector experts from a single company can provide insights that are closer to field, which can also help in deciding on the details of use-case-specific solutions.

Based on the related work, there are important gaps and requirements for further research in the natural gas sector for blockchain adoption. Detailed case studies need to be conducted, and wide range of solution options should be comparatively evaluated, considering advantages and associated risks, when determining solutions specific to a use case. This paper presents one of the first in-depth case studies for blockchain application in the natural gas sector. It contributes to the literature by,

- prioritizing the prominent application areas of blockchain for SOCAR operations,
- identifying the requirements for each use case,
- and determining suitable blockchain types and consensus mechanisms specific to each application, as well as considering the operational performance, costs, and risks.

This work provides a replicable and scalable methodology that can be used in future studies in the natural gas sector and other sectors with a potential adoption of blockchain, such as mobility, health, food, e-government, finance and others.

3. Methodology

Based on the contextual background explained in Section 2, a two stage semi-structured interview was prepared to be conducted with the executives of a natural gas company SOCAR, for a case study with the following main aims:

- identify the primary areas of use with the most urgent need or the highest potential benefits in applying blockchains,
- determine the operational performance, cost, and other related requirements specific to each prioritized area of application,
- tailor the most suitable blockchain solution for each identified area of use, including consensus mechanisms and considering the associated risks.

The first stage interview had questions related to

- the occurrence and importance of the challenges, which can be addressed by blockchain applications, encountered in the company's operations and processes,
- the importance of the needs and potential improvements that can be achieved in the company's operations and processes,
- the sensitivities of the company's financial operations and processes to different factors,
- the importance of the potential benefits of blockchain applications for the company's operations and processes, from the perspective of the executives,
- the priority of the potential blockchain applications in the natural gas industry, from the perspective of the company's executives,
- the importance of the data that could be collected through blockchain for the company's operations and processes,
- the importance of the risks (based on the content provided in Section 2.1.3) associated with blockchain applications for the company's operations and processes.

The second stage of the interview was prepared based on the insights gained from the answers provided in the first stage interview. It had more in-depth questions, aiming to highlight the needs and requirements per primary area of use of blockchains for the company, and determining the most suitable blockchain applications for each area of use. It had questions related to

- the network participants that will be allowed to access and view the data collected for each primary blockchain area of use identified by the company executives in the first stage of the interview,
- the network participants that will be allowed to hold distributed ledger records, even those not authorized to access the information available in the records, to increase the number of copies for enhanced security for each primary blockchain area of use identified in the first stage of the interview,
- the need for pseudonymity of the network participants that will hold distributed ledger records for each primary area of use identified by the company executives,
- the number of assets or nodes that will be monitored, provide information to the system, and communicate with others for each identified primary area of use,
- the number of transactions per second (TPS) and the transaction speed that will be needed for each identified primary area of use,
- any energy consumption-related expectations of the blockchain application for each identified area of use,
- the risk of being targeted by cyberattacks of the blockchain application for each identified area of use (as part of the risk considerations explained in Section 2.1.3),
- the relative operational cost expectations of blockchain applications for each identified area of use.

A general diagram of the methodology is provided in Figure 3.

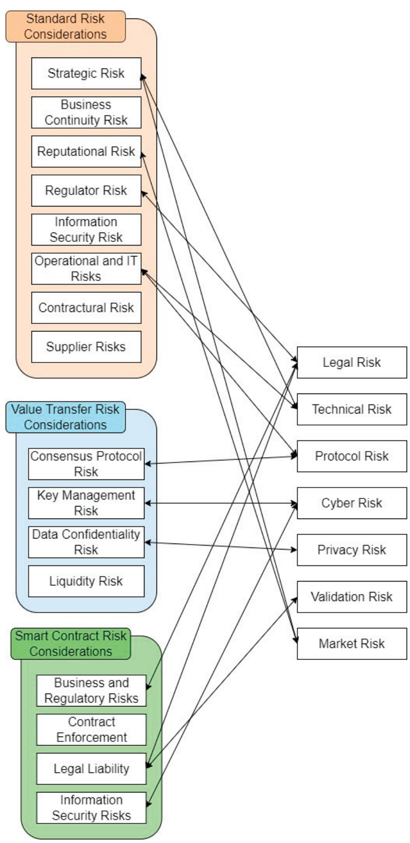


Figure 3. Interrelations between the blockchain risks identified in two prominent studies [41–43].

Both interviews were prepared to be conducted with the same participants, meaning that the executives which took part in the first interview were the participants of the second interview too. The second interview was performed one month later than the first interview. Prior to both interviews, no specific information about natural gas sector challenges listed in the literature, potential blockchain application areas, or benefits of blockchain applications were provided to any of the interviewed executives, to prevent any biases and to solely gain their individual insights based on their operational and procedural experience.

4. Case Study

A case study was conducted with The State Oil Company of the Azerbaijan Republic (SOCAR). The company runs oil and gas exploration, production, processing, transport, and marketing in both Azerbaijan and international markets. It has various activities in Turkey, Georgia, Ukraine, Germany, Switzerland, and Romania, in addition to trading activities mainly in Switzerland, Singapore, and Nigeria. With roots back to the 1950s and beyond, under different organizational names and structures, today's SOCAR was officially established in 1992, after the Republic of Azerbaijan restored its independence [24,45–48]. The first oil wells in the country were drilled in Bibiheybat in 1847, and shortly after in Balakhany. In 1901, Azerbaijan was the world's leading oil producer with 11 million tons of annual oil production, while the US was producing 9.1 million tons annually. In 1941, Azerbaijan produced 23.5 million tons of oil, representing 71.4% of the Soviet Union's production. Azerbaijan was also the world's first offshore oil producer. In 1949, 40 km offshore and 90 km from Baku, a field named "Neft Dashlari (Oil Rocks)" was discovered, which was followed by several other offshore fields in the following years. Currently, offshore production provides more than 60% of SOCAR's oil. Starting in 1994, SOCAR has signed 32 production sharing agreements so far, with foreign oil companies all over the world. The company has around an EUR 50 billion annual revenue, more than 90% of which is recorded in foreign markets.

The two stage semi-structured interviews were conducted with executives from gas distribution. Eleven executives took part in the interviews and provided their opinion.

In the first stage interview, regarding the challenges that are encountered in operation, all the executives emphasized the infrastructure, stating that the management and monitoring of massive numbers of customers and assets is important and becomes challenging from time to time. The reliability of financial transactions due to the involvement of third parties and the need for intermediaries is collectively an area that does not cause any challenges; but it has importance and needs to be carefully considered in the future operations and technological adaptations of the company. Similarly, inaccuracies in gas data, due to delays in gathering data from the meters in the field and related supply challenges collectively, were stated as an area which does not cause any problems; but has importance and should be carefully considered in future operations

Three operational improvements were emphasized by the interviewees. In particular, the storage and verification of the certification of technical field staff (related to hydrogen sulfide (H2S), a poisonous, corrosive and flammable gas, commonly found in drilling and production of natural gas, first aid training, welding, and others) for safe operation of field equipment and devices was given the highest importance. This was followed by the reduction of operational costs and delays, enhanced transparency with the industrial stakeholders, and improvement of employee hiring processes and work performance.

Among the potential benefits of blockchain applications, higher transparency, improved auditability, and traceability were considered the most important by the interviewed executives of the company.

Among the application areas of blockchain, automated leakage detection in natural gas pipelines was stated as the most prominent, followed by gas assets life-cycle management.

The most important data that can be collected and stored by blockchain applications was stated as the current gas stock data, followed by the auditing of reconciliation, based on the tracking of sides that do not fulfill their responsibilities; verification of compliance with trade agreements; and, if required, charging penalties.

Among the blockchain risks introduced in Section 2.1.3, the security of smart contracts (information security as part of smart contract risk consideration category) was given the highest importance, followed by compliance with different systems and protocols (reputational risk), information security (as part of standard risk consideration category), and privacy (data confidentiality).

The first stage interview highlighted six primary application areas of blockchains for SOCAR's operations:

- pipeline leakage monitoring
- gas asset life-cycle management,
- current gas stock monitoring,
- auditing of reconciliation,
- field technical staff certification,
- employee hiring and working performance.

The first stage findings are summarized in Figure 4.

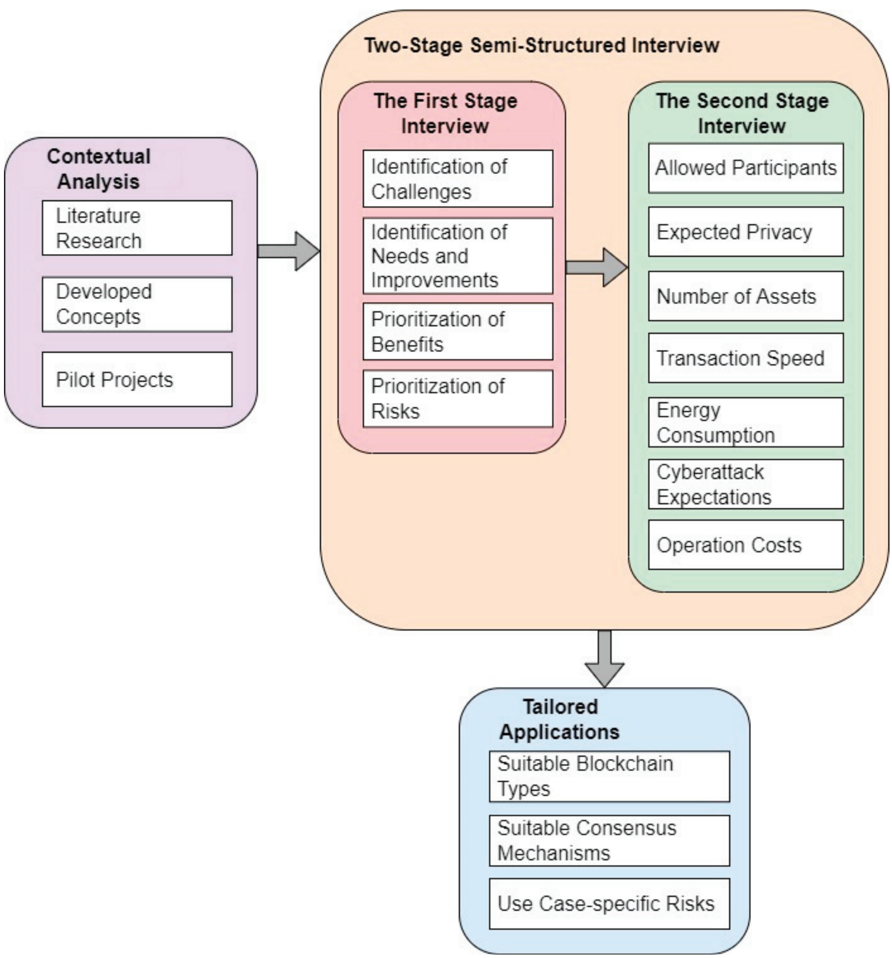


Figure 4. General diagram of the methodology followed.

In the second stage interview, the network participants that can be allowed to access and view the data were reported to be the internal departments and authorized reliable organizations for gas asset life-cycle management, current gas stock monitoring, auditing of reconciliation, field technical staff certification, and employee hiring and working performance application areas. Only for pipeline leakage monitoring were external participants with pseudonymity accepted by the majority of the interviewees.

The only network participants that would be allowed to hold the distributed ledger records for the application areas mentioned in the previous paragraph were stated by all the executives as nodes that belong to the company itself.

The personal information of the network participants that would hold the distributed ledger records were desired to be known by all the executives.

The executives stated that there would be thousands of assets or nodes that would be monitored, provide information to the system, and communicate with others; and less than tens of thousands.

The number of transactions per second (TPS) was stated as thousands for all the applications, except field technical staff certification and employee hiring and working performance. For these two application areas, less than ten to several tens of TPS was stated by the majority of the executives, while a considerable number of executives still thought that thousands of TPS could be needed, as in the other applications.

Low electric energy consumption was collectively stated as a desired aspect of the blockchain solutions that would be implemented for each area of application.

Current gas stock monitoring and the auditing of reconciliation potential applications were stated to have a higher risk of being targeted by cyberattacks, followed by employee hiring and working performance applications. The other applications were stated to have moderate risks, similar to other systems, platforms, and infrastructures.

The relative operational cost expectations were similar to the other systems, meaning that blockchain applications are not required to have low costs; but high costs would not be accepted either.

Based on the insights, experiences, and expectations provided by the company executives, tailored blockchain solutions were determined for each primary application area. The overall findings of the second stage interview with use case-specific applications and mechanisms are summarized in Figure 5.

The suitable blockchain types and consensus mechanisms are shown in Figure 6. In the figure, each arrow color represents dependence to different blocks (such as blue used for any arrow leaving the block "transaction speed") for better visualization of dependencies. Solid line is used to show strong suitability, while dashed line is used to represent partial suitability. For natural gas network pipeline monitoring applications, a hybrid blockchain with authorized company nodes to create blocks, and with external participants allowed to access and view data, seemed to be the suitable solution.

For the other five prioritized application areas, a private blockchain can be primarily preferred, due to restricted access, low energy consumption expectations, no pseudonymity, and fast TPS requirements. For applications that need higher transparency, are expected to have a higher risk of being targeted by cyberattacks (current gas stock monitoring, auditing of reconciliation and optionally for employee hiring and working performance applications), or that require high scalability (gas asset life-cycle management), a consortium blockchain was preferred, with authorized organizations taking part in validation of new blocks, providing a higher level of security, trust, scalability, and transparency.

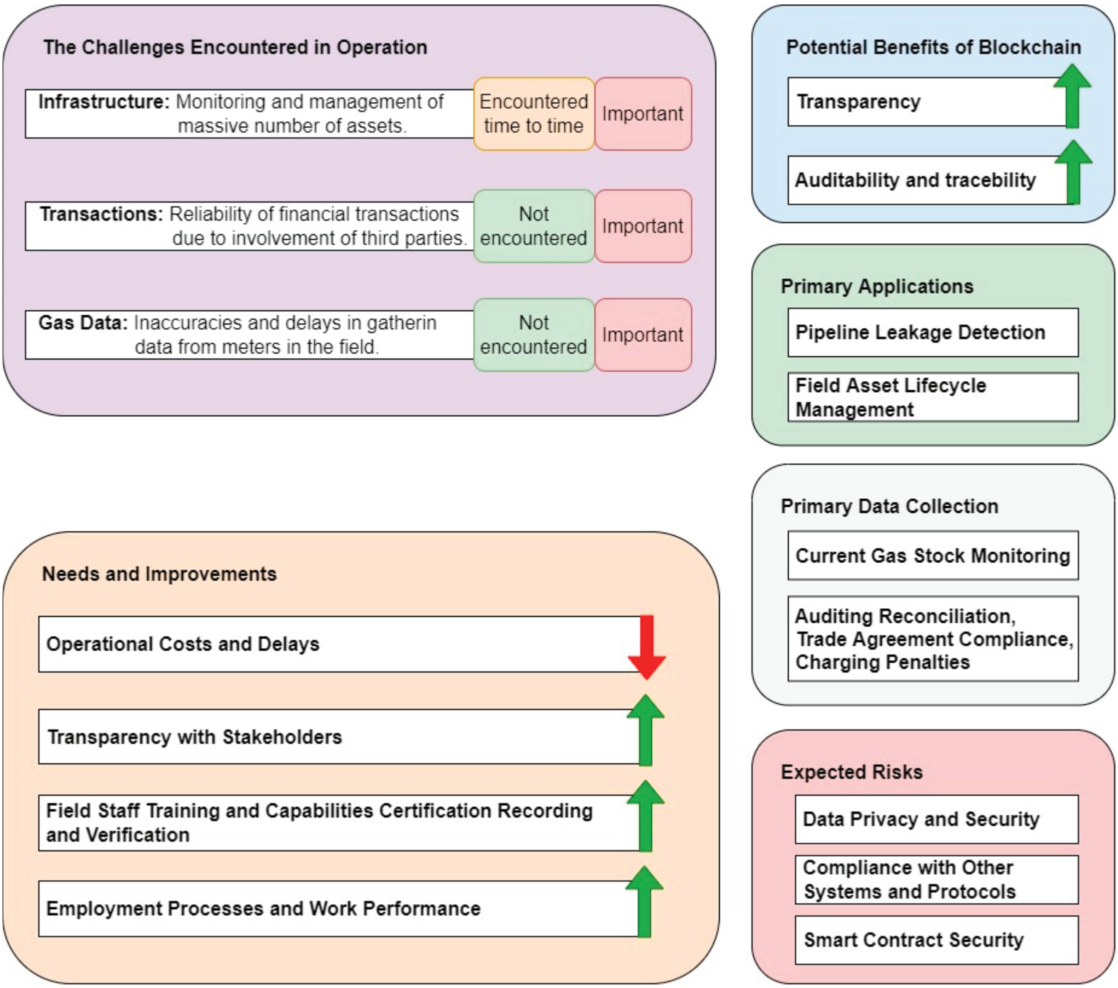


Figure 5. The summary of the prominent findings of the first stage interviews with the company executives, where red arrow represents the need for reduction and green arrow represents the need for improvement.

In none of the applications was PoW considered to be suitable, due to high energy consumption and costs. PoS and DPoS was preferred for applications requiring higher security (current gas stock monitoring, auditing of reconciliation and optionally for employee hiring and working performance applications) and moderate TPS (field technical staff certification and employee hiring and working performance), while PoET, PBFT, and PoA were preferred for the other four applications requiring a high transaction speed.

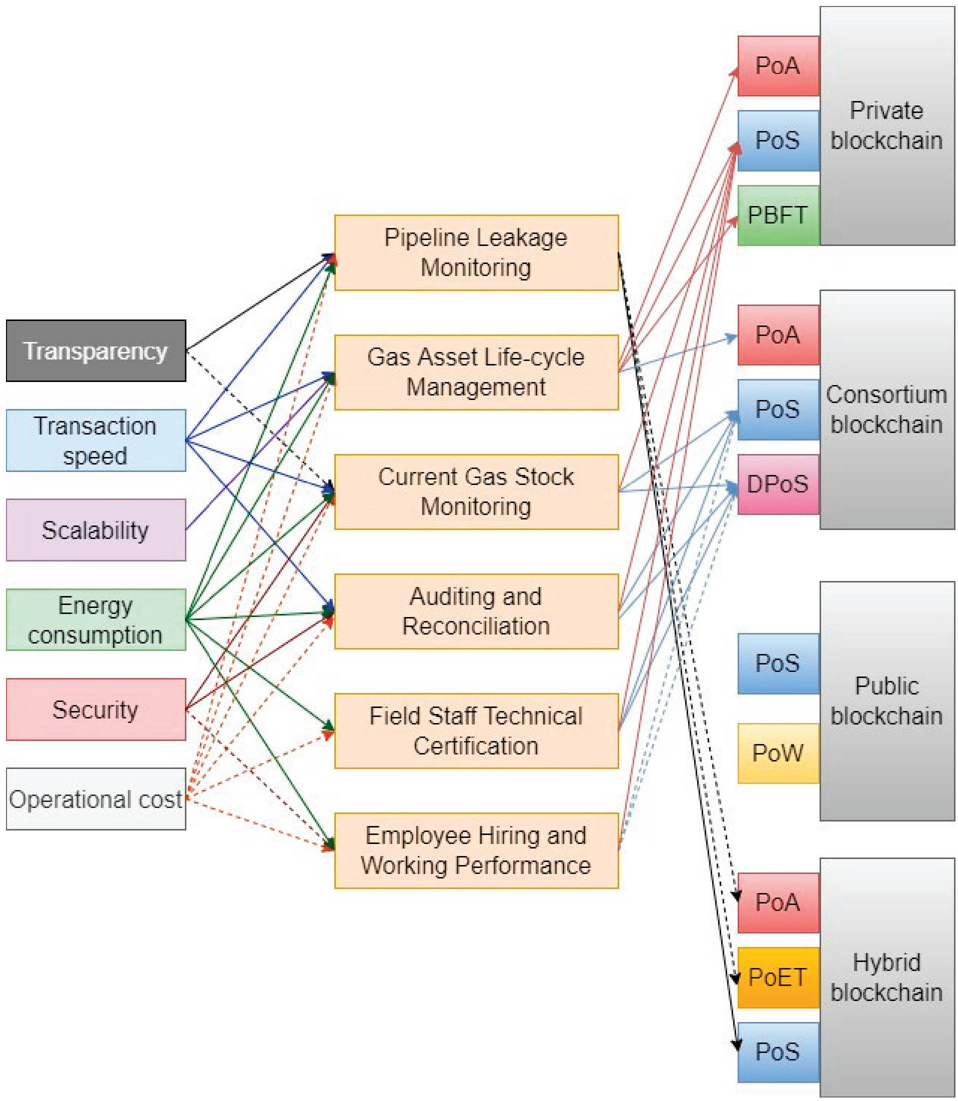


Figure 6. Summary of the findings of the second stage interview with use case-specific applications.

5. Discussion and Limitations

This study showed that the primary areas of implementation of blockchain in the natural gas industry, from the perspective of the industrial experts, are considerably different compared to the past related conceptual studies available in the literature. Contrary to the literature expectations about a wide deployment of blockchain for fostering investments in gas exploration and enhancing billing and payment, the company executives gave a much higher priority to pipeline leakage monitoring. Moreover, two areas of use, field staff technical certification and employee hiring and working performance, which were briefly mentioned as potential areas in the past conceptual studies, were found among the prominent application areas for the company in this case study. Another important finding is that the industry experts gave more importance to transparency, traceability, and auditability, compared to enhancing transaction speed, stakeholder integration, and supply chain processes automation. The study shows the value of conducting detailed case studies involving industrial experts and stakeholders to highlight unique priorities and expectations regarding industry- and company-specific challenges and opportunities.

This study focused on a single large enterprise, to highlight the primary potential use cases of blockchain and determine the most suitable blockchain solutions. This was the method adopted in several other studies in the literature, to conduct detailed studies and determine tailored solutions based on the challenges and priorities of a single company. The primary use cases may differ from company to company, and it would be useful to follow an approach similar to the one presented in this study when working with different natural gas companies. Moreover, sector-wide general suitable areas of blockchain adoption might be highlighted if several industry players were included in future case studies.

The interviews were conducted with 11 executives from the company. Further interviews with team managers and field staff might highlight some distinct challenges and different potential areas of use. Alternatively to conducting interviews, in case of extensive IoT sensor and meter availability and historical meter recording access, data analytics could be implemented to highlight the challenges and determine potential areas of use. Such data are currently not widely available, but it could become easier to access this in the near future, with increasing digitalization efforts.

This study covered a three month period, in the first quarter of 2022. In time, based on the sectoral trends, or based on experiences of pilot applications, the executives' views may change and the primary areas of use of blockchain from their perspective may differ. The methodology described in this paper could be periodically repeated, to obtain up-to-date views and determine appropriate solutions about blockchain adoption in SOCAR operations.

This study considers some of the most commonly used consensus algorithms. However, there are many other consensus protocols, and new approaches will emerge in time. Different algorithms can offer unique advantages specific to an application area, and any potentially suitable algorithm can also be included in such decision making processes.

6. Conclusions

This study represents one of the first detailed case studies on blockchain applications in the natural gas industry. A two-stage semi-structured interview was conducted to identify the primary areas of use and operational expectations and to determine tailored blockchain solutions specific to each application area. The case study with SOCAR executives highlighted the six primary application areas of blockchain for the operations of the company. Pipeline network monitoring, gas asset life-cycle management, and field technical staff certification were prioritized over billing, shipment tracking, and other potential applications mentioned in the literature. Higher transparency, improved audibility, and traceability were stated as the most important benefits of blockchain from the perspective of the interviewed executives. Based on the expectations and requirements, predominantly private blockchain (especially for field technical staff certification, employee hiring, and working performance), optionally and contextually consortium blockchain (particularly for current gas stock monitoring, auditing of reconciliation, gas asset life-cycle management), and rarely hybrid blockchain (pipeline leakage monitoring) seemed to be suitable. Public blockchains and PoW are not likely to be suitable for any of the six identified primary areas of application; while PoS and DPoS could be used for applications that have a higher risk of being targeted by cyberattacks, and PoET, PBFT, and PoA could be used in applications requiring high TPS.

This study provided valuable insights into SOCAR's potential areas of use of blockchain and the suitable solutions that could address the challenges and requirements of specific application areas. The methodology developed in this study could be used in future case studies in the natural gas industry or similar sectors, and the findings of this study could be useful for similar organizations. Future works could focus on conducting detailed case studies in other promising sectors for blockchain applications and pilot demonstrations of the tailored applications for the gas industry use cases in the field. It would also be valuable to explore the unique advantages of the emerging consensus mechanisms, as a result of modified work-based (such as Proof of Meaningful Work, Proof of Edit Distance and other), stake-based (Leasing PoS, Variable Delayed PoS and other), burn-based (Proof of Processed Payments, Proof of Disintegration), capacity/space-based (Proof of History, Proof of Research, Proof of Reputation, Proof of Zero, Proof of Value, Proof of Quality, Proof of Presence and other), BFT-based (Federated Byzantine Agreement, Ouroboros, and others), and directed acyclic graph-based (Hashgraph, Block-Lattice-Directed Acyclic Graphs) consensus mechanisms or their hybrid versions (Proof of Activity, High Interest Proof of Stake and other). Layer 2 blockchain applications could also be considered in future research and implementation efforts, to overcome potential scaling issues.

Author Contributions: conceptualization and methodology M.Z. and C.Z.; validation M.Z. and C.Z.; supervision C.Z., Z.F.M., S.Q. and A.B.; writing—original draft preparation M.Z.; writing—review and editing C.Z., Z.F.M., S.Q. and A.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank The State Oil Company of the Azerbaijan Republic (SOCAR) executives for their active participation in interviews, as well as other employees for the support provided in conducting this study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. International Energy Agency. Natural Gas Information: Overview. 2021. Available online: https://www.iea.org/reports/natural-gas-information-overview/production (accessed on 17 February 2022).
2. International Energy Agency. Electricity Information: Overview-Electricity Production. 2021. Available online: https://www.iea.org/reports/electricity-information-overview/electricity-production (accessed on 17 February 2022).
3. Miao, Y.; Zhou, M.; Ghoneim, A. Blockchain and AI-based natural gas industrial IoT system: Architecture and design issues. *IEEE Netw.* **2020**, *34*, 84–90. [CrossRef]
4. IBM. Blockchain can Help Transform Supply Chain Networks in the Chemicals and Petroleum Industry. 2018. Available online: https://www.ibm.com/downloads/cas/B4OYMO5Q (accessed on 12 April 2022).
5. Bazaee, G.; Hassani, M.; Shahmansouri, A. Identifying Blockchain Technology Maturity's Levels in the Oil and Gas Industry. *Pet. Bus. Rev.* **2020**, *4*, 43–61.
6. Gartner. Hype Cycle for Blockchain Business Shows Blockchain Will Have a Transformational Impact a Cross Industries in Five to 10 Years. 2019. Available online: https://www.gartner.com/en/newsroom/press-releases/2019-09-12-gartner-2019-hype-cycle-for-blockchain-business-shows (accessed on 17 February 2022).
7. World Economic Forum. Digital Transformation Initiative: Oil and Gas Industry. 2017. Available online: https://reports.weforum.org/digital-transformation/wp-content/blogs.dir/94/mp/files/pages/files/dti-oil-and-gas-industry-white-paper.pdf (accessed on 9 August 2022).
8. Zehir, S.; Zehir, M. Internet of things in blockchain ecosystem from organizational and business management perspectives. In *Digital Business Strategies in Blockchain Ecosystems*; Springer: Cham, Switzerland, 2020; pp. 47–62.
9. Brookbanks, M.; Parry, G. The impact of a blockchain platform on trust in established relationships: A case study of wine supply chains. *Supply Chain Manag. Int. J.* **2022**, *27*, 128–146. [CrossRef]
10. Aslam, J.; Saleem, A.; Khan, N.T.; Kim, Y.B. Factors influencing blockchain adoption in supply chain management practices: A study based on the oil industry. *J. Innov. Knowl.* **2021**, *6*, 124–134. [CrossRef]
11. Karger, E.; Jagals, M.; Ahlemann, F. Blockchain for Smart Mobility—Literature Review and Future Research Agenda. *Sustainability* **2021**, *13*, 13268. [CrossRef]
12. Gimenez-Aguilar, M.; De Fuentes, J.M.; Gonzalez-Manzano, L.; Arroyo, D. Achieving cybersecurity in blockchain-based systems: A survey. *Future Gener. Comput. Syst.* **2021**, *124*, 91–118. [CrossRef]
13. Wang, Q.; Li, R.; Zhan, L. Blockchain technology in the energy sector: From basic research to real world applications. *Comput. Sci. Rev.* **2021**, *39*, 100362. [CrossRef]
14. Górski, T. Towards Continuous Deployment for Blockchain. *Appl. Sci.* **2021**, *11*, 11745. [CrossRef]

15. IBM. Blockchain. 2022. Available online: https://www.ibm.com/topics/what-is-blockchain (accessed on 21 April 2022).
16. Xu, X.; Weber, I.; Staples, M. *Architecture for Blockchain Applications*; Springer: Cham, Switzerland, 2019; pp. 1–307.
17. Górski, T. Reconfigurable Smart Contracts for Renewable Energy Exchange with Re-Use of Verification Rules. *Appl. Sci.* **2022**, *12*, 5339. [CrossRef]
18. Huang, S.; Wang, G.; Yan, Y.; Fang, X. Blockchain-based data management for digital twin of product. *J. Manuf. Syst.* **2020**, *54*, 361–371. [CrossRef]
19. Schmidt, C.G.; Wagner, S.M. Blockchain and supply chain relations: A transaction cost theory perspective. *J. Purch. Supply Manag.* **2019**, *25*, 100552. [CrossRef]
20. Liu, L.; Tsai, W.T.; Bhuiyan, M.Z.A.; Peng, H.; Liu, M. Blockchain-enabled fraud discovery through abnormal smart contract detection on Ethereum. *Future Gener. Comput. Syst.* **2022**, *128*, 158–166. [CrossRef]
21. Xu, J.; Liu, H.; Han, Q. Blockchain technology and smart contract for civil structural health monitoring system. *Comput.-Aided Civ. Infrastruct. Eng.* **2021**, *36*, 1288–1305. [CrossRef]
22. Business Wire. U.S. Blockchain Consortium Launches to Lead Blockchain Adoption in the Oil and Gas Industry. 2019. Available online: https://www.businesswire.com/news/home/20190226005320/en/U.S.-Blockchain-Consortium-Launches-to-Lead-Blockchain-Adoption-in-the-Oil-and-Gas-Industry (accessed on 20 March 2022).
23. Blockchain for Energy. Use Cases. 2022. Available online: https://www.blockchainforenergy.net/use-cases-1 (accessed on 21 March 2022).
24. Zhao, F.; Chan, W.K.V. When Is Blockchain Worth It? A Case Study of Carbon Trading. *Energies* **2020**, *13*, 1980. [CrossRef]
25. Ahmad, R.W.; Salah, K.; Jayaraman, R.; Yaqoob, I.; Omar, M. Blockchain in oil and gas industry: Applications, challenges, and future trends. *Technol. Soc.* **2022**, *68*, 101941. [CrossRef]
26. Forbes. Where Blockchain Technology Can Disrupt the Oil and Gas Industry. 2022. Available online: https://www.forbes.com/sites/forbesbusinesscouncil/2021/09/27/where-blockchain-technology-can-disrupt-the-oil-and-gas-industry/?sh=2185e78714ab (accessed on 12 April 2022).
27. Deloitte. Is Blockchain's Future in Oil and Gas Transformative or Transient? 2017. Available online: https://www2.deloitte.com/content/dam/Deloitte/de/Documents/energy-resources/gx-blockchain-report-future-in-oil-and-gas.pdf (accessed on 14 April 2022).
28. Lu, H.; Huang, K.; Azimi, M.; Guo, L. Blockchain technology in the oil and gas industry: A review of applications, opportunities, challenges, and risks. *IEEE Access* **2019**, *7*, 41426–41444. [CrossRef]
29. Miao, Y.; Song, J.; Wang, H.; Hu, L.; Hassan, M.M.; Chen, M. Smart Micro-GaS: A cognitive micro natural gas industrial ecosystem based on mixed blockchain and edge computing. *IEEE Internet Things J.* **2020**, *8*, 2289–2299. [CrossRef]
30. Xiao, W.; Liu, C.; Wang, H.; Zhou, M.; Hossain, M.S.; Alrashoud, M.; Muhammad, G. Blockchain for secure-GaS: Blockchain-powered secure natural gas IoT system with AI-enabled gas prediction and transaction in smart city. *IEEE Internet Things J.* **2020**, *8*, 6305–6312. [CrossRef]
31. Blockchain Research Institute. Oil, Natural Gas, and Blockchain. 2020. Available online: https://www.blockchainresearchinstitute.org/project/oil-natural-gas-and-blockchain/ (accessed on 11 April 2022).
32. Lyridis, D.V.; Andreadis, G.O.; Papaleonidas, C.; Tsiampa, V. A novel methodology using BPM to assess the implementation of blockchain in the midstream LNG supply chain. In Proceedings of the 2021 World of Shipping Portugal, Porto, Portugal, 28–29 January 2021; pp. 1–19.
33. Li, M.; Lal, C.; Conti, M.; Hu, D. LEChain: A blockchain-based lawful evidence management scheme for digital forensics. *Future Gener. Comput. Syst.* **2021**, *115*, 406–420. [CrossRef]
34. Albrecht, S.; Reichert, S.; Schmid, J.; Strüker, J.; Neumann, D.; Fridgen, G. Dynamics of Blockchain Implementation—A Case Study from the Energy Sector. In Proceedings of the 51st Hawaii International Conference on System Sciences, Hilton Waikoloa Village, HI, USA, 3–6 January 2018; pp. 1–10.
35. Le, T.V.; Hsu, C.L.; Chen, W.X. A Hybrid Blockchain-Based Log Management Scheme with Non-Repudiation for Smart Grids. *IEEE Trans. Ind. Inform.* **2021**, *18*, 5771–5782. [CrossRef]
36. Kirli, D.; Couraud, B.; Robu, V.; Salgado-Bravo, M.; Norbu, S.; Andoni, M.; Kiprakis, A. Smart contracts in energy systems: A systematic review of fundamental approaches and implementations. *Renew. Sustain. Energy Rev.* **2022**, *158*, 112013. [CrossRef]
37. Oyinloye, D.P.; Teh, J.S.; Jamil, N.; Alawida, M. Blockchain consensus: An overview of alternative protocols. *Symmetry* **2021**, *13*, 1363. [CrossRef]
38. Manolache, M.A.; Manolache, S.; Tapus, N. Decision Making using the Blockchain Proof of Authority Consensus. *Procedia Comput. Sci.* **2022**, *199*, 580–588. [CrossRef]
39. Hu, X.; Zheng, Y.; Su, Y.; Guo, R. IoT Adaptive Dynamic Blockchain Networking Method Based on Discrete Heartbeat Signals. *Sensors* **2020**, *20*, 6503. [CrossRef] [PubMed]
40. Kaur, S.; Chaturvedi, S.; Sharma, A.; Kar, J. A research survey on applications of consensus protocols in blockchain. *Secur. Commun. Netw.* **2021**, *2021*, 6693731. [CrossRef]
41. Deloitte. Blockchain Risk Management: Risk Functions Need to Play an Active Role in Shaping Blockchain Strategy. 2017. Available online: https://www2.deloitte.com/content/dam/Deloitte/us/Documents/financial-services/us-fsi-blockchain-risk-management.pdf (accessed on 20 March 2022).

42. Shahin, M.; Babar, M.A.; Zhu, L. Continuous integration, delivery and deployment: A systematic review on approaches, tools, challenges and practices. *IEEE Access* **2017**, *5*, 3909–3943. [CrossRef]
43. Kadry, H. Blockchain applications in midstream oil and gas industry. In Proceedings of the International Petroleum Technology Conference, Dhahran, Saudi Arabia, 13–15 January 2020; OnePetro: Richardson, TX, USA, 2020.
44. Yan, M.; Gan, W.; Zhou, Y.; Wen, J.; Yao, W. Projection method for blockchain-enabled non-iterative decentralized management in integrated natural gas-electric systems and its application in digital twin modelling. *Appl. Energy* **2022**, *311*, 118645. [CrossRef]
45. Mamedov, Z.F.; Qurbanov, S.H.; Streltsova, E.; Borodin, A.; Yakovenko, I.; Aliev, A. Mathematical models for assessing the investment attractiveness of oil companies. *SOCAR Proc.* **2021**, *4*, 102–114. [CrossRef]
46. Borodin, A.; Panaedova, G.; Frumina, S.; Kairbekuly, A.; Shchegolevatykh, N. Modeling the Business Environment of an Energy Holding in the Formation of a Financial Strategy. *Energies* **2021**, *14*, 8107. [CrossRef]
47. Fedorova, E.; Lapshina, N.; Borodin, A.; Lazarev, M. Impact of information in press releases on the financial performance of Russian companies. *Ekon. Polit.* **2021**, *16*, 138–157. [CrossRef]
48. SOCAR. History of SOCAR. 2022. Available online: https://socar.az/socar/en/company/about-socar/history-of-socar (accessed on 18 March 2022).

energies

Article

Mechanisms for Tax Regulation of CO_2-Equivalent Emissions

Alex Borodin [1,*], Vladislav Zaitsev [1], Zahid F. Mamedov [2], Galina Panaedova [3] and Andrey Kulikov [4]

1 Department of Sustainable Development Finance, Plekhanov Russian University of Economics, 117997 Moscow, Russia
2 Department for Organization and Management of Scientific Activities, Azerbaijan State University of Economics, 1001 Baku, Azerbaijan
3 Department of Tax Policy and Customs Affairs, North-Caucasus Federal University, 355017 Stavropol, Russia
4 Department of Organization of Medical Provision and Pharmacoeconomics, I.M. Sechenov First Moscow State Medical University (Sechenov University), 119991 Moscow, Russia
* Correspondence: aib-2004@yandex.ru

Abstract: The aim of the work is to develop a mechanism for cross-border carbon regulation for countries importing products to the EU, which will equally allow importing countries to fulfill the conditions of the Carbon Border Adjustment Mechanism (CBAM), encourage manufacturers to reduce CO_2 emissions, and also provide importing countries with opportunities to replenish their budget by introducing paid emission quotas greenhouse gases. The work makes a significant contribution to stimulating the reduction of CO_2 emissions by producers due to the proposed tax mechanism and preventing the leakage of greenhouse gases on the territory of third countries according to the CBAM policy. The EU evaluates double taxation, so if a carbon tax has been withdrawn in the territory of the exporting country, then such a tax will not be levied again in the EU. All this involves stimulating exporting countries by creating their own taxation systems, which will have international qualifications and be recognized by countries around the world. When choosing a taxation mechanism, it is important to choose the specifics for visiting group gases. The study was conducted on the basis of methods of comparison, modeling, analysis and deduction.

Keywords: green economy; greenhouse gases; cross-border carbon regulation; investments; taxes

Citation: Borodin, A.; Zaitsev, V.; Mamedov, Z.F.; Panaedova, G.; Kulikov, A. Mechanisms for Tax Regulation of CO_2-Equivalent Emissions. *Energies* **2022**, *15*, 7111. https://doi.org/10.3390/en15197111

Academic Editors: Luigi Aldieri and Antonis A. Zorpas

Received: 2 September 2022
Accepted: 22 September 2022
Published: 27 September 2022

1. Introduction

All over the world, environmentalists are sounding the alarm about the increase in atmospheric temperature, which entails the melting of glaciers and the possible cataclysms associated with this [1–8]. The main cause of warming is the endless emissions of greenhouse gases due to the development of production and increased consumption.

The European Union is planning to introduce transboundary carbon regulation, which aims to curb carbon emissions by imposing additional duties on emissions and phasing out carbon quotas. As a result, companies will be forced to modernize production and reduce emissions, and the states of the European Union will receive additional budget revenues. This carbon tax is planned to be levied not only from enterprises whose production is located in the EU, but it will also apply to all imported goods on the territory of the EU member states. However, in order to avoid double taxation, EU Member States will not re-levy the tax on imported goods if they were previously subject to carbon tax in other countries [9–15]. In this regard, the Russian authorities are also developing and implementing a system for accounting for greenhouse gas emissions, as well as developing a system for taxing such emissions. In this paper, we will consider the prospects for introducing a carbon tax in Russia, and also evaluate possible additional revenues from such a tax.

The contribution of the work is to propose a working mechanism for cross-border carbon regulation for importing countries, which is aimed at encouraging manufacturers to reduce their CO_2 emissions. The mechanism includes the variability of taxation depending on the types of greenhouse gases emitted. The paper also provides a possible budgetary effect from the introduction of the proposed mechanism and shows the impact of the tax on the financial performance of manufacturing companies. The proposed incentive measures in the form of an additional tax should have a positive impact on third countries to introduce a mechanism for cross-border carbon regulation.

2. The Concept of Reducing CO_2 Emissions in the Literature and in Regulations

The trend is such that almost all major players in the industry market consider themselves adherents of the ESG (Environmental, Social and Corporate Governance) principles [16–18]. Russian companies are no exception. The paper presents data from the annual reports of several major Russian industrial companies that seek to reduce their CO_2 emissions. Thus, Rosneft, in its annual report [19], states that the reduction of greenhouse gas emissions is part of its 2022 strategy as part of the Company's commitment to the UN Sustainable Development Goals and contribution to the implementation of the priority goal "Combating Climate Change". In June 2019, Rosneft joined the initiative of leading international oil and gas companies and signed the Guidelines for Reducing Methane Emissions in the Natural Gas Supply Chain [20].

Gazprom claims in its annual report [21] that reducing CO_2 emissions is part of its corporate strategy. Measures are being taken to minimize the negative impact of climate change on production activities. Energy efficiency and energy saving programs, effective technological processes for various climatic conditions are being developed and implemented; Programs are being implemented to improve the efficiency of the system of production, transportation and operation of the gas transmission network, a program to adapt the production activities of PJSC Gazprom to changing climatic and geocryological conditions. In 2021, Gazprom Group companies were recognized as the best Russian oil and gas companies in the CDP rating. According to the totality of the disclosed indicators, they were assigned a climate rating of "B", while in four categories out of 11 ("Emissions coverage 1 and 2", "Management", "Initiatives to reduce emissions" and "Disclosure of opportunities"), PJSC Gazprom received the maximum rating of "A". Experts of the CDP partnership once again recognized that Gazprom is taking all possible and coordinated actions to protect the climate, disclose complete and reliable information on climate issues, conduct full-scale work on planning and resolving issues on climate change.

Severstal also adheres to the principles of reducing the carbon footprint. Chairman of the Board of Directors of the company A. Mordashov in his address to shareholders [22] says that "based on the goals announced in 2020, in 2021 we set a new task for the medium term—to reduce specific carbon dioxide emissions per ton of steel by 10% by 2030". This is one example of Severstal's commitment to reducing its environmental impact and contributing to global efforts to achieve the goals of the Paris Agreement. In the reporting year, Severstal received the award of the World Steel Manufacturers Association as a leader in the field of sustainable development among the largest steel producers in the world. Severstal became the first Russian company to join the ResponsibleSteel global standardization and certification initiative aimed at ensuring the maximum contribution of steel producers to the implementation of sustainable development goals. Climate change entails not only risks, but also new opportunities, such as an increase in demand for eco-friendly products". Severstal's annual report [23] also states that in order to increase interest in solving the tasks of the Company's climate agenda, targets for reducing greenhouse gas emissions were included in the KPIs of the 11 top managers. All targets for reducing greenhouse gas emissions for 2021 are set at 5%. In addition, KPIs on carbon intensity and energy efficiency were established for Severstal CEO, Director of Occupational Safety and Industrial Safety and Chief Power Engineer. There are also mechanisms for encouraging other employees of the Company who are directly involved in projects aimed at solving the tasks of the climate agenda and reducing greenhouse gas emissions [24].

According to the company, Norilsk Nickel [25] focuses on the production of low-carbon products. The company occupies a strong starting position in the market in terms of absolute and specific greenhouse gas emissions, maintaining one of the lowest indicators in terms of absolute and specific greenhouse gas emissions among comparable international companies in the mining and metallurgical sector. In 2021, Norilsk Nickel, for the first time, assessed the specific carbon footprint of all manufactured products by developing a calculation methodology in accordance with international standards for the product life cycle assessment (LCA ISO 14040/14044). The methodology was certified by the international company in the field of product life trace assessment (LCA) Sphera Solutions GmbH—a recognized expert in this matter in the mining and metallurgical sector, the results of quantitative calculation of the carbon footprint of the Company's products for 2020 were certified by the auditor EY. The carbon footprint of refined nickel produced by the Company amounted to 8.1 tons of CO_2-eq. per ton, which is significantly lower than the industry average [25].

Rusal, another major Russian metallurgical company indicates in its report [26] that disclosure of information in accordance with the TCFD recommendations is part of the climate change management mechanism. To assess the effectiveness of the management approach in this area, the Company conducts internal and external audits and verification, uses data assessment and monitoring systems, participates in external ratings, benchmarking competitors' indicators and collects feedback from customers by conducting surveys. In 2021, Rusal participated in more than 10 large-scale surveys in the field of ESG factors, responded to more than 200 requests sent by customers related to the carbon footprint. The methodology for calculating greenhouse gas emissions in the metallurgical segment is certified by the independent organization TÜV Austria as part of the audit and verification of greenhouse gas emissions data.

Thus, all of the above indicates the strict commitment of the main manufacturing giants of Russia to reduce CO_2 emissions, which means that they are potentially ready to introduce mandatory tax regulation of emissions by the state and the importers of their products.

The statistics on the global dynamics of emissions are well reflected in the BP company report [27], which shows the dynamics of emissions of the main regions, as well as the countries included in these regions. Unfortunately, we cannot observe a clear positive trend in reducing CO_2 emissions, which is largely due to an increase in global production. For example, China has shown a significant increase in its carbon footprint since 2016. There are no prerequisites for reducing such a trace at the moment.

The Ecosystem Marketplace website [28], as well as the World Bank website [29], provides statistics on the volume of voluntary trade in carbon units; as well as prices to the countries issuing carbon units. Based on the statistics provided, we can observe a significant increase in the voluntary market for trading carbon units. Additionally, the Ecosystem Marketplace website presents various international mechanisms for accounting for greenhouse gas emissions that have received international recognition. Among the listed mechanisms, the leader is Verified Carbon Standard, which covers about 69% of all existing carbon units.

In many works [30–37], the field of the green economy as the basic policy of further development of states is investigated. The impact of the green economy on society, as well as on the agrarian and industrial system of states is investigated. The instruments of financing the green economy, which for the most part are "green" bonds, are considered.

The UNFCCC Sites and platforms [38] and United Nations Web Page [39] information portals present declarations, conventions and other regulatory documents that relate to the topic of our research. First of all, we will be interested in the Paris Agreement on Climate Change and the Kyoto Protocol, since they are the basic documents regulating activities to reduce CO_2 emissions.

In our research, we will use the main document regulating taxation in the Russian Federation—the Tax Code of the Russian Federation [40]. Based on the existing developed taxation mechanisms, we will create a new mechanism capable of regulating taxation in the field of CO_2 emissions.

Alternative using of CO_2, its storage, chemical reactions using CO_2 are described by researchers in investigations [41–48].

3. Data and Methods

To determine the mechanism of cross-border carbon regulation, data were taken from the published annual reports of the main Russian companies in the oil and gas industry and metallurgy, since these industries are defined in the CBAM concept approved in the EU. Based on the companies' reports, data on actual greenhouse gas emissions by year were selected. We need the amount of greenhouse gas emissions to determine the tax base of companies. Additionally, to assess the impact of the introduction of a carbon tax on companies in the oil and gas and metallurgical industries, the main financial indicators from the published financial statements of the studied companies by year were used. The initial data were processed on the basis of methods of comparison, modeling, analysis and deduction.

Consider the carbon emissions of some backbone enterprises for 2018, 2019, 2020. Consider emissions in Scope 1, direct emissions, and Scope 2, indirect emissions (Table 1 and Figure 1).

Table 1. Emissions in Scope 1, direct emissions, and Scope 2, indirect emissions, mln t.

Company	2018	2019	2020
Rosneft	76.9	81.2	81
Severstal	27.77	28.11	27.86
Nornickel	9.94	9.95	9.70
Rusal	28.59	28.11	25.86
Gazprom	128.3	123.17	105.74

The overall dynamics of carbon emissions in the chart below.

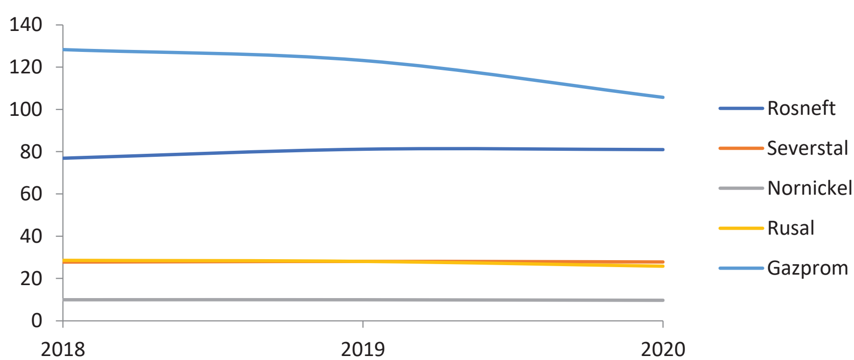


Figure 1. The graph of CO_2 emissions shows that the dynamics of the main companies is stable, with the exception of Gazprom, which shows the dynamics of reducing CO_2 emissions from 2019 to 2020. The data are given in million tons. The data are taken from the sustainability reports of companies for 2021.

From the dynamics above, it is obvious that oil and gas companies (Gazprom, Rosneft) have significantly higher emissions compared to metallurgical companies. In addition, for the period 2018–2020, we do not see positive dynamics in reducing greenhouse gas emissions, with the exception of Gazprom. However, it should be taken into account here that this company has the largest amount of emissions among those considered, therefore, apparently, it has the potential for reduction.

To assess the possible impact on government revenues, as well as to determine the level of cost of carbon units, we will conduct some research on some backbone enterprises of the Russian Federation. At the moment, the Russian Federation is considering the following rate for a carbon unit equivalent to 1 ton of greenhouse gas emissions: 2000 rubles per unit. This rate is uniform and does not have diversification depending on the type of activity of the enterprise. Thus, having data on emissions and the cost of a carbon unit, we will evaluate possible budget revenues in retrospect for 2018–2020 (Table 2).

Table 2. Cost of emissions, billion rubles.

Company	2018	2019	2020
Rosneft	153.8	162.4	162.0
Severstal	55.5	56.2	55.7
Nornickel	19.9	19.9	19.4
Rusal	57.2	56.2	51.7
Gazprom	256.6	246.3	211.5

In total, for five companies, additional budget revenue from carbon dioxide emissions will amount to about 500 billion rubles in 2020. Obviously, such a size of payments by companies will create significant budget revenues, but there are significant risks for both the companies themselves and for buyers of products, since it is obvious that manufacturers will pass on additional costs to buyers, which will lead to price increases and inflation may increase.

The financial performance of selected companies for 2020 and evaluate their ability to pay a carbon tax are shown below (Table 3).

Table 3. Financial indicators, billion rubles.

Financial Indicators	Rosneft	Severstal	Nornickel	Rusal	Gazprom
Revenue	5757	494.8	1117	633	6322
Cost price	5379	283.7	324	525	5666
EBITDA	1209	175.6	552	64	1467
EBITDA margin	21.0%	35.3%	49.5%	10.2%	23.2%

It is clear from the analysis that the companies have different levels of EBITDA margin. The highest level of profitability is shown by Norilsk Nickel and Severstal, the lowest among the studied companies is Rusal.

Evaluation of the impact of an additional carbon tax on the EBITDA margin of companies with unchanged prices for manufactured products is shown below (Table 4).

Table 4. Financial indicators, billion rubles.

Financial Indicators	Rosneft	Severstal	Nornickel	Rusal	Gazprom
Revenue	5757	494.8	1117	633	6322
EBITDA	1047	119.88	533	13	1255
EBITDA margin	18.2%	24.2%	47.7%	2.0%	19.9%
Reduction of EBITDA	2.8%	11.1%	1.7%	8.2%	3.3%

Based on the table above, we see that Rusal without state emission quotas or without increasing the cost of products has a minimum return on sales of 2%, which is significantly lower than the market. The carbon tax has the greatest impact on EBITDA on steel companies Severstal and Rusal. Companies in the oil and gas industry (Rosneft, Gazprom) are minimally affected by the carbon tax.

Based on the observation made, the impact of an additional tax on greenhouse gas emissions can be optimized for the carbon tax rate to encourage oil and gas companies to reduce emissions. A 7–8% reduction in companies' margins will have a significant impact on companies (Tables 5 and 6).

Table 5. Financial indicators, billion rubles.

Financial Indicators	Rosneft	Gazprom
Revenue	5757	6322
EBITDA	804	938
EBITDA margin	14.0%	14.8%
Reduction of EBITDA	7.0%	8.4%

Table 6. Additional state income, billion rubles.

Financial Indicators	2018	2019	2020
Rosneft	384.5	406	405
Gazprom	641.5	615.85	528.7
Total	1026	1021.85	933.7
Additional state income	615.6	613.11	560.22

Thus, the table above shows that potentially with an increase in the carbon unit rate from 2000 thousand rubles to 5000 rubles for oil and gas producing companies, the additional state income only at the expense of Rosneft and Gazprom can amount to 560 billion rubles in 2020.

Taking into account the tax rates and the additional income of the state, the most important factor is the sources of formation of the company's revenue, namely the price for the domestic consumer. If the state does not develop an effective system for regulating and monitoring domestic prices, then the introduction of an additional tax may be a blow to the well-being of citizens.

4. Results

Consider the process of verification and trading in the international market for carbon credits.

According to the national accreditation system, as of 22 December 2021, Rosaccreditation receives applications from organizations for accreditation as greenhouse gas verification bodies. When accrediting organizations, it is important to understand that accredited organizations must be recognized abroad and have a transparent international system of assessment and verification.

Accreditation is voluntary, therefore Rosakkreditatsiya cannot predict the number of applicants, however, by now they declare about ten companies. Currently, Rosaccreditation together with the National Accreditation Institute have trained independent accreditation experts.

The introduction of a new area of accreditation plays a crucial role in the recognition of Russian carbon reporting in foreign countries. Since only in this case, manufacturers will be able to avoid double taxation. At the beginning of 2022, Roascreditation plans to apply for mutual recognition of reporting under the International Accreditation Forum (IAF) system. Thus, in case of successful recognition of accredited Russian organizations for the validation and verification of greenhouse gas emissions, they will be able to use the international IAF mark, which will allow them to receive recognition of the activities of such organizations abroad.

Within the framework of the 26th UN Climate Conference, the system of international trading in carbon units was approved. According to the approved rules, participating countries can buy carbon units from countries that have reduced their greenhouse gas emissions below their obligations, i.e., countries with unused carbon credits. Currently, there are international mechanisms for accounting for greenhouse gases, which have international recognition. These are mechanisms such as:

- Verified Carbon Standard;
- Gold Standart;
- Clean Development Mechanism;
- American Carbon Registry;
- Climate Action Reserve;
- Plan Vivo.

Among these mechanisms, the leader is the Verified Carbon Standard, which covers about 69% of all existing carbon units.

European transboundary carbon regulation is another step towards reducing greenhouse gas emissions and improving natural conditions. However, even in such a mechanism, one can count on additional state revenues. On the one hand, this is a challenge for companies, and on the other hand, it is an opportunity for further economic growth, since the sustainable development policy is currently highly valued by investors. Additionally, the policy of the "green" economy generates new financial instruments that allow you to attract borrowed capital. With balanced state regulation, Russian producers will be able to pay tax not in favor of the European Union, but in favor of the budgets of the budget system of the Russian Federation. Of course, the main agenda for Russia is the applicable tax rates, as well as the verification of carbon units according to international standards (Table 7).

Table 7. Types of international standards.

International Standards	Geography of Application	Comments
Verified Carbon Standard (VCS)	World	Carbon tax in Colombia and South Africa, CORSIA
Gold Standard	World	Carbon tax in Colombia and South Africa, CORSIA
Clean Development Mechanism (CDM)	World	—
American Carbon Registry (ACR)	World	CORISA, Washington State CAR
Climate Action Reserve (CAR)	USA, Canada, Mexico	CORISA, Washington State CAR
California Compliance Offset Program	USA	California ETS (USA), Quebec ETS (Canada)
Australia ERF	Australia	Australia's Emission Reduction Fund (ERF) Safeguard
Alberta Emission Offset System	Alberta (Canada)	Alberta Technological Innovation and Emission Reduction Regulation (Alberta TIER)
China GHG Voluntary Emission Reduction Program	China	Pilot PTS in Beijing, Chongqing, Fuijian, Guangdong, Hubei, Shanghai, Shenzhen and Tianjin, CORSIA
British Columbia Offset Program	Province of British Columbia (Canada)	Greenhouse Gas Industry Reporting and Control Act (GGIRCA)
J-Credit Scheme	Japan	STV Saitama
Thailand Voluntary Emission Reduction Program	Thailand	—
Spain FES—CO_2 Program	Spain	—
Fujian Forestry Offset Crediting Mechanism	Fujian Province (China)	Pilot STV in Fujian
Guangdong PU Hui Crediting Mechanism	Guangdong Province (China)	Pilot STV in Guangdong
Quebec Offset Crediting Mechanism	Canada	California ETS (USA), Quebec ETS (Canada)

Given the current trends and the established trend in ESG, many corporations are heading for environmentally friendly development, and in order to confirm the policy of sustainable development, attract additional investment in projects, they voluntarily participate in paid programs to reduce harmful emissions.

According to the Ecosystem Marketplace, the volume of CO_2 trading on the voluntary market is (Figure 2).

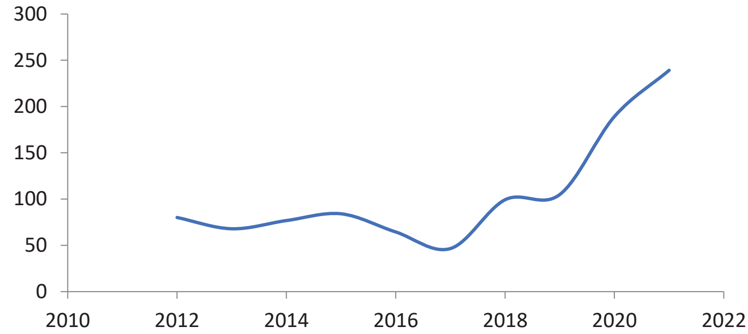


Figure 2. The graph illustrates the growing volume of CO_2 emissions trading on the voluntary market according to the Ecosystem Marketplace. The data are given in million tons eq CO_2.

We have seen a significant increase in the volume of voluntary trading in carbon units since 2017. Given the current trend towards decarbonization of their products, large enterprises will continue to support this trend in the future.

Issuance and repayment of carbon credits (independent and compliance standards) by year are from 2004 to present. Issuance and write-off of credits are reported by the American Carbon Registry (ACR), ART TREES, the Climate Action Reserve (CAR), California Air Resources Board (CARB), CDM (for credits issued after 2016), City Forest Credits, Climate Forward, Coalition for Rainforest Nations, EcoRegistry, Global Carbon Council, Gold Standard, Plan Vivo, ProClima and Verified Carbon Standard (VCS).

The world creates a turnover of carbon credits (carbon credits) using carbon credits. Carbon credits are permits for emissions into the atmosphere. Companies have quotas for emissions into the atmosphere, their dynamics is shown below (Figure 3).

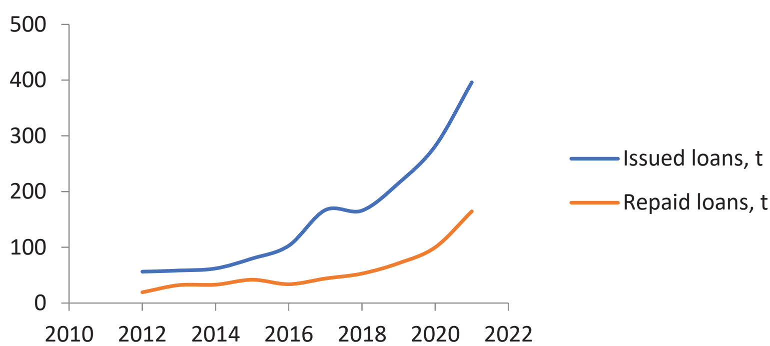


Figure 3. The illustrated dynamics of the issued quotas for CO_2 emissions shows a significant increase in demand for this regulatory instrument. Data according to the Ecosystem Marketplace.

In order to evaluate the overall emissions market by leading manufacturing countries, as well as the global market, we present the following data according to a BP study (Figure 4).

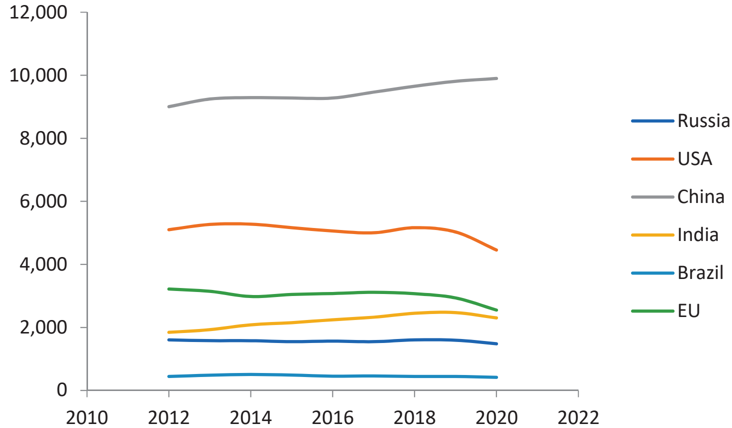


Figure 4. The illustrated dynamics of CO_2 emissions by the main producing countries shows the predominant influence of China on global CO_2 emissions. According to the graph, China is increasing CO_2 emissions by increasing production. Data according to the BP study, million tons.

Using the example of the main countries with the highest CO_2 emissions, we see that Russia is not the country with the highest carbon dioxide emissions, and China is the undisputed leader among polluting countries, followed by the USA and the countries of the European Union. At the same time, over the past 10 years, the dynamics of emissions of many countries has not changed, with the exception of the USA and the EU, which, as can be seen in the graph above, have been reducing their CO_2 emissions since 2018. China, on the other hand, has been increasing carbon emissions since 2016. In Russia and other countries, a weak dynamics of emissions can be traced, we can say that the volume of emissions does not change.

The supply and supply prices of carbon unit futures in involuntary and regulated markets have a significant difference in value. This is due to the fact that, of course, companies, although they want to maintain the status of "green" and follow the principles of sustainable development, but at the same time, if possible, do not spend big money on maintaining such a status.

Below are the values of carbon units in the voluntary and regulated markets (Table 8).

Table 8. Values of carbon units in the voluntary and regulated markets.

System	Price/tCO2e	Date	Source
California-Québec	USD 23.30	18 August 2021	California Air Resources Board
Chinese ETS Pilots: -Beijing -Chongqing -Guangdong -Shanghai -Hubei -Shenzhen -Tianjin -Fujian	 CNY 87.84 (USD 13.56) CNY 38.48 (USD 5.94) CNY 43.70 (USD 6.75) CNY 40.00 (USD 6.18) CNY 40.86 (USD 6.31) CNY 28.60 (USD 4.42) CNY 28.32 (USD 4.37) CNY 14.30 (USD 2.21)	 30 September 2021 30 September 2021 30 September 2021 30 September 2021 30 September 2021 30 September 2021 30 September 2021 30 September 2021	ICAP Allowance Price Explorer
EU ETS	EUR 58.86 (USD 68.08)	12 October 2021	European Energy Exchange
Republic of Korea	KRW 30.100 (USD 25.26)	14 October 2021	Korea Exchange
New Zealand	NZD 64.80 (USD 45.03)	14 October 2021	Jarden CommTrade New Zealand
Nova Scotia	CAD 36.71 (USD 29.49)	9 June 2021	Nova Scotia, Department of Environment
RGGI	USD 9.30	9 August 2021	RGGI, Inc.
Switzerland	EUR 39.25 (USD 45.40)	10 March 2021	Schweizer Emissionshandelsregister

At the same time, the prices on the voluntary market in the period from 2016 to 2020 are in US dollars (Table 9).

Table 9. The prices on the voluntary market.

Countries	2016	2017	2018	2019	2020
Africa	4.1	5.3	4.3	3.9	4.2
Asia	1.6	2.3	3.1	1.8	1.2
Europe	1.2	1.7	4.8	3.1	6.1
Latin America	3.8	2.7	2.3	3.5	3.8
North America	2.9	3.5	2.9	3.6	6.2
Oceania	4.9	9.4	15.1	12.5	1.9

From the graphs above, in 2020, the cost of a carbon unit in Europe in 2020 is $6.1, and in the regulated market it is $68 as of 2021.

Russia is a party to the Paris Agreements of 12 December 2015 and the Kyoto Protocol of 4 November 2004. According to these documents, the countries participating in the agreements should strive to reduce anthropogenic greenhouse gas emissions, as well as create conditions for their capture and disposal. Create voluntary projects to achieve emission reduction goals. In order for the measurement of the amount of emissions to be comparable and the same in all countries, the so-called concept of a carbon unit is introduced, which is equivalent to one ton of CO_2 emissions. Verification procedures are carried out and records are posted in special registers. The carbon unit is currently a universal instrument of legal relations related to greenhouse gas emissions. It is by verified carbon units that the existing carbon footprint is determined and reports are created.

To date, the circulation of carbon units takes place on voluntary and regulated markets in accordance with applicable international standards in the field of climate projects.

For the first time, the “emissions market” reached the international level in 2005 after the start of the Kyoto Protocol, which provides for the following regulatory mechanisms for the participating countries:

- greenhouse gas emissions trading.
- a mechanism that allows the acquisition of carbon units in case of successful implementation of environmentally friendly projects in developing countries (clean development).
- joint implementation of climate projects, as a result of which the resulting carbon units are distributed among the participants of such projects.

Up until 2012, Russia implemented about 108 environmentally friendly development projects on its territory, as a result of which about 300 million carbon units were put into circulation. After 2012, Russia has not used the existing mechanisms of the Kyoto Protocol.

In addition to the projects existing under the Kyoto Protocol, voluntary climate projects have become widespread. Thus, thanks to the implementation of such projects, about 1.2 billion carbon units have been introduced in the world, most of which fall on the international standards VCS (Verified Carbon Standard), which is usually applied simultaneously with the CCB standard (Climate, Community and Biodiversity Standards) and the GS standard (Gold Standard).

The implementation of climate projects and participation in voluntary national accounting and verification standards allow companies to demonstrate their commitment to sustainable development, in turn, the results of such projects can be used for their own corporate development, attracting investors and the production of carbon units.

At the current moment, Russia is facing certain problems in the implementation of environmentally friendly projects, since national systems for accounting and verification of carbon units have not yet been created. When creating national systems, an important factor is the compliance of such systems with international standards and accreditation abroad, otherwise Russian enterprises will not be able to operate carbon units on world markets.

The main purpose of the formation and implementation of the Russian system of verification of climate projects is to create mechanisms through which sustainable development in the field of ecology becomes possible, as well as attracting so-called "green" investments in the economy.

Important principles of the formation of the Russian system of climate projects are:

- recognition and implementation of standards according to voluntary international standards.
- transparency of the mechanism and exclusion of the possibility of double accounting of carbon units (for example, on the territory of the Russian Federation and on the territory of the EU).
- absence of corruption component (personal interest, conflict of interests) between verifiers of carbon units and companies participating in the implementation of projects.
- recognition of carbon units by the civil code, as well as all possible operations, contracts with their participation.
- the possibility of state incentives for the implementation of climate projects.

The main issues to be determined are the definition of the tax base and the system of tax calculation. The tax base of the mineral extraction tax according to Article 338 of the Tax Code of the Russian Federation [20] can be defined as the value of extracted minerals, or as the amount of extracted minerals in kind. For greenhouse gas emissions, the tax base is applied as the number of tons of carbon dioxide equivalent emissions. The next even more significant issue is the tax rate. Since the tax base is calculated as the amount of CO_2 emissions, interest rates on the cost will not be suitable for calculation.

The basis for calculating the MET rate for natural gas production is clause 11 clause 2 of Article 342 of the Tax Code of the Russian Federation.

According to the Tax Code of the Russian Federation, the MET rate for natural gas production is calculated as:

$$NS*Eut*Cs + Tg \quad (1)$$

where

NS—the basic tax rate equal to 35 rubles per 1000 cubic meters of gas.
Eut—a unit of conventional fuel.
Cs is a coefficient that characterizes the complexity of mining.
Tg is an indicator that characterizes the costs of transporting combustible gas.

The proposed calculation formula has some similarities with the calculation of the MET rate.

The rate for emissions of 1 ton of CO_2-eq.

$$CO_2\text{-eq.} = BNS*Eug*Cs \quad (2)$$

where

BNS is the basic tax rate, which is approved by law.
Eug—a unit of conditional equivalent.
Kk is the coefficient characterizing the component composition of the gas.

Eug is determined by the following formula:

$$Eug = 0.7*(Cevr*Devr + Csrv*(1 - Devr))*R/BNS \quad (3)$$

where

Cevr—the average price of futures on European regulated markets for carbon units.
Devr—the share of products supplied to the European market.
Csrv is the average price of carbon units for the period in the international voluntary markets Verified Carbon Standard (VCS) and China GHG Voluntary Emission Reduction Program.
P—the average exchange rate of the US dollar to the ruble for the billing period.

For example, we will calculate the cost of 1 ton of CO_2-eq emissions.

As the value of the base tax rate, we take the 2000 rubles available in the draft regulatory documents for 1 ton of emissions.

The value of the methane content in the emissions will be taken to calculate the following: up to 1%—the value of Kks = 1, the methane content up to 5%—Kks = 1.3, the methane content over 5%—a coefficient of 1.5.

To calculate, we will take the average European price of futures for carbon units of 70 US dollars, the share of exported products to the European Union countries of 40%, the average price of carbon units on the voluntary market of 10%, the exchange rate is 100 rubles per US dollar.

With the accepted macroparameters, we obtain a coefficient of Eug = 1.19.

In total, the tax rate on CO_2 emissions is equal to $2000 \times 1.19 \times 1 = 2380$ for greenhouse gas emissions with a methane content of up to 1%, 3094 for emissions with a methane content of up to 5%, 3570 for emissions with a methane content of over 5%.

The proposed formula is more elastic, since it allows taking into account the share of exported products, world quotations for carbon units, the ruble exchange rate, the component composition of emissions. Taking into account the proposed formula will stimulate supply in the domestic market, as well as provide additional revenues to the budget of the budgetary system.

Thus, having studied the available information on the effect of carbon units on the world stage, the state should work out in detail and carefully the issue of verification and accounting of carbon units. Because in any case, in addition to voluntary standards, the countries participating in the Paris Agreements, in particular the countries of the European Union, will introduce national mechanisms to regulate the carbon footprint, and charge an additional tax on products that produced carbon dioxide emissions. All this will lead to significant additional revenues to the budget. However, the existing draft laws provide for the possibility of mutual accounting of carbon units with countries where verification of carbon units takes place according to accepted international standards. Thus, Russia has a chance to receive additional substantial budget revenues due to the carbon tax. Additionally, an important area for attracting investments is the possibility of attracting so-called "green" investments, which are aimed at implementing environmentally friendly projects. The participation of companies in improving the environmental friendliness of their products and reducing greenhouse gas emissions can provide a significant boost to the development of the economy. When determining the taxation mechanism, it is important to take into account the specifics of greenhouse gas emissions, namely the content of methane and other related gases. Taxation needs to be made flexible and understandable for businesses, taking into account global carbon unit futures quotes, including quotes on mandatory payments in the European Union, as well as quotes on voluntary global carbon unit markets. Different quotes should be taken into account, since there is a significant difference in the value of futures on regulated and voluntary markets. It is also necessary to take into account the share of exported products with the help of appropriate coefficients, which will help support the supply in the domestic market.

5. Discussion

Regulation of CO_2 emissions is currently being discussed by many experts. Many see this as additional opportunities and drivers of economic growth, while others believe that regulating emissions will entail an exceptionally excessive tax burden on consumers of goods and services. However, one way or another, all experts agree on one thing—emissions of CO_2 and other greenhouse gases must be reduced, because otherwise we will all face global climate change for the worse.

Cross-border regulation of carbon dioxide emissions in excess of quotas for carbon dioxide emissions in production, additional taxation of emissions, emissions of carbon dioxide and emissions in production in excess of quotas. This procedure produces not only at the enterprise, it includes production on the territory of the member states of the

European Union, but also for all imported goods based on them. The participation of natural resources in the natural nature of their products and the increase in greenhouse gas emissions can have a significant impact on the development of the economy.

Cross-border carbon regulation may turn out to be a new driver of the development of the Russian economy. It is important that the Russian side introduces a mechanism for tax regulation of CO_2 in a timely manner, otherwise there is a risk for Russian producers to become uncompetitive in the European market. It is worth noting that due to the increase in global production capacities, mainly due to the Asia-Pacific region, the dynamics of reducing CO_2 emissions is insignificant and does not meet the conditions of the Paris Climate Agreement. The Government also needs to determine how the additional fiscal burden will affect the purchasing power of citizens. We see that the main emitters of CO_2 in Russia and the world are large companies with traditional production, which are mining, for them the problem of switching to a green economy may be the significant size of the main fund aimed at traditional production. In our opinion, the optimal solution for the state would be to actively encourage companies to buy carbon units on the voluntary market in order to assess the real effect of the introduction of the practice of active carbon regulation. This practice, among other things, can help companies attract additional financing through "green" capital raising tools, since new generation investors actively participate in environmentally friendly projects.

The research hypothesis is that if exporting countries to the EU will be subject to an additional tax for excess CO_2 emissions, this will encourage companies to reduce their emissions, and countries will be able to replenish their budget at the expense of companies that do not pursue goals to reduce their emissions. The results of the study are directly useful and can be applied by the governments of exporting countries for their products in the form of using the developed mechanism of tax incentives to reduce CO_2 emissions.

6. Conclusions

The scientific article is devoted to possible mechanisms for regulating greenhouse gas emissions into the atmosphere on the territory of the Russian Federation. Today, the most important part of the development of any company, both foreign and domestic, is the sustainable development of ESG. Environmental issues are acute and relevant because life on earth will largely depend on ecology. The operations enshrined in the Kyoto Protocol must be carried out by all countries participating in the market. To date, there is an increase in the production of total emissions of non-gas gases. To better implement the Kyoto agreements, the European Union intends to introduce transboundary carbon regulation. The purpose of such regulation is to further stimulate producers to reduce greenhouse gas emissions and reduce greenhouse gas emissions from the environment.

Having studied the available information on the effect of carbon units on the world stage, the state should work out in detail and carefully the issue of verification and accounting of carbon units. Because in any case, in addition to voluntary standards, the countries participating in the Paris Agreements, in particular the countries of the European Union, will introduce national mechanisms to regulate the carbon footprint, and charge an additional tax on products that produce carbon dioxide emissions. All this will lead to significant additional revenues to the budget. However, the existing draft laws provide for the possibility of mutual accounting of carbon units with countries where verification of carbon units takes place according to accepted international standards. Thus, Russia has a chance to receive additional substantial budget revenues due to the carbon tax. Additionally, an important area for attracting investments is the possibility of attracting so-called "green" investments, which are aimed at implementing environmentally friendly projects. The participation of companies in improving the environmental friendliness of their products and reducing greenhouse gas emissions can provide a significant boost to the development of the economy. The article is of great interest to the scientific community, since the proposed mechanism for regulating the tax burden on companies producing products with CO_2 emissions has not been proposed before. Based on the proposed mechanism, which includes the oil and gas industry and metallurgy, it is possible to further expand it and apply it to other industries that are regulated by CBAM: cement, organic chemicals and fertilizers. In general, the main task of the mechanism is to achieve the goals of the Paris Agreements, which has a significant positive impact on the global environment. Prospects for further research of the problems of state regulation of CO_2 emissions considered in the article will be aimed at using green financial instruments in order to stimulate the implementation of environmentally friendly projects.

Author Contributions: Conceptualization, V.Z.; methodology, A.B.; software, A.B.; formal analysis, G.P.; writing—original draft preparation, Z.F.M.; writing—review and editing, A.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Lagasio, V.; Cucari, N. Corporate governance and environmental social governance disclosure: A meta-analytical review. *Corp. Soc. Responsib. Environ. Manag.* **2019**, *26*, 710–711. [CrossRef]
2. Albuquerque, R.; Koskinen, Y.; Zhang, C. Corporate social responsibility and firm risk: Theory and empirical evidence. *Manag. Sci.* **2018**, *65*, 4451–4469. [CrossRef]
3. Huang, D.Z. Environmental, social and governance (ESG) activity and firm performance: A review and consolidation. *Account. Financ.* **2019**, *61*, 335–360. [CrossRef]
4. Jo, H.; Harjoto, M.A. Corporate governance and firm value: The impact of corporate social responsibility. *J. Bus. Ethics* **2011**, *103*, 351–383. [CrossRef]
5. Orlitzky, M.; Schmidt, F.L.; Rynes, S.L. Corporate social and financial performance: A meta-analysis. *Organ. Stud.* **2003**, *24*, 403–441. [CrossRef]
6. Reddy, K.; Gordon, L.W. The effect of sustainability reporting on financial performance: An empirical study using listed companies. *J. Asia Entrep. Sustain.* **2010**, *6*, 19–42.
7. Borisov, A.N.; Borodin, A.I.; Gubarev, R.V.; Dzyuba, E.I.; Sagatgareev, E.R. Managing the Investment Attractiveness of the Federal Subjects of Russia in the Context of the UN Sustainable Development Goals. *MGIMO Rev. Int. Relat.* **2022**, *15*, 202–230. [CrossRef]
8. Baker, H.; Anderson, R. (Eds.) An overview of Corporate Governance. In *Corporate Governance: A Synthesis of Theory, Research and Practice*; John Wiley & Sons: New York, NY, USA, 2011.
9. Böhringer, C.; Carbone, J.C.; Rutherford, T.F. Embodied Carbon Tariffs. *Scand. J. Econ.* **2018**, *120*, 183–210. [CrossRef]
10. Branger, F.; Quirion, P. Would border carbon adjustments prevent carbon leakage and heavy industry competitiveness losses? Insights from a meta-analysis of recent economic studies. *Ecol. Econ.* **2014**, *99*, 29–39. [CrossRef]
11. Demailly, D.; Quirion, P. European Emission Trading Scheme and competitiveness: A case study on the iron and steel industry. *Energy Econ.* **2008**, *30*, 2009–2027. [CrossRef]
12. Branger, F.; Quirion, P.; Chevallier, J. Carbon Leakage and Competitiveness of Cement and Steel Industries under the EU ETS: Much Ado about Nothing. *Energy J.* **2016**, *37*, 109–135. [CrossRef]
13. Naegele, H.; Zaklan, A. Does the EU ETS cause carbon leakage in European manufacturing? *J. Environ. Econ. Manag.* **2019**, *93*, 125–147. [CrossRef]
14. Dechezleprêtre, A.; Sato, M. The Impacts of Environmental Regulations on Competitiveness. *Rev. Environ. Econ. Policy* **2017**, *11*, 183–206. [CrossRef]
15. Neuhoff, K.; Ritz, R. *Carbon Cost Pass-through in Industrial Sectors*; EPRG Working Paper 1935; University of Cambridge: Cambridge, UK, 2019. [CrossRef]
16. Edgecliffe-Johnson, A. ESG Groups try to thin a thicket of sustainability metrics. *Financial Times*, 11 June 2019.
17. Greenwald, C. ESG and Earnings Performance. 2010. Available online: https://www.thomsonreuters.com/content/dam/openweb/documents/pdf/tr-com-financial/case-study/esg-and-earnings-performance.pdf (accessed on 20 January 2022).
18. Verde, S.F.; Acworth, W.; Kardish, C.; Borghesi, S. *Achieving Zero Emissions Under a Cap-and-Trade System; EUI Policy Brief*; Issue 2020/26 June 2020; ICAP/FSR: Berlin, Germany, 2020; Available online: https://icapcarbonaction.com/en/?option=com_attach&task=download&id=695 (accessed on 1 September 2022).
19. Rosneft Web Page. Available online: https://www.rosneft.ru/Investors (accessed on 19 March 2022).
20. Borodin, A.; Panaedova, G.; Frumina, S.; Kairbekuly, A.; Shchegolevatykh, N. Modeling the Business Environment of an Energy Holding in the Formation of a Financial Strategy. *Energies* **2021**, *14*, 8107. [CrossRef]
21. Gazprom Web Page. Available online: https://www.gazprom.ru/investors/disclosure (accessed on 19 March 2022).
22. Borodin, A.; Tvaronavičienė, M.; Vygodchikova, I.; Panaedova, G.; Kulikov, A. Optimization of the Structure of the Investment Portfolio of High-Tech Companies Based on the Minimax Criterion. *Energies* **2021**, *14*, 4647. [CrossRef]

23. Severstal Web Page. Available online: https://severstal.com/rus/ir/indicators-reporting/financial-results (accessed on 19 March 2022).
24. Borodin, A.; Tvaronavičienė, M.; Vygodchikova, I.; Kulikov, A.; Skuratova, M.; Shchegolevatykh, N. Improving the Development Technology of an Oil and Gas Company Using the Minimax Optimality Criterion. *Energies* **2021**, *14*, 3177. [CrossRef]
25. Nornickel Web Page. Available online: https://www.nornickel.ru/investors/reports-and-results/ (accessed on 19 March 2022).
26. Rusal Web Page. Available online: https://rusal.ru/investors/info/hkse (accessed on 19 March 2022).
27. BP Web Page. Available online: https://www.bp.com/ru_ru/russia/retail.html (accessed on 19 March 2022).
28. Ecosystem Marketplace Web Page. Available online: https://www.ecosystemmarketplace.com/ (accessed on 12 March 2022).
29. World Bank Web Page. Available online: https://www.worldbank.org/en/home (accessed on 14 March 2022).
30. Coria, J.; Jaraite, J. Transaction Costs of Upstream Versus Downstream Pricing of CO_2 Emissions. *Environ. Resour. Econ.* **2019**, *72*, 965–1001. [CrossRef]
31. Mehling, M.A.; van Asselt, H.; Das, K.; Droege, S.; Verkuijl, C. Designing Border Carbon Adjustments for Enhanced Climate Action. *Am. J. Int. Law* **2019**, *113*, 433–481. [CrossRef]
32. Monjon, S.; Quirion, P. How to design a border adjustment for the European Union Emissions Trading System? *Energy Policy* **2010**, *38*, 5199–5207. [CrossRef]
33. Sakai, M.; Barrett, J. Border carbon adjustments: Addressing emissions embodied in trade. *Energy Policy* **2016**, *92*, 102–110. [CrossRef]
34. Cosbey, A.; Droege, S.; Fischer, C.; Munnings, C. Developing Guidance for Implementing Border Carbon Adjustments: Lessons, Cautions, and Research Needs from the Literature. *Rev. Environ. Econ. Policy* **2019**, *13*, 3–22. [CrossRef]
35. Kortum, S.; Weisbach, D.J. The Design of Border Adjustments for Carbon Prices. *Natl. Tax J.* **2017**, *70*, 421–446. [CrossRef]
36. Das, K. Can Border Adjustments Be WTO-Legal? *Manch. J. Int. Econ. Law* **2011**, *8*, 65–97.
37. Böhringer, C.; Balistreri, E.J.; Rutherford, T.F. The role of border carbon adjustment in unilateral climate policy: Overview of an Energy Modeling Forum study (EMF 29). *Energy Econ.* **2012**, *34*, S97–S110. [CrossRef]
38. UNFCCC Sites and Platforms. Available online: https://unfccc.int/files/meetings/paris_nov_2015 (accessed on 25 March 2022).
39. United Nations Web Page. Available online: https://www.un.org/ru/documents/decl_conv (accessed on 25 March 2022).
40. Tax Code of the Russian Federation. Available online: http://www.consultant.ru/document/cons_doc_LAW_19671/ (accessed on 12 March 2022).
41. Chen, L.; Zhao, M.; Li, X.; Liu, Y. Impact research of CH_4 replacement with CO_2 in hydrous coal under high pressure injection. *Min. Miner. Dep.* **2022**, *16*, 121–126. [CrossRef]
42. Jia, B.; Chen, Z.; Xian, C. Investigations of CO_2 storage capacity and flow behavior in shale formation. *J. Pet. Sci. Eng.* **2022**, *208*, 109659. [CrossRef]
43. Yang, L.; Xu, T.; Feng, G.; Liu, K.; Tian, H.; Peng, B.; Wang, C. CO_2-induced geochemical reactions in heterogeneous sandstone and potential conditions causing the tight cementation. *Appl. Geochem.* **2017**, *80*, 14–23. [CrossRef]
44. Jin, C.; Liu, L.; Yiman, L.; Zeng, R. Capacity assessment of CO_2 storage in deep saline aquifers by mineral trapping and the implications for Songliao Basin, Northeast China. *Energy Sci. Eng.* **2017**, *5*, 81–89. [CrossRef]
45. Munz, I.A.; Brandvoll, Ø.; Haug, T.A.; Iden, K.; Smeets, R.; Kihle, J.; Johansen, H. Mechanisms and rates of plagioclase carbonation reactions. *Geochim. Cosmochim. Acta* **2012**, *77*, 27–51.
46. Ghacham, A.B.; Cecchi, E.; Pasquier, L.C.; Blais, J.F.; Mercier, C. CO_2 sequestration using waste concrete and anorthosite tailings by direct mineral carbonation in gas–solid–liquid and gas–solid routes. *J. Environ. Manag.* **2015**, *163*, 70–77. [CrossRef]
47. Wilson, M.; Monea, M. IEA GHG Weyburn CO_2 monitoring and storage project: Summary report 2000–2001. In Proceedings of the 7th International Conference Greenhouse Gas Control Technology (GHGT-7), Vancouver, BC, Canada, 5–9 September 2005.
48. Koukouzas, N.; Kypritidou, Z.; Purser, G.; Rochelle, C.A.; Vasilatos, C.; Tsoukalas, N. Assessment of the impact of CO_2 storage in sandstone formations by experimental studies and geochemical modeling: The case of the Mesohellenic Trough, NW Greece. *Int. J. Greenh. Gas Control* **2018**, *71*, 116–132. [CrossRef]

energies

MDPI

Article

Distributed Energy as a Megatrend of Audit of Investment Processes of the Energy Complex

Natalie Gryzunova [1,*], Kirill Vedenyev [2], Victoria Manuylenko [3], Igor Keri [1] and Michał Bilczak [4]

1 Department of Sustainable Development Finance, Plekhanov Russian University of Economics, 117997 Moscow, Russia
2 LLC "ETS-Energo", 115533 Moscow, Russia
3 Department for Finance and Credit, North-Caucasus Federal University, 355017 Stavropol, Russia
4 Department of Economic Sciences, University of Warmia and Mazury in Olsztyn, 10719 Olsztyn, Poland
* Correspondence: gryzunova.nv@rea.ru

Citation: Gryzunova, N.; Vedenyev, K.; Manuylenko, V.; Keri, I.; Bilczak, M. Distributed Energy as a Megatrend of Audit of Investment Processes of the Energy Complex. *Energies* **2022**, *15*, 9225. https://doi.org/10.3390/en15239225

Academic Editor: Alex Borodin

Received: 1 November 2022
Accepted: 29 November 2022
Published: 5 December 2022

Abstract: The global trend is constantly increasing investments in strategic sectors of the economy, for example the electric power industry, which, in many countries, is becoming diversified and dispersed due to the multitude of entities investing in energy production and renewable resources, which leads to an increase in the heterogeneity of investment decisions. There is an urgent need to control the movement of investments, budget funds, as well as their development in the process of implementing investment programs of energy companies. The control of the movement of investments is the most promising direction of studying the subject of finance and audit. The increasing volume of public and private targeted investments in the energy sector and the lack of control over the effectiveness of investment projects (since each program contains several thousand lists of projects) necessitated the introduction of additional regulation of budget spending. The development of a mathematical apparatus for such regulation led to the creation in the Russian Federation of an institute of an independent public technological and price audit (TPA). The TPA is seen as a mechanism to ensure an effective project evaluation and selection process. This article describes methodological improvements using power system optimization models. The Integrated MARKAL-EFOM System (TIMES) was developed as part of the Energy Technology Systems Analysis Program of the IEA-ETSAP, an international community that uses long-term energy scenarios to conduct in-depth energy and environmental analyzes. This approach includes two different but complementary systematic approaches to energy modeling: an engineering approach and an economic approach. The same approach is used when conducting a TSA, when an investment object is evaluated as a set of technological and price parameters. The article considers a model of resource allocation in the energy sector and a mechanism for using TPA for investment projects with state participation in a natural monopoly. An approach to the financial and long-term distribution of investments of electric power companies based on the search for a balance of interests of the supplier and consumer and available energy sources is proposed. A model has been developed to find the optimal plan of technical solutions, taking into account the balance of the possibilities of the electric power industry and the needs of the economy. The relevance of the article is due to the requirements of investment efficiency, since the prevailing share in the costs is occupied by the costs of equipment and the construction of power plants.

Keywords: distributed energy; electric power industry; alternative energy sources; actor; modeling; investments; technological and value audit

1. Introduction

All financiers in the world are busy studying the possibilities of new energy (distributed energy). In Russia, new energy has led to innovations in auditing and financial control. More and more professional organizations are paying attention to the methods of conducting a technological price audit (TPA) and financial control over the investment flow in the energy sector [1–3]. Tasks solved with the help of TPA include the following:

1. Control of the amount of capital costs for the construction (reconstruction) of energy facilities;
2. Control over the availability of sources of financing for the relevant project;
3. Project payback control;
4. Control of the need to implement a project to develop or improve the reliability of the power system.

From 2023, Russia plans to launch a system of mandatory carbon reporting for enterprises.

Each country has its own drivers for the development of the electric power industry. It all depends on what energy resources the state has, in what climate zone it is located, what technologies and financial resources it owns, how traditional the region's energy is, how much it costs, and how much the state's policy is aimed at decarbonization, reducing the carbon footprint. In Russia, the Russian Federation has its own unique conditions, and they differ in each region. According to the data of the Ministry of Energy of Russia (https://minenergo.gov.ru/node/532, accessed on 1 September 2022) the largest volume of installed electrical capacity in the country is accounted for by thermal power plants (about 67%), which consume gas, coal and fuel oil for the production of electrical energy. Further, hydroelectric power plants are in second place in terms of installed electrical capacity (about 20%), and nuclear power plants are in third place, the share of which is about 12%. Renewable energy sources in the Russian Federation account for about 1% of the total installed capacity of power plants of the UES of Russia (https://www.atomic-energy.ru/list/news, accessed on 1 September 2022). It should be noted that despite the current, very small share of renewable energy facilities, this generation direction is rapidly developing and on the horizon of 10 years, its share in the overall balance will increase significantly [4].

The Russian government has approved the Low-Carbon Development Strategy until 2050. The implementation of the target scenario will require investments in reducing greenhouse gas emissions in the amount of about 1% of GDP in 2022–2030 and up to 1.5–2% of GDP in 2031–2050. By 2050, their net emission will decrease by 60% from the level of 2019 and by 80% from the level of 1990. Further implementation of this scenario will allow Russia to achieve carbon neutrality by 2060 (https://www.atomic-energy.ru/list/news, accessed on 1 September 2022).

The increasing volume of public and private targeted investments in the energy sector and the lack of control over the effectiveness of investment projects (since each program contains several thousand project lists) necessitated the introduction of additional regulation of budget spending. The development of a mathematical apparatus for such regulation led to the creation of the institute of independent technological and price audit (TPA). The TPA is the most effective mechanism for ensuring an effective evaluation and selection of a project with a strict time limit [5].

Due to the aggravation of environmental problems due to global climate change, as well as the desire of many countries for energy independence, renewable energy sources (RES) have appeared. The impetus was also the fact that in 2015 at the COP21 Paris conference on climate change, the leadership of 196 countries of the world came to an agreement "on taking measures to prevent devastating climate change" (https://www.c-o-k.ru/articles/razvitie-raspredelennoy-generacii-v-mire-i-v-rossii, accessed on 1 September 2022).

So far, there are no serious drivers in the field of reducing the carbon footprint in Russia, but there are many projects for alternative, that is, small-scale, distributed energy in cases where it is economically beneficial.

The main emphasis is now placed on meeting all the needs for energy resources based on innovative technologies. The requirements for equipment and technologies contain the standards of the "green economy". These requirements are the guarantor of investments in the Russian Federation. Currently, numerous state and interstate programs are being implemented to transition from centrally controlled large high-tech generation integrated by high-voltage networks to generation at the place of consumption, to "smart" power distribution networks with local "system operators", proactive consumption, and changing the configuration of energy supply for freight and public transport and others providing "distribution" solutions and technologies.

For example, all public transport methods in large cities in Russia are already absolutely safe for the environment.

In particular, it should be noted that during the COVID-19 pandemic, the population and many companies migrated from large cities to the periphery, which contributed to the use of alternative energy sources. After the pandemic, the reverse process was observed, but the economic situation has changed a lot. The structure and cost of rent and energy resources have changed dramatically.

Hydropower is an alternative power source. Nuclear power in Russia, and in the world generally, is a serious alternative to gas and coal power. Now, consider the sun, the wind, and in the very distant future, junk energy or tidal. In Russia, these two industries have been created thanks to the participation of PJSC Rosnano; the Hevel plant in Chuvashia produces solar panels that are in the top five in terms of energy efficiency in the world. There are three factories in Nizhny Novgorod, Ulyanovsk and Taganrog, which are engaged in the construction of wind farms [5].

The distribution of investments among projects and programs focused on energy conservation and energy efficiency is extremely uneven. For example, in the Russian Federation, the maximum investment flows are now concentrated in the Kaluga, Magadan and Omsk regions (https://www.economy.gov.ru/material/file/d81b29821e3d3f5a8929c84d808de81d/energyefficiency2019.pdf, accessed on 1 September 2022). Energy is also unevenly generated by companies and regions. The planning of generating capacities, as well as the development of environmental policy tools and incentives for cost-effective and reliable implementation of energy policy goals is quite a difficult task, especially for entities located in different energy regions. In order to remain on the energy market, generating companies must form an optimal product portfolio for various consumers. The formation of an assortment of energy products is the task of microeconomics. Currently, this market is just beginning to take shape; however, a special TIMES module has been created to model the production process of generating companies [6,7].

The main criteria for choosing an investment program are energy security, capacity utilization and efficiency in the use of energy resources. For example, The European Union Dynamical Exascale Entry Platform (EU-DEEP) offered recommendations for almost every country that need to be achieved to ensure a technological safety improvement program for a number of years.

According to the authors, to develop a plan for supplying local economic entities with energy resources, one should use the theory of production functions and mathematical optimization.

Forming the energy policy of a generating company is a rather difficult task, especially for entities located in regions with different levels of energy supply and different needs of the population. Generating companies are now renewing their equipment fleet. In all countries of the world, this process is carried out with state support.

Therefore, there is a need for public audit control, technological price audit. For an effective TPA, audit standards are constantly being developed and improved, both at the national and international levels for facilities that meet the criteria for mandatory audit [8,9]. Thus, this article attempts to ascertain which group of actors should invest in which generation technology, and where in the Russian Federation in particular, so that the supply sector is aimed at achieving the goals of the energy program at minimal system costs.

2. Materials and Methods

The intersection of the issues of mathematical modeling of the flow of investments, distribution of energy resources and optimization of their structure, innovations in the energy sector and audit is an innovative area of research. TPA is a Russian innovation in financial control. The main difference between TPA and conventional audit is that TPA is a public mandatory audit, which is divided into two aspects: technological and price. A technological audit is an expert assessment of the justification for the choice of the designed technological and design solutions, as well as their compliance with modern materials and equipment necessary for the operation of a capital construction facility. A price audit is an expert assessment of the cost of a capital construction object, taking into account the technological audit. Thus, TPA is an independent expert assessment of the economic, technical and technological characteristics of a capital construction investment project at different stages of the project life cycle, carried out by an independent organization.

E. Brisset (2018) [10], financial director of Schneider Electric, draws attention to the fact that distribution processes are such that soon "everyone will be his own power engineer." E. Brisse describes the change in distribution: direct external customers have appeared and the partner sales channel is still operating; increased diversification into alternative energy sources, for example, increased contacts with green energy companies and power grid companies. Now, many companies are working on the complete unification of processes.

Control over the investment flow should be carried out at various levels: the state, professional specialized organizations, society and investors. According to the Russian Ministry of Energy (https://minenergo.gov.ru/node/558, accessed on 1 September 2022), the volume of financing of investment programs of the largest state-owned electric power companies amounted to more than 614 billion dollars. US and institutional investors account for most of the investment, although the energy sector has many market shareholders. At the same time, the largest share of investments fell on the power grid complex of the country (PJSC Rossetti, PJSC FGC UES, part of the enterprises of the PJSC RusHydro group). The volume of financing investment programs of the electric grid complex once again confirms the special attention paid to the state regarding the financial control of investment activities. One of the tools of this type of control is the legislation in the field of technological and price audit of investment programs of electric grid organizations. One of the signs of the correct direction of financial control of grid companies, chosen by the state, is the result of the implementation of the annual plan for financing investment programs by electric power industry entities for 2021, according to which PJSC Rossetti and PJSC FGC UES are the leaders in the execution of financing investment programs; see Figure 1.

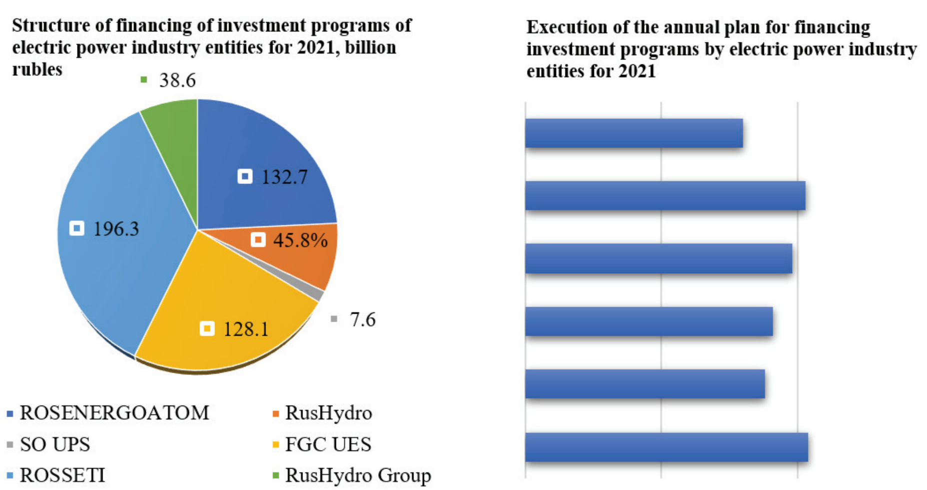


Figure 1. Structure of financing of investment programs of state electric power companies (https://minenergo.gov.ru/node/558, accessed on 1 September 2022).

With the help of the TIMES model generator, a significant number of power system models have been developed. MARKAL/TIMES is a model based on linear programming for energy system investment at the lowest cost, optimized in accordance with a number of restrictions of investors and users located in one of the 13 regions of the Russian Federation with special features in energy supply [11]. However, most models of energy systems consist of several medium actors representing large groups of decision makers, without taking into account their heterogeneity both in terms of investment volume and in terms of their location [12]. The volume of investments in the electric power industry of the Russian Federation annually amounts to 614 billion dollars. The United States and the bulk of investment come from institutional investors, although the energy sector has many market shareholders. The formation of an economic-mathematical model for the distribution of energy resources and investments and their optimization by region and by project is a complex process of long-term financial planning.

It is necessary to take into account the peculiarities of the resource potential, the cost of transportation and production, the heterogeneity of investors, including institutional ones. Energy development is now oriented towards distributed generation, due to the fact that today, decentralization is a megatrend in the world, according to A. Troshin (2019). Therefore, now it is necessary to create not just substations that expand the distribution network, but alternative generators. A. Troshin (2019) [5] gives the following example. "Suppose you have a house in a village with a peak demand of 50 kilowatts. The village gives only 20 kilowatts. Where do you get the remaining 30 kilowatts? We put solar panels on the roof, and a lead-acid storage device in the basement, which produces 30 kilowatts of energy. This is the best world practice." In general, in a number of countries, integrated energy planning is a regular process based on the continuous revision of the calculated tariff values in accordance with the actual data on the economic situation on the scale of the country, region, and Figure 2.

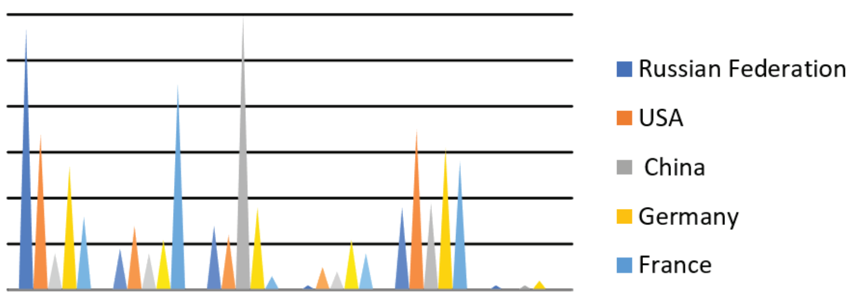


Figure 2. Structure of alternative energy resources in 2021 (Global Energy Trends—2022 Edition (https://yearbook.enerdata.ru/total-energy/world-consumption-statistics.html, accessed on 1 September 2022).

According to the commentary of [13,14] the following issues are relevant within the framework of the energy development task:

(1) Determination of priorities in production, volumes or efficiency;
(2) Regulation of dependencies between the rate of commissioning of generating capacities and the growth of the risk of tariff increases;
(3) Risks of excess capacity;
(4) Drawing up long-term forecasts for fuel and energy: assortment, change in the structure of assets, cost forecast, assessment of volatility in the need for investment.

Consider the starting points for modeling the project of an electric power company:

(1) At present, there is no competitive advantage of Russian manufacturers in terms of costs; moreover, the energy intensity is the highest in the world;

(2) The efficiency of energy consumption should be regulated by multi-unit tariffs, "price signals" [15];
(3) The resource conservation policy should allow the transition to responsible investment;
(4) Distribution processes should take into account the elasticity and optimization of alternative supply additions [16].

Ordering new equipment by the electric power industry to provide the consumer with the necessary amount of electrical and thermal and alternative energy can lead to the construction of excess capacity and inefficient use of investments, energy intensity is still too high (especially in the Russian Federation), and distribution processes are limited. The relevance of the audit to ensure the formation of an optimal investment program for the development of the energy complex is due to the high costs of purchasing power equipment, uneven distribution of investment programs across regions and different levels of financial control [17,18]. The energy system of the Russian Federation consists of the UES of Russia (seven unified energy systems (IPS)—the IPS of the Center, the Middle Volga, the Urals, the North-West, the South and Siberia) and territorially isolated energy systems (Chukotka Autonomous Okrug, Kamchatka Krai, Sakhalin and Magadan regions, Norilsk-Taimyr and Nikolaev energy regions, energy systems of the northern part of the Republic of Sakha (Yakutia)) (http://www.suenco.ru, accessed on 1 September 2022).

Graphs of peak loads of energy consumption by consumers, along with energy supply quality standards and the degree of reliability of the energy system, should be taken into account when drawing up a forecast of energy consumption. This can be done based on monitoring, elasticity (both in terms of price and income), establishing the type of relationship between the average per capita income of a family and the quantity and structure of electricity consumption. To form a program for the development of the energy complex, it is necessary to consider the entire set of possible technical solutions that can be implemented at all stages of the technological chain "production—transportation—consumption of energy resources", taking into account the elasticity of the population's demand for energy, see Table 1. In the short term, electricity is a commodity essential, as can be seen from the data in Table 2 in almost all countries, for which there are practically no substitute goods, and in all countries, see Table 2. This gives reason to expect short-term price elasticity to be low. In the long run, electricity demand should be more elastic. For an industrial consumer, the demand for electricity can be written as a cost minimization problem and the Cobb-Douglas production function can be used for each generating company.

$$\begin{cases} Q_e = A * L^{\alpha} * L^{\alpha} * R^{e} * K^{\beta} \to max \\ p_e * R + w * L + p_r K \leq Y \\ \alpha + \beta + e > 1 \end{cases} \quad (1)$$

where Q_e is the Cobb-Douglass production function, the amount of electricity generated by the generating company, kWh; A is a technological coefficient determined by a technological audit, reflecting the specifics of the equipment of a given company, for example, the coefficient of power utilization, wear and tear, the coefficient of technological replacement of resources [19–22]; L is the number of employees; w is the average wage; p_{ie} is the price of the i-th resource (oil, coal, natural gas, electricity, biomass, thermal power engineering); $p_{ei}R$—the cost of consumed resources for energy production; R is a vector of resources; K is the amount of capital consumed, investments in the generating company; p_r—price of capital; Y is the budget constraint of the generating company; α, e, β—elasticity of resources: labor, raw materials, capital; $\alpha + \beta + e$—the sum of elasticity's shows the type of production scale.

Table 1. The largest electric power companies (http://www.suenco.ru, accessed on 1 September 2022).

The Company	Installed Capacity, Kw	The Volume of Electric Power Generation, Billion kWh.
Generating companies		
The Inter RAO Group is a diversified energy holding that manages assets in Russia, as well as in Europe and the CIS	−33.7	132.5
Rosenergoatom Concern JSC (part of the Electric Power Division of Rosatom State Corporation) is one of the largest enterprises in the Russian electric power industry and the only company in Russia that performs the functions of an operating organization (operator) of nuclear power plants	29.0	204.3
RusHydro Group is one of the largest Russian energy holdings. RusHydro is a leader in the production of energy based on renewable sources, developing generation based on the energy of water flows, solar, wind and geothermal energy	39.4	144.2
LLC Gazprom Energoholding is one of the largest owners of electric power (generating) assets in Russia (controlling stakes in PJSC Mosenergo, PJSC MIPC, PJSC TGK-1 and PJSC OGK-2)	39.0	146.5
JSC "Unipro" production and sale of electric energy and capacity and thermal energy, represented in the markets of distributed generation and engineering	11.2	46.6
PJSC Enel Russia	9.4	41.3
PJSC Fortum is one of the leading producers and suppliers of heat and electricity in the Urals and Western Siberia, and also develops renewable sources of generation	4.9	28.1
PJSC "Quadra—Power Generation" is one of the largest Russian territorial generating companies (TGC), the company was created on the basis of thermal generating capacities and thermal grid assets of regional AO-energos in 11 regions of the Central Federal District	2.9	9.7
JSC EuroSibEnergo	19.5	67.6
Siberian Generating Company LLC. (Novosibirsk, Russia)	10.0	46.0
PJSC "T plus"	15.7	55.0

Table 2. Coefficients of elasticity of energy demand for the population for 2014–2019 (%) (https://www.economy.gov.ru/material/file/d81b29821e3d3f5a8929c84d808de81d/energyefficiency2019.pdf, accessed on 1 September 2022).

Period	Russia	Japan	Sweden	Norway	Germany	USA
Energy intensity of GDP	60	20	29	25	22	15
Price elasticity of demand						
Short-term	−0.06	−0.10	−0.11	–	−0.09	−0.09
Long-term	−0.1	−0.19	−0.11	–	−0.14	−0.13
Elasticity of demand by income						
Short-term	0.6	0.53	–	0.50	0.27	0.12
Long-term	0.1	1.02	–	0.81	0.42	0.17

Defining the value of elasticity:

The price elasticity of demand for the labor factor will be equal to:

$$E_p = \frac{\frac{\partial l}{l}}{\frac{\partial w}{w}} = \frac{\partial log l}{\partial log w} = \alpha \quad (2)$$

The elasticity of demand by income determines which category the energy product currently belongs to: the worst product, the first necessity, the second or luxury:

$$E_I = \frac{\frac{\partial q}{q}}{\frac{\partial y}{y}} = \frac{\partial logq}{\partial logy} = \gamma \quad (3)$$

The price elasticity of demand for the raw materials, resources factor will be equal to:

$$E_p = \frac{\frac{\partial r}{r}}{\frac{\partial p_e}{p_e}} = \frac{\partial logr}{\partial logp_e} = e \quad (4)$$

The price elasticity of demand for the capital factor will be equal to:

$$E_p = \frac{\frac{\partial k}{k}}{\frac{\partial p_r}{p_r}} = \frac{\partial logk}{\partial logp_r} = \beta \quad (5)$$

The condition for reaching the limit of technology use is determined by the equality of the average and marginal products differentiated by energy resources:

$$\text{MPr} = \text{APr} \quad (6)$$

The database for the purposes of econometric estimation was prepared on the basis of sources from Rosstat and the Ministry of Energy of Russia.

For example, one should take into account the spread of smart home and smart system technologies for energy supply of companies, RAB (Regulatory Asset Base) investment (this is a system of long-term tariff formation, the main purpose of which is to attract investments in the expansion and modernization of infrastructure) which is carried out in parallel with TPA. Companies in the RAB system receive a guaranteed return on investment and return on investment sufficient to service loans and make a profit. In addition, they receive an incentive to reduce costs, since the saved funds remain in the company, in contrast to the "cost plus" system used historically in Russia. From the point of view of consumers, the advantages of the RAB system are the increased reliability of power supply and the quality of services provided through new investments [23,24].

To apply RAB investment, the guidelines for tariff regulation using the method of return on invested capital are applied, which define the rates of return on invested capital.

Unfortunately, according to forecasts, the target benchmarks for the energy intensity of GDP in the Russian Federation are to reduce it by at least 60% while maintaining the current production rates. This goal will be achieved according to forecasts only in 2043, with a significant lag behind the plan (https://www.economy.gov.ru/material/file/d81b29821e3d3f5a8929c84d808de81d/energyefficiency2019.pdf, accessed on 1 September 2022).

Let us denote the set of all possible technical solutions at all stages of the technological process of generating energy resources as J (j = 1, 2, . . . , J), and xji are the costs of the technical solution of the energy complex development program in the region. The index j shows the number of the activity from the entire set of possible activities J. The index i shows what kind of resources the activity belongs to. In this case, i = 1—nuclear power plants, i = 2—hydropower facilities, i = 3—thermal power plants. As can be seen from Figure 1, i varies in the range from 1 to 6. Then the set of technical solutions for the XJi energy complex development program for resource i activities includes: {x1i, x2i, . . . , xj − 2i, xj − 1i, xji, xj + 1i, xj + 2i, . . . , xJi}. The xji variable from the set of technical solutions can take the values 0 or 1 depending on whether the measure is implemented or not (1 if the measure is implemented, and 0 if it is rejected).

For example, based on the classical microeconomic theory of profit maximization for a household, we can write down the optimization problem of utility maximization, in which the demand for electricity is formed:

$$\begin{cases} U(q,r) \to max \\ p_e q + p_r r = I \\ MRS = \frac{MU_e}{p_e} = \frac{MU_r}{p_r} \end{cases} \quad (7)$$

where U (q, r) is the utility function for the household; q is the volume of electricity consumption; r is the volume of consumption of other goods.

p_e is the price of electricity; p_r—the price of other goods (the cost of the consumer basket); I—the budget constraint of the household (its income).

In the long term, electricity consumers have the opportunity and time to form a stock of power-consuming equipment in an optimal way. Accordingly, the long-term model does not directly take into account the volume of stocks of power-consuming equipment, implying that in the long term it is formed in an optimal way—depending on prices and incomes. Each investment project has its own characteristics, which can be divided into the following four groups. Economic features [25]:

- The amount of capital costs for the implementation of the investment project Kj (thousand rubles);
- The service life for which the project is designed Tj (year);
- The cost of operating costs in the t year of the service life of the solution E t (thousand rubles);
- The cost of debt service costs associated with financing the development program at all stages of the production cycle for T years Kj (thousand rubles).
- Technological features (they determine the method of production of electrical and thermal energy): CHP, TPP using various types of fuel (coal, gas, fuel oil, nuclear energy, etc.);
- Hydroelectric power plants;
- Tidal power plants; solar panels;
- Solar collectors; geothermal stations;
- Wind power plants;
- Combined methods of energy production using two or more technologies.
- Signs of a logistical connection between energy production and its consumption:
- Scheme of centralized power generation;
- Scheme of decentralized power generation;
- Scheme of combined (part of centralized, part of decentralized) energy generation;
- The scheme of energy transport from the producer to the consumer;
- Energy storage scheme.
- Technical features:
- Is the volume of produced resource per year Wji;
- Regime maps of resource depletion $W^i(t)$.
- The initial data for the formation of a program for the development of the energy complex are:
- Data on the demand for energy resources for the period of implementation of the development program;
- A source of energy for the production of a resource within the boundaries of the energy complex;
- Environmental requirements that limit the use of technical solutions and technologies.

The amount of funds for the project by years of program implementation will be denoted by CFig(t). The volume of investments should be made taking into account the long-term forecast of energy consumption. To do this, it is necessary to assess consumer demand depending on the value of the non-linear tariff for the energy resource:

pit = generation cost (up to 40% of the price) + transmission tariff (up to 50% of the price) + sales and infrastructure surcharges (8)

The tariff should be set in such a way as to encourage resource conservation of consumers.

In a deterministic form, the dependence of consumer demand g in the *t*-th year for the corresponding resource *i* have the form:

$$W_g^k(t) = f_g\left(p^i\right) \tag{9}$$

The volume of resource consumption for all consumers will be equal to:

$$\sum_{g}^{G_\tau} W^i(t) = \sum_{g}^{G_\tau} f * \left(p^i\right) \tag{10}$$

where *G*—j, investment volume per year (*g* = 1, 2, *G*).

The depth of the forecast should correspond to the time for which the project is designed. When forecasting, the probabilities of the occurrence of a particular scenario should be determined.

Let us designate the scenarios of dynamics in time of demand for resources—μi. The number of developed scenarios for changing demand over time can be different.

The most likely scenario ("before and after" (BAU)) is a continuation of the current conditions, when there is no environmental policy or model improvements, and serves as a benchmark. In addition to BAU, several other scenarios are considered:

(1) Achievement of certain quotas for renewable energy sources provided for by the Law on Renewable Energy Sources for each control year of the modeling horizon (RES);
(2) The introduction of taxes on carbon emissions, which increase during the control years of the modeling horizon (CO_2);
(3) Resource-saving technologies that reduce energy consumption.

The mathematical expectation of the volume of consumption for the corresponding type of resource for the *S*-th scenario will be equal to:

$$M\left(W_g^i(t)\right) = \sum_{g}^{G}\sum_{s=1}^{S} \mu_{s*} f_g(p_t^i) \tag{11}$$

In the conditions of state regulation where $W^i(t)$ is the volume of investments in the project in the *t*-th year by the consumer *g*, units. Res./year; μ_S is the probability of the implementation of the *s*-th scenario.

Each variant of the set of technical solutions of the energy complex development program is determined by the volume of the produced resource W i for the entire set of technical solutions J in at all stages of the technological process (production, transportation and consumption of energy resources). In this way, a system of constraints can be defined. Each variant of the set of technical solutions of the energy complex development program is determined by the volume of the produced resource W i for the entire set of technical solutions J in accordance with the schedule of its consumption Wg in the entire range (T):

WJi > Wgi; Wji (T) > Wgi (T) (12)

Taking into account the probabilities of the occurrence of resource consumption scenarios in the entire range T:

Wji > M (Wi); Wji (T) > M (Wi (T)) (13)

The amount of excess in relation to the volume of consumption of energy production can be considered a measure of ensuring the reliability of energy supply. A measure of reliability is any algorithm for judging whether there is a necessary level of reliability or a degree of confidence in the performance of specified functions by some object in the past, present and future tense. The measure of reliability includes indicators and criteria (logical and analytical expressions) related to the algorithm for inferring a judgment about reliability [25].

The cost of the costs of ensuring the reliability of energy supply is denoted by:

$$\text{Vi (T)} = \text{f (Wi (T)} - \text{Wi (T))}. \tag{14}$$

The higher the reliability of the power supply system, the more expensive the cost of generated energy.

We can propose the following formulation of the target function for the formation of an optimal program for the development of the energy complex: meeting the needs of consumers for heat and electric energy in the required volume and with the required reliability of energy supply, with minimal costs at all stages of the technological process production, transportation and consumption of energy resources. Under the conditions of state regulation of energy tariffs, the tariff directly depends on the production costs and transportation costs of energy resources.

The volume of capital investments in year t for some technical solution j is equal to K_j and for T years is calculated by the formula:

$$K_j^k = \sum_j^k K_j^k * (t) * x_j^k \tag{15}$$

For a certain set of technical solutions in the amount of J we obtain:

$$K_j^k = \sum_j^J \sum_t^T K_j^k * (t) * x_j^k \tag{16}$$

The operating costs per year e for some event o will be equal to Uo and for E years will be:

$$E_j^k = \sum_t^T E_j^k * (t) * x_j^k \tag{17}$$

The operating costs associated with the implementation of technical solutions for T years in the amount of J will be equal to the sum of the operating costs for all activities:

$$E_j^k = \sum_j^J \sum_t^T E_j^k * (t) * x_j^k \tag{18}$$

Energy conservation policy involves the protection of biodiversity and involves the differentiation of ownership of energy resources to ensure competition in the field of production.

Attracting sources of financing leads to the appearance of debt servicing costs on a loan allocated for the implementation of a technical solution j per year t in the amount of:

$$I_j^k = \sum_t^T I_j^k * (t) * x_j^k \tag{19}$$

The cost of debt servicing at all stages of the production cycle for T years will be:

$$I_j^k = \sum_j^J \sum_t^T I_j^k * (t) * x_j^k \tag{20}$$

The costs of ensuring the reliability of energy supply for a certain set of technical solutions in the amount of O over E years will be:

$$V_j^k = \sum_j^J \sum_t^T V_j^k * (t) * x_j^k \quad (21)$$

Then the objective function of forming an optimal program for the development of the energy complex for resource i can be written as follows:

$$\begin{gathered} \sum_j^J \sum_t^T K_j^k * (t) * x_j^k + \sum_j^J \sum_t^T V_j^k * (t) * x_j^k \\ + \sum_j^J \sum_t^T I_j^k * (t) * x_j^k + \sum_j^J \sum_t^T E_j^k * (t) * x_j^k \rightarrow min \end{gathered} \quad (22)$$

3. Results

There is a change in the energy development trend in the world, which is manifested in a slowdown in the growth rates of production and consumption of primary energy resources and electricity in the general context of a decrease in the growth rates of the world population and GDP. The developed model makes it possible to find the optimal plan of technical solutions, taking into account the balance of the possibilities of the electric power industry and the needs of the economy in energy resources, taking into account the scenario being implemented in the selected region. On the basis of the plan for the production of energy products, equipment is selected and public investments are distributed, the effectiveness of which is assessed by audit methods. The approach considered here reflects the relationship between investment and the distribution structure of alternative sources. Thus, it is shown that the relevance of consideration in the programs for the development of technical solutions in the energy sector is due to the structure of the cost of energy, in which, as already noted above, the predominant share (60%) is occupied by the costs of building power plants, including the entire value chain from energy equipment suppliers to the construction of power plants. In terms of energy supply, this includes fuel extraction, primary and secondary production, and external imports and exports. The "agents" on the supply side are the "producers" and are listed in Table 3. Different types of energy are delivered to consumers in the residential, commercial, agricultural, transport and industrial sectors. "Agents" from the side of demand for energy are "consumers", for whom a multi-level personalized tariff for energy products is being developed. Solar energy, wind energy, wave energy, biomass energy, geothermal energy and hydroelectricity are all examples of sustainable energy. The mathematical, economic and engineering relationships between these "producers" and "consumers" of energy are the basis underlying the TIMES models [6,7]. Approbation of the considered model contributes to the transition of the economy from the stage of high energy intensity to a new level of increasing the rate of energy efficiency based on the use of renewable sources. Based on the financial statements of TNCs of energy companies, a calculation was made using a mathematical model, the calculation results are presented in Table 3, and these are the recommended optimal values.

Table 3 shows the optimal structure of resources for generating companies for energy production, taking into account the optimization of investments and taking into account the specifics of the regions, which is determined by the technology audit. The model allows defining future investment roles.

In addition, the cost-effective path for the system indicates that institutional investors should be solely focused on making all high-value investments in offshore wind power in the north. The rest of the investment potential of institutional investors in other regions should be directed to traditional sources. The relative roles of regions show the cumulative net electricity exchange between regions over the modeling horizon to determine the roles each region should play in the future to form the system at the lowest cost. The relative roles of regions show the cumulative net electricity exchange between regions. Modeling allows one to determine the roles that each region should play in the future to form a system for the production of energy products at the lowest cost.

Table 3. Total indicators by companies.

Elements of the Structure, %	Gazprom Energoholding	RusHydro Group	Rosenergoatom Concern	Inter RAO Group	PJSC "Enel Russia"	JSC "Unipro"
Natural gas	7	1	11	16	51	2
Electricity		94	58	45	45	88
Coal	4	2	4	3	1	3
Fuel oil	5					
Biomass	9	2	5	8	1	3
Diesel fuel	2					
Oil	18	1	20	28	1	3
Heat	2	0	2	0	1	1
Power engineering water	2					
Total	100	100	100	100	100	100
Long-term elasticity of demand by income	0.3	0.2	0.1	0.2	0.3	0.20.2
Number of employees	40	43	41	40	40	25
Capital intensity	0.6	0.5	0.7	0.4	0.4	0.3

This additional generation is then exported to the south and west.

In the BAU scenario, the fuel mix for electricity generation does not change significantly over the modeling horizon, with the exception of phasing out nuclear power from 2023. However, with the policy scenario imposing targets for the share of renewable energy sources (RES), hard coal is replaced by renewable sources, while the system remains relatively inert towards phasing out lignite until the end of the simulation horizon. In CO_2 emission scenarios, natural gas is noticeably rapidly replacing lignite and hard coal, as they are costing the system prohibitively due to the increasing carbon tax imposed. Given the significant amount of carbon emissions through natural gas, as well as the steady increase in carbon taxes over the modeling horizon, carbon capture and storage (CCS) in combination with natural gas and biomass technologies, as well as other renewable energy sources, will gradually replace most of the fossil fuels by 2060. The total net electricity exchange between regions over the entire modeling horizon (only in scenarios with regional division and transmission between regions) will increase significantly [21].

The total net electricity exchange between regions over the entire modeling horizon (only in scenarios with regional division and transmission between regions).

Since the goal in both scenarios is to achieve a certain share of renewable generation in final electricity consumption (not total generation), these two factors remain the same in both scenarios. Thus, losses in the network are compensated by more energy production.

4. Discussion

The concept of life in the energy industry is changing rapidly, with most smart energy solutions coming from Europe and the United States. Gary Huang (2021) [26] observes that if the country does not engage in digitalization in the energy sector, this may lead to a situation where the national substation will be controlled from abroad. The problems of "control interception" in the energy sector were dealt with by such scientists as Gamayunova O., Vatin N. (2015) Clayton, E. (1999) [27].

Technical innovations with renewable energy sources are now implemented by many companies around the world. For example, the Rockefeller Family Foundation (RFF) and the IKEA Charitable Foundation decided to create a joint fund to support renewable energy programs [28].

The authors of [8] describe the basic procedure for conducting TCA. The authors of [18] considered the problems of optimizing design solutions and controlling the reliability of costs. The authors Karakozova I.V., Prokhorova Y.S. (2015) [17] considered the technological and price audit of the terminal-logistics center project. The authors of Savushkin S.A., Gorbunov V.G., Tsyganov V.V., Lemeshkova A.V. (2016) [9] considered the controlling of investment programs of electric power companies. The authors of Gryzunova N.V., Kiseleva I.A., Tramova A.M. (2021) [29] showed that the solution of the problem of finding the optimal option for designing energy facilities essentially boils down to choosing the optimal method for comparing capital costs and operating costs. Klyuev, Yu.B. et al. (1992) [25] showed that the solution of the problem of finding the optimal option for the design of energy facilities essentially comes down to choosing the optimal way to measure capital costs and operating costs. At the same time, the publications known to us do not consider the issues of forming an optimal investment program for the development of the energy complex, taking into account the limited amount of financial resources allocated for investment needs.

Models for optimizing the structure of electrical networks are highlighted by Yu.B. Klyuev Yu.B (1992), Savushkin S.A., Gorbunov V.G. Artyugina and V.R. Okorokov (1988), Brisset E. (2018) and Wang S. et al. (2020) [9,22,25]. It is shown that the solution to the problem of finding the optimal design option for energy facilities essentially results in choosing the optimal way to measure capital costs and operating costs Ogedengbe E., Aderoyu P.A., Shitta M.B. (2019) [30].

At the same time, the publications known to us do not consider the issues of forming an optimal program of projects for the development of a complex of distributed energy and TPA to control the effectiveness of capital investments.

5. Conclusions

The sustainability and diversity of the types of energy produced in the region can be achieved by modeling distributed energy, optimizing consumption and available resources. The local assortment base determines the structure of the equipment fleet. Planning TPA involves the use of the TIMES model generator.

1. In the course of the analysis, it can be concluded that the existing methodology for conducting TPA does not take into account such a stage in the implementation of an investment project as optimizing the structure of consumption of energy resources in the energy system.
2. The TPA methodology will be more efficient, covering a wide range of financial parameters, if TPA is carried out at the stage of business planning.
3. The TPA mechanism will allow simultaneous use of key indicators and control them within the approved boundaries.
4. Comparative analysis showed that the TPA methodology is rational, but the risks during the operation period are significant.
5. We consider it expedient, within the framework of measures to develop the existing methodology for conducting TPA for investment projects with state participation, to expand the list of ongoing stages. Additionally, take into account the methodology for conducting TPA for investment projects of natural monopoly facilities.

Subsidiaries of electric power organizations are often natural monopolies.

The practice of using TPA will expand, as the Russian Energy Development Strategy until 2035 includes measures to decarbonize, replicate and scale low- and non-carbon technologies, stimulate the use of secondary energy resources, changes in tax, customs and budgetary areas. The strategy provided for the development of green finance, measures to increase the absorption capacity of forests and the utilization of greenhouse gases. Currently, programs are already being formed that are consistent with the recommendations of the European Union Dynamical Exascale Entry Platform (EU-DEEP) for the use of alternative energy sources in the coming decades.

Author Contributions: Conceptualization, N.G.; methodology, K.V.; software, V.M.; formal analysis, I.K.; writing—original draft preparation, M.B.; writing—review and editing, N.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Schubert, T.; Breitschopf, B.; Plötz, P. Energy efficiency and direct and indirect consequences of energy audits and implementation support programs in Germany. *Energy Policy* **2021**, *157*, 112486. [CrossRef]
2. Moreva, Y.A.; Surovtsov, M.M.; Panova, E.A. *Development of Distributed Generation in the World and in Russia*; Kurchatov Institute: Moscow, Russia, 2020. Available online: https://www.c-o-k.ru/articles/razvitie-raspredelennoy-generacii-v-mire-i-v-rossii (accessed on 1 September 2022).
3. Clayton, E. Debt, Investment, and Product Market Competition. 11 November 2008. NYU Working Paper No. FIN-99-056. Available online: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1298329# (accessed on 1 September 2022).
4. Degtyarev, K.S. Global Energy Trends. Available online: https://yearbooi.enerdata.ru/total-energy/world-consumption-statistics.html (accessed on 1 September 2022).
5. Troshin, A. Energy Develops Through Customization, Interviews, Technologies, 10 October 2019. 12:00. *Moscow business Magazine Invest Foresight*. 21 June 2021. Available online: https://www.if24.ru/ (accessed on 1 September 2022).
6. Keppo, N.S. Incorporating homeowners' preferences of heating technologies in the UI TIMES model. *Energy* **2018**, *148*, 716–727.
7. Tash, A.; Akhanchyan, M.; Fahl, E. Improved representation of investment decisions in the German energy supply sector: An approach to optimization using the TIMES model. *Rev. Energy Strategy* **2019**, *26*, 100421. [CrossRef]
8. Kutsenko, D.I.; Petrochenko, M.V.; Naboka, A.A. Methods of Conducting a Technological and Price Audit of an Investment and Construction Project. *Alfabuild* **2019**, *3*, 23–35.
9. Savushkin, S.A.; Gorbunov, V.G.; Tsyganov, V.V.; Lemeshkova, A.V. Technological and Price Audit of the Terminal and Logistics Center Project. 2016, pp. 47–56. Available online: https://elibrary.ru/item.asp?id=26377377 (accessed on 1 September 2022).
10. Brisset, E. Smart Energy is a Necessity. *Invest Foresight*, 4 September 2018. Available online: https://www.if24.ru/gari-huan-uskorit-tsifrovizatsiyu-rossii/(accessed on 1 September 2022).
11. Salvucci, R.; Tattini, J.; Gargiulo, M.; Lehtil, A.; Iarlsson, I. Modelling transport modal shift in TIMES models through elasticities of substitution. *Appl. Energy* **2018**, *232*, 740–751. [CrossRef]
12. Azam, W.; Khan, I.; Ali, S.A. Alternative energy and natural resources in determining environmental sustainability: A look at the role of public spending on final consumption in France. *Environ. Pollut.* **2022**, 1–7. [CrossRef]
13. Belussi, L.; Danza, L.; Svaldi, S.D. Integrated Intelligent Energy Audit System: Methodology and Application. *Energy Proced.* **2017**, *140*, 231–239, ISSN: 1999-2300. [CrossRef]
14. Frani, M.Z.; Goyal, V.I. Testing the peciing order theory of capital structure. *J. Financ. Econ.* **2003**, *67*, 217–248. [CrossRef]
15. Bergenzle, K.; Guniel, F.A. Intersectoral flexibility, investments in storage and integration of renewable energy sources: Taking into account the impact of network tariffs. *Energy Policy* **2022**, *164*, 112937. [CrossRef]
16. Çağman, S.; Soylu, E.; Ünver, Ü. Research of easy-to-use energy efficiency indicators for energy audit and energy monitoring of industrial compressed air systems. *J. Clean Prod.* **2022**, *365*, 132698. [CrossRef]
17. Karakozova, I.V.; Prokhorova, Y.S. Technological and price audit as a tool for optimizing design solutions and monitoring the reliability of costs in construction. *Econ. Entrep.* **2015**, *56*, 682–686, ISSN: 1999-2300.
18. Wang, X.; Zhao, T.; Chang, C. FAHP-MCGP Integrated Approach to Project Selection and Resource Allocation in risk-based Internal Audit Planning: Case Study. *Comput. Ind. Eng.* **2020**, *152*, 107012. [CrossRef]
19. Kukoverov, M.V. RANEPA, Moscow On Price Elasticity of Electricity Demand. *J. New Econ. Assoc.* **2019**, *2*, 70–92. [CrossRef]
20. Liu, C.; Alharti, M.; Khan, I. Nonlinear analysis of the impact of Natural resources and education on environmental quality: Green Energy and its Role in the Future. *Resources* **2022**, *79*, 102940.
21. Zachary, A.; Tavria, V.; Li, G. Ensuring sustainable consumption and production patterns in Africa: Data from green energy perspectives. *Energy Policy* **2022**, *169*, 113183.
22. Artyugina, I.M. *Methods of Technical and Economic Analysis in Energy [Test]*; Artyugina, I.M., Korokov, L.V.R., Eds.; Publishing House: Moscow, Russia, 1988; 264p.
23. Liu, C.; Alharti, M.; Khan, I. The role of the Trilemma in the Global Energy sector Transition to sustainable Energy: A Study of Economic Growth and the Environment. *Energy Policy* **2022**, *170*, 113238. [CrossRef]
24. Feiju, F.; Pfeiffer, A.; Dudich, N. A model of long-term investment in capacity and operational planning of energy consumption using power-to-X technologies and flexibility. *Renew. Sustain. Energy* **2022**, *167*, 112781.
25. Kluev, I.B.; Lavrov, A.N.; Okorokov, V.R. *Economic-Mathematical Modeling of Manufacturing Systems Energy: Studies*; For Stud. Universities, Higher School: Moscow, Russia, 1992; 430p.
26. Huang, G. We will help accelerate the digitalization of Russia. *Invest-Foresight*, 25 June 2021; INFOLine Information and Analytical Agency, Russia, Saint Petersburg. Available online: https://www.advis.ru/php/view_news.php?id=91F04F3A-6D93-FE4A-BE39-108EA409B2EF(accessed on 1 September 2022).
27. Gamayunova, O.; Vatin, N. The role of the state and citizens to improve energy efficiency. *Appl. Mech. Mater.* **2015**, *725–726*, 1493–1498. [CrossRef]

28. The Rockefellers Will Lead the Development of Green Energy. *Moscow Business Magazine Invest Foresight*, 21 June 2021. Available online: https://www.if24.ru/(accessed on 1 September 2022).
29. Gryzunova, N.V.; Kiseleva, I.A.; Tramova, A.M. Controlling Investment Programs of Electric Power Companies, Russia. *Bull. North Cauc. Fed. Univ.* **2021**, 49–62. Available online: https://vestnikskfu.elpub.ru/jour/article/view/174/174 (accessed on 1 September 2022).
30. Ogedengbe EO, B.; Aderoy, P.A.; Shita, M.B. Optimization of energy efficiency by determining the size of a renewable energy project using several target functions. *Energy Rep.* **2019**, *5*, 898–908. [CrossRef]

energies

MDPI

Article

Estimation of Tax Expenditures Stimulating the Energy Sector Development and the Use of Alternative Energy Sources in OECD Countries

Yuliya Tyurina [1], Svetlana Frumina [1,2,*], Svetlana Demidova [1], Aidyn Kairbekuly [3] and Maria Kakaulina [1]

[1] Department of Public Finance, Financial University under the Government of the Russian Federation, 49 Leningradskiy Ave., 125993 Moscow, Russia
[2] Department of World Financial Markets and Fintech, Plekhanov Russian University of Economics, 36 Stremyanny Lane, 117997 Moscow, Russia
[3] Procurement Department, Nazarbaev Intellectual School of Physics and Mathematics in Semey, Semey 071411, Kazakhstan
* Correspondence: frumina@mail.ru

Abstract: The energy crisis caused by global structural changes in the economic sphere is the cause accelerating the energy transition based on the concept of sustainable development. This study is to test the hypothesis about the incentive effect of tax expenditures on alternative energy and energy conservation. The objects of empirical research are the EU, OECD countries, OECD partner countries and Russia from 2018–2020. The tools of scientific research are based on methods of economic–statistical and comparative analysis and expert judgments. The concept of tax expenditures in terms of decarbonization is analyzed using a systematic approach. The integrated methodological approach shows the relationship between the tax policy and government strategies in achieving sustainable development goals to ensure the transition to rational energy consumption patterns and sustainable energy sources. The authors analyze incentives for the energy sector and alternative energy sources in the considered groups of countries, and they assess the scale of tax expenditures in the energy sector for OECD countries. There are two types of tax expenditures for achieving environmental sustainability—increasing renewable energy sources and improving the energy efficiency. The authors apply the multivariate average formula to assess the scale of tax incentives in OECD countries. The results are typified depending on the scale of tax expenditures as one of the tools and these results are grouped according to the dynamics. In the presented sample, a wide range of tax benefits and preferences is typical for the leading countries in the ranking. The countries at the bottom of the ranking support fossil fuels, but they have already started the energy transition.

Keywords: tax expenditures; tax incentives; energy sector; alternative energy sources; scale of tax expenditures

Citation: Tyurina, Y.; Frumina, S.; Demidova, S.; Kairbekuly, A.; Kakaulina, M. Estimation of Tax Expenditures Stimulating the Energy Sector Development and the Use of Alternative Energy Sources in OECD Countries. *Energies* **2023**, *16*, 2652. https://doi.org/10.3390/en16062652

Academic Editor: Peter Connor

Received: 8 February 2023
Revised: 1 March 2023
Accepted: 4 March 2023
Published: 11 March 2023

1. Introduction

The concept of tax expenditures has a long history and has managed to obtain legislative consolidation and international recognition. In general, tax expenditures are a loss of income that comes from certain reliefs, tax laws that provide exemptions, deductions from the tax base, a tax credit that is deducted from tax liability before payment, preferential rates and delays.

Tax incentives are benefits provided to certain payers compared to other payers. This may be the opportunity not to pay a tax or pay a smaller amount. The larger the size of the tax benefit, the greater the state participation in activities of the one to whom it is granted. Granting the tax benefit looks like this: the payer does not redistribute their income to the state, but at the same time the state provides them with the opportunity to use the benefit and leaves funds at their disposal that could be used to pay obligations. Tax incentives are considered as tax expenditures of the budget because they reduce its revenue.

Tax expenditures have their own history. In this case, the Federal Republic of Germany (hereinafter referred to as the FRG) and the United States of America (hereinafter referred to as the USA) were the first to apply the system estimating budget shortfalls. In 1954, the report of the Federal Republic of Germany justified the convertibility of tax incentives and subsidies, and since 1959 they began to draw up reports that contained data on subsidies, including information on tax expenditures. The concept was developed in the 1980s in the USA. Since incentives reduce financial discipline and create abuse in the form of benefits to special interests, the concept was to solve this problem. In 1967, tax expenditures were included in the budget as a separate item. As soon as the number of benefits began to increase, their efficiency needed to be estimated. So, the Ministry of Finance began to provide reports on direct subsidies and tax preferences [1].

Further, the concept became an integral part of the budget, and was fixed by the regulatory provision. Then, when approving the budget, the report considered the rational use of tax expenditures [2]. To save time and simplify administration, a subsidy needed to be paid by reducing the tax base. Subsequently, there was an idea to replace direct expenditures, which could save the state money, since it is a necessity condition in times of tight budgetary policy [3]. Some measures, such as estimating tax expenditures to improve budgetary control, have been widely used in world practice since the 1970s.

Over time, the developed concept has become relevant and significant for many countries. It became the main topic for discussion at the meetings of the International Fiscal Association and the Organization for Economic Cooperation and Development (hereinafter referred to as the OECD). Various consultations and meetings led to the fact that participating countries were recommended to prepare a report highlighting tax expenditures. Identifying and quantifying tax expenditures is critical to understand the overall impact of the tax system [4].

The history of the concept of tax expenditures testifies to disagreements in understanding the essence, and, in general, the significance. The contradictions in government circles led to uniform recommendations and rules, materials and basic provisions, which formed the basis for consultations by the International Monetary Fund (hereinafter referred to as the IMF). Then, such countries as Austria, Canada, Great Britain, France, Spain, Belgium and some other countries started estimating tax expenditures [5]. Thus, it can be concluded that many countries have come to the opinion that the concept of tax expenditures was effective. At that time, about 80% of OECD countries were already preparing reports, which indicates the practical significance and necessity to create a theoretical basis for further implementation.

Further, the IMF defines recommendations and reflects government policies that may be qualified as tax expenditures. Currently, there is no consensus on the definition of tax expenditures. Each country determines it individually, based on the features and principles of calculation and the principles of its fiscal system, but general definitions are given in publications of international organizations. The OECD defines tax expenditures as the provision of government resources by reducing tax liabilities in lieu of direct budget expenditures.

Reforming the system of tax incentives can become an additional source, an alternative to raising tax rates and it can make tax systems more efficient and fairer [6] in terms of improving welfare and protecting the environment.

The introduction of tax incentives and preferences that support fossil fuels and accelerate the transition to renewable energy sources are in line with the UN Sustainable Development Goals, two of which directly support the energy change (Goals 7 and 12). Clean renewable energy, being a fundamental basis for the theory of sustainable development [7], accelerates the transition to a "green" economy, improves the environmental safety [8] and reduces geopolitical risks for states importing traditional energy resources.

In the context of the global agenda, to increase the level of decarbonization in the world's economies, an increase in renewable energy sources (hereinafter referred to as RESs) and energy conservation require incentive measures from governments. The purpose of this study is to estimate tax expenditures as stimulus measures that ensure transformations in the energy sector.

The paper begins with a discussion of the concept of tax expenditures in terms of decarbonization. Theoretical and empirical literature is viewed in Section 2. The data set and approaches used to assess the impact of tax expenditures are described in Section 3. This is followed by the results with grouping of countries by the level of tax expenditures for energy efficiency and renewable energy sources in Section 4. Section 5 contains a list of the vectors to keep tax incentives and emission targets, which are followed by the conclusion in Section 6. References are found at the end of this paper.

2. Literature Review

Theoretical foundations and relevant empirical literature are detailed in separate subsections in this section.

2.1. Theoretical Background

Three general approaches are distinguished for determining benchmark taxes and determining tax expenditures: the conceptual approach, the legal approach and the subsidizing approach [9]. Many scientific works present detailed descriptions of the method for estimating tax expenditures for the exemption from the personal income tax, the capital gains tax and the withholding tax, the corporate income tax, including the minimum tax, as well as tax expenditures for customs duties and excises, the value added tax and registration fees [10].

Those works that examine the impact of tax expenditures on the budget and capital (including investment) are very popular. The EUROMOD micro-simulation model is used to quantify the impact of tax expenditures on government tax revenues and household disposable income. This model includes the interaction between various tax tools and tax credits [11]. To assess the impact of tax expenditures on the economic activity (increase in investment capital) of residents in special economic zones, we use one-factor power econometric models [12].

Tax expenditures, despite their clearly positive side, have several imperfections. The problems accompanying the tax expenditure system can be divided into three main blocks—informational, technical and functional—depending on the nature of the problem.

Informational problems identified in the analysis of African countries are related to the lack of reporting on tax expenditures or inconsistency in reporting requirements [13]. More than 64% of African countries do not provide any information about their tax expenditures, while most of the countries that report tax expenditures miss important information such as political targets and key beneficiaries. Informational problems are also associated with a lack of the transparency and accountability. The study carried out in all countries showed that statistical data underestimate the amount of tax expenditures. For example, Portugal and Costa Rica provide only total estimates aggregated by the tax base. In addition, China and Saudi Arabia do not publish any official information about tax expenditures at all. The functional block reflects the problems associated with the inconsistency of tax expenditures with the stated goals and negative side effects, such as increasing inequalities and contributing to climate change [14]. It is possible to single out the functional–information block of problems identified in a study of the G20 countries, where schemes for tax expenditures to a large extent turned out to be non-transparent, expensive and often ineffective to achieve the stated goals, causing undesirable side effects. New tax incentives are introduced regularly without proper control despite the limited transparency on the magnitude of existing tax expenditures. For example, out of 43 G20 and OECD countries, 8 countries have not reported on tax expenditures over the past 10 years, 26 have published a basic report over the past 10 years and only 9 countries regularly publish a detailed and comprehensive report [15]. Technical problems include, for example, the inability to replicate best practices in estimating the amount of tax expenditures [16]. In Germany, large-scale estimations of tax expenditures are carried out once per legislative cycle, in accordance with the mandate to estimate each type of tax expenditure at least once every 10 years. Ireland estimates each type of tax expenditure every five years, but this country recognizes that the quantification cannot be prepared for many types of tax expenditures. Another technical problem identified in the analysis of one country was the lack of unified approaches when defining the conceptual model of the tax reference structure and, consequently, the generally accepted criteria when qualifying a tax law norm as an element of the tax reference structure or tax benefits (expenses). It leads to different interpretations of the same deviations from this structure [17].

In terms of tax expenditures for groups of G20 countries, it is advisable to increase the transparency of tax incentives through more frequent and complete reports on tax expenditures; improve the structure of tax incentives to minimize windfalls and negative spillovers within and between countries; and phase out tax expenditures that harm the environment, including tax incentives for fossil fuels and other schemes that promote the unsustainable use of natural resources [18].

Ensuring access to clean energy is critical to the sustainable recovery of OECD economies. In addition to access to energy at the individual level, energy security, which can be broadly defined as the availability of sustainable sources of energy at an affordable price, is a key driver of economic growth. At the same time, effective taxes on energy encourage citizens and businesses to opt for more environmentally friendly products, reducing climate damage and air pollution [19].

2.2. Empirical Literature

According to the UNEP, the mass of anthropogenic emissions of greenhouse gases in the world exceeds the allowable amount to achieve the target threshold of a level well below 2 °C (Paris Agreement to limit global warming), and, moreover, the preferred threshold of 1.5 °C. Annual emissions of CO_2 equivalents have increased by 40–50% compared to 1990. About 75% of emissions are accounted for by the G20 countries; emissions from developing countries increased by 2–4 times compared to 1990 [20].

The most significant contribution to global anthropogenic emissions is made by the PRC, the USA, the EU-27, India, Russia and Japan—with 67.8% of global emissions at the end of 2021 [21]. Figure 1 shows changes in CO_2 emissions for countries with a global share of more than 1%.

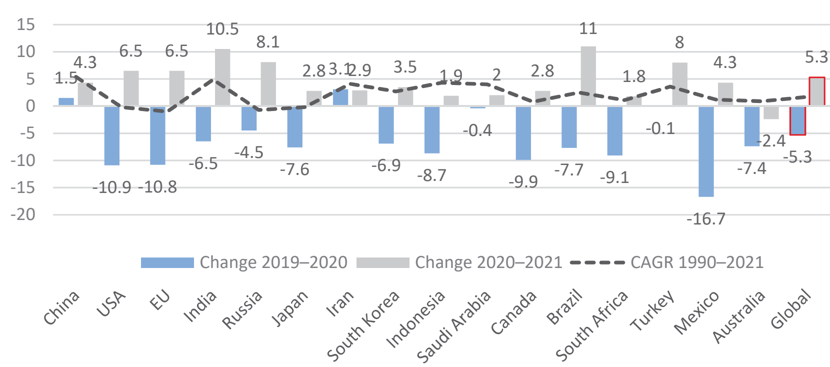


Figure 1. Dynamics of CO_2 emissions in selected countries in the periods 2019–2020, 2020–2021, from 1990–2021 (%).

In 2021, global CO_2 emissions returned to the pre-pandemic level of 2019, increasing immediately by 5.3% compared to 2020 (China and Iran, despite COVID-19 restrictions, increased CO_2 emissions in 2020 as well). The highest growth in emissions in 2021 came from India (+10.5%) and Brazil (+11%). Brazil, India, Russia, Turkey, China, Iran and Saudi Arabia emitted more CO_2 in 2021 than in 2019. Australia was the only country that maintained the trend of reducing CO_2 emissions in 2021, there was a decrease of 2.4%. The

EU, Russia, the USA and Japan showed the CAGR of CO_2 emissions compared to 1990. At the same time, more than 60 countries (the UK, the EU, the USA, China, Japan, etc.) announced that they will achieve "carbon neutrality" by 2050–2060 and even earlier. The fulfillment of the tasks set requires system-wide transformations, and various deterrent and incentive tools. Incentive tools contribute to certain behavior patterns, such as tax incentives and preferences for alternative energy sources—RESs. Although individual studies show that tax incentives may not have the desired effect, both for one country [22] and a group of countries [23], their scale can be quite impressive. In some countries, lost revenues from tax incentives amount to more than 13% of GDP [24]. Thus, the dynamics of greenhouse gas emissions are not uniform in different countries.

At the same time, the tax policy differs significantly in different countries. Some countries introduce incentives for energy taxes, others do not have similar taxes at all. From an economic point of view, the absence of a tax is equivalent to exemption from its payment, but it cannot be estimated as a tax expense, due to the absence of this tax base. In the context of environmental sustainability, GTED highlights tax spending that is to reduce greenhouse gas emissions, improve energy efficiency, promote renewable energy, protect biodiversity or support climate change adaptation. When considering measures to support fossil fuels by the OECD [25], almost 60% of all measures can be tax expenditures, which is significant enough, but not complete. Tax expenditures for fossil fuels can be divided into three broad groups: final consumption of fossil fuels; fossil fuels as inputs for production; production of fossil fuels, including extraction, processing and transportation [26]. We will adhere to the position that the comparison of tax expenditures in the energy sector is rather conditional, but at the same time it reflects the general trend in the area under consideration.

Optimistic forecasts by 2050 show a share of investments in renewable energy projects of about 77% of all investments in the electric power industry [27], although there is also a dispersion of indicators here [28]. However, experts tend to assume a rather optimistic scenario for the development of global renewable energy to reduce greenhouse gas emissions, as shown in various studies [29,30].

The hypothesis about the impact of tax regulation on RESs in terms of reduction of greenhouse gas emissions was confirmed when considering the sample of countries for 1991–2018 [31]. We note a more significant contribution of RESs in the reduction of greenhouse emissions for countries with a high tax burden in the environment. At a certain threshold level of RES development, the tax policy can be tightened without the loss of efficiency. These results emphasize the role of tax regulation in the environment and they are consistent with previous findings [32] about the positive impact of energy taxes on curbing emission growth.

The governments of the EU countries independently determine incentive measures to develop RESs: preferential prices for electricity generated using RESs; trade in electricity consumption quotas—"green" certificates (Sweden); tax incentives for enterprises using RESs; "green" tariffs (Denmark), etc. [33].

The EU Bioeconomy Monitoring System (BMS) has been developed as part of the EU Bioeconomy Strategy. In 2022, seven new indicators were added to BMS dashboards, including: sustainable management of natural resources, reducing dependence on non-renewable unsustainable resources, regardless of mining jurisdiction. Dashboards display almost 30% of indicators, covering 67% of all regulatory criteria [34]. Figure 2 presents the share of renewable energy sources for transport, electricity, heating and cooling in the EU countries from 2015–2019.

The indicators of the EU countries are quite heterogeneous in terms of the share of renewable energy sources, with 15 countries showing an indicator below the average (19.7% in 2019). The largest share of RESs is observed in Sweden (56.4% in 2019). Sweden is a world leader in decarbonization, with a goal of achieving "zero" emissions by 2045. This is followed by Finland (43.1%), Latvia (41%), Denmark (37.2%), Austria (33.6%), Estonia (31.9%), Portugal (30.6%), Croatia (28.5%), Lithuania (25.5%), Romania (24.3%), Slovenia (22%), Bulgaria (21.6%) and Greece (19.7%). Most countries progressively increased the share of RESs in transport, electricity, heating and cooling, with the exception of Austria (2015—33.5%, 2016—33.4%, 2017—33.1%, 2018—33.8%, 2019—33.6%), Greece (decrease in 2016—15.4% compared to 2015—15.7%, then growth), the Netherlands (decrease in 2016—14.4% compared to 2015—14.5%, then growth), Ireland (decrease in 2018—10.9% compared to 2017—13.5%, then growth), Italy (2015—17.5%, 2016—17.4%, 2017—18.3%, 2018—17.8%, 2019—18.2%), Latvia (decrease in 2016—37.1% compared to 2015—37.5%, then growth), Lithuania (2015—25.8%, 2016—25.6%, 2017—26%, 2018—24.7%, 2019—25.5%), Luxembourg (decrease in 2019—7.1% compared to 2018—9.0%), Portugal (2016—30.9%, 2017—30.6%, 2018—30.2%, 2019—30.6%), Romania (2016—25%, 2017—24.5%, 2018—23.9%, 2019—24.3%), Slovenia (2015—22.9%, 2016—22%, 2017—21.7%, 2018—21.4%, 2019—22%) and Spain (2017—17.6%, 2018—17.5%, 2019—18.4%). The most significant increase in the share of RESs in 2019 was shown by Slovakia (+5% to 16.9%), the most significant drop was in Luxembourg (−1.9% to 7.1%) and this is the lowest share of RESs among the EU countries.

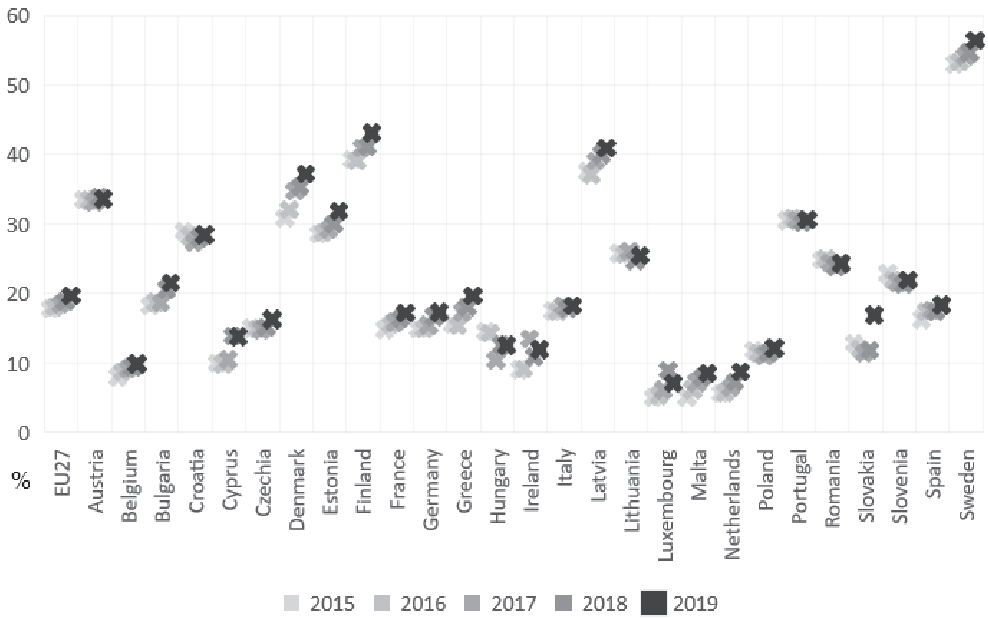


Figure 2. The share of RESs for transport, electricity, heating and cooling in the EU countries from 2015–2019, %. Source: compiled by the authors.

The European Green Deal [35,36] defines the target for participating countries to become a climate neutral continent by 2050. In this regard, the Energy Efficiency Directive [26] and other energy regulations have been finalized to guarantee the reduction of greenhouse gas emissions by at least 55% by 2030. The EU countries must achieve reductions of 1.5% of the final energy consumption every year between 2024 and 2030 (today it is about 0.8%).

At the same time, the reduction in the specific energy consumption slowed down (−1%) globally in 2021 compared to the average value for 2000–2019 (−1.5%) [36]. Figure 3 presents the energy intensity of the EU economies, which is understood as the ratio between the gross domestic energy consumption and GDP, calculated for a calendar year.

The most energy-intensive country in the EU is Bulgaria (360 toe/M€ in 2020). This country's indicator significantly exceeds that of other countries throughout the entire analyzed period, but we should note a rapid decrease in energy intensity by 47% compared to 2000. The lowest energy intensity indicators (compared to the EU average) are in Ireland (39 toe/M€ in 2020), Denmark (54), Malta (64), Luxembourg (67), Italy (90), Germany (92), Austria (92), Sweden (9), the Netherlands (99) and France (103). The leaders in reducing the energy intensity, after Bulgaria, are Romania (−229), Slovakia (−217), Lithuania (−187), Estonia (−186), Poland (−146), the Czech Republic (−143) and Latvia (−107).

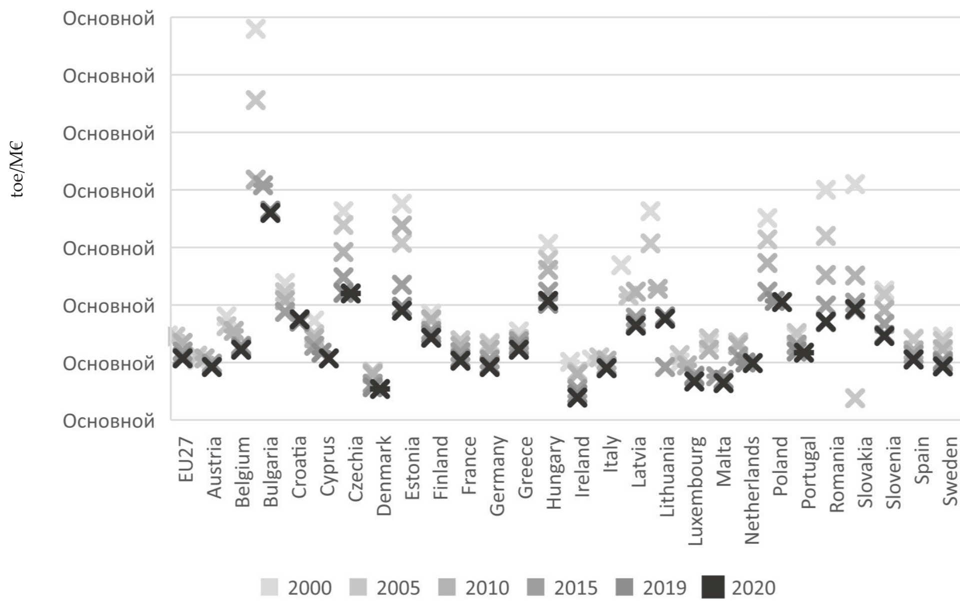


Figure 3. The energy intensity of the EU countries in 2000–2020, toe/M€. Source: compiled by the authors.

For most advanced economies, renewable capacity scaling limits are the difficulty while permitting and extending grid infrastructure. As for developing countries, the lack of affordable financing and sparse infrastructure are the main problems. According to expert estimates, if these problems are solved by 2025, the growth of RES capacities can increase by 25% [37] compared to the baseline forecast, which assumes an increase in electricity production from RESs by 60% by 2050 ("clean zero" scenario).

To achieve environmental sustainability, OECD countries have implemented several policy initiatives to improve the energy efficiency by increasing the share of renewable energy consumption in the energy mix. Great attention is paid to tax incentives to increase investments in energy efficient technologies [37].

3. Materials and Methods

This section will describe the data set and approaches used to assess the impact of tax expenditures.

3.1. Data

The authors assess the relationship between tax incentives and preferences (tax expenditures for the state budget) and the incentive effect on the energy sector and alternative energy sources. The sample of countries for analysis includes some OECD countries and OECD partner countries (Australia, Germany, Greece, Denmark, India, Ireland, Spain, Italy, Latvia, Mexico, the Netherlands, Poland, Russia, Finland, France, Sweden and South Korea). The sample of countries depended on the availability of data. The development of alternative energy is associated with a constant reduction in traditional sources, which means that it is necessary to consider partner countries in energy trade. The authors use annual data for 2018–2020.

The main sources of statistical data were the Global Tax Expenditures Database (GETS), OECD reports, EU Joint Research Center (JRC) publications, EU Bioeconomy Monitoring System (BMS) and analytical studies of consulting companies. The directions of tax reforms were studied in reports published by the governments and ministries of finance of individual countries.

3.2. Methodology

At the first stage, ten OECD countries are ranked in terms of the share of tax expenditures for stimulating the energy sector in total tax expenditures for developing priority sectors of the economy. The authors estimate the level of tax expenditures for the energy efficiency and renewable energy sources in the volume of tax revenues of consolidated budgets.

At the second stage, the authors typify tax expenditures for environmental sustainability.

At the third stage, the share of tax expenditures for increasing renewable energy sources and the energy efficiency in total tax expenditures for environmental sustainability is estimated. The rating of countries is carried out.

At the fourth stage, the authors apply a multivariate average formula to estimate the scale of tax incentives in OECD countries. The idea of using the multivariate average as an integrated indicator for rating territories in terms of tax expenditures is not new and it is covered in the work of Yu.A. Steshenko and A.V. Tikhonova [38], who use this mechanism to estimate tax incentives in Russian regions.

At the fifth stage, a matrix of grouping countries is built depending on the share of tax expenditures for the energy efficiency and renewable energy sources in the volume of tax revenues of consolidated budgets, with the allocation of three groups (low, average, high).

At the sixth stage, the multivariate average reflecting the magnitude of tax expenditures for the energy sector in each country is calculated by the following formula:

$$\bar{p}_i = \frac{1}{k}\sum_{j=1}^{k} \frac{x_i}{\bar{x}_j} \tag{1}$$

x_{ij}—the value of the j-th variable (indicator of tax expenditures) for the i-th object (country);

$\bar{x}_j$—the average value of the j-th variable (indicator of tax expenditures) for all analyzed countries.

We use indicators of tax expenditures for OECD countries from the previous tables (Tables 1–3), namely:

x_1—tax expenditures for stimulating the energy sector (as % of the country's GDP);

x_2—tax expenditures for stimulating the energy sector (as % of tax revenues of the country's consolidated budget);

x_3—tax expenditures for increasing renewable energy sources (as % of the country's GDP);

x_4—tax expenditures for increasing renewable energy sources (as % of tax revenues of the country's consolidated budget);

x_5—tax expenditures for energy efficiency improvements (as % of the country's GDP);

x_6—tax expenditures for energy efficiency improvements (as % of tax revenues of the country's consolidated budget).

The advantage of the multivariate average is the ability to assess a certain general characteristic of various objects (countries, territories, etc.), based on various indicators and using a single methodology for their calculation. In our study, this characteristic was the scale of tax expenditures, and all indicators of tax expenditures were calculated as a percentage of GDP or tax revenues of the budget.

Table 1. Tax expenditures stimulating the energy sector development in selected OECD countries and key OECD partner countries from 2018–2020.

Year	Austria	India	Spain	South Korea	Russia	France	Sweden
% of GDP							
2018	0.04	0.07	0.002	0.01	0.1	0.01	0.005
2019	0.04	0.08	0.002	0.01	0.1	0.01	0.005
2020	0.04	0.09	0.002	0.01	0.13	0.01	0.005
% of tax revenues of the consolidated budget							
2018	0.14	0.59	0.01	0.02	0.52	0.1	0.02
2019	0.13	0.6	0.01	0.02	0.94	0.1	0.01
2020	0.12	0.6	0.01	0.02	1.1	0.1	0.01

Source: compiled by the authors.

Table 2. Tax expenditures aimed at achieving environmental sustainability in selected OECD countries from 2018–2020.

Country	Year	Tax Expenditures Related to Increased Use of Renewable Energy Sources		Tax Expenditures Related to Energy Efficiency Improvements	
		% of GDP	% of Tax Revenues of the Consolidated Budget	% of GDP	% of Tax Revenues of the Consolidated Budget
Germany	2018	0.01	0.05	-	-
	2019	0.01	0.13	-	-
	2020	0.03	0.15	-	-
Denmark	2018	0.25	0.77	-	-
	2019	0.24	0.72	-	-
	2020	0.25	0.7	-	-
Ireland	2018	-	-	0.001	0.01
	2019	-	-	0.001	0.01
	2020	-	-	0.001	0.01
Spain	2018	-	-	0.02	0.1
	2019	-	-	0.02	0.1
	2020	-	-	0.01	0.07
Italy	2018	0.0027	0.01	-	-
	2019	0.003	0.013	-	-
	2020	0.0036	0.016	-	-
Netherlands	2018	0.03	0.12	0.03	0.14
	2019	0.03	0.13	0.03	0.11
	2020	0.04	0.15	0.03	0.1
Mexico	2018	0.012	0.1	-	-
	2019	0.02	0.12	-	-
	2020	0.025	0.14	-	-
Poland	2018	0.01	0.07	-	-
	2019	0.015	0.09	-	-
	2020	0.015	0.1	-	-
South Korea	2018	0.004	0.02	0.01	0.05
	2019	0.004	0.02	0.01	0.08
	2020	0.004	0.02	0.01	0.1
Finland	2018	0.01	0.01	0.33	1.58
	2019	0.01	0.02	0.3	1.46
	2020	0.01	0.02	0.29	1.41
France	2018	0.01	0.02	0.09	0.51
	2019	0.01	0.02	0.05	0.3
	2020	0.01	0.02	0.05	0.3
Sweden	2018	-	-	0.16	0.68
	2019	-	-	0.23	1.04
	2020	-	-	0.25	1.1

Source: compiled by the authors.

Table 3. Ranking of OECD countries by share of tax expenditures related to the promotion of environmental sustainability in 2020.

Country	Tax Expenditures Related to Increased Use of Renewable Energy		Tax Expenditures Related to Energy Efficiency Improvements	
	%	Ranking	%	Ranking
Poland	83.3	1	-	-
Germany	38.1	2	9.5	9
Sweden	33.3	3	33.3	4
Italy	33.3	3	16.7	6
Denmark	30	4	10	8
Finland	28.6	5	42.9	3
Mexico	25	6	-	-
Netherlands	19.4	7	8.3	10
South Korea	17.6	8	52.9	1
France	17.6	8	26.5	5
Latvia	4.3	9	-	-
Ireland	-	-	50	2
Spain	-	-	33.3	4
Russia	-	-	12.5	7

Source: compiled by the authors.

4. Results

Tax expenditures for stimulating the energy sector in terms of traditional energy sources (fossil fuels) include various types of preferences and incentives for taxpayers, namely: tax deductions; tax deferrals; tax exemption; reduction of tax rates; tax incentives, discounts and refunds; zero rating (a regime that implies that the entire value chain of the supply is exempt from taxes).

The study ranked ten OECD countries by the share of tax expenditures for stimulating the energy sector in total tax expenditures for developing priority sectors of the economy (Figure 4).

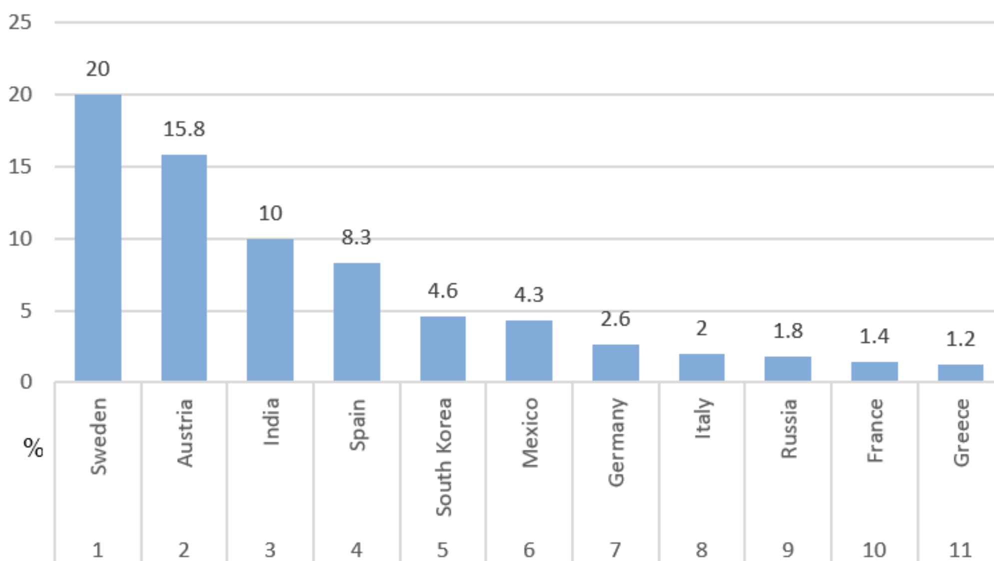


Figure 4. Ranking of OECD countries and OECD key partner countries by the share of tax expenditures for stimulating the energy sector in 2020. Source: compiled by the authors.

As Table 1 shows, in the period from 2018 to 2020, there were no significant changes in the level of tax expenditures to support the energy complex in the countries studied. Most likely, this is a consequence of the economic recession that arose due to the COVID-19 pandemic and it was in the form of a lack of budget funds for these purposes. Of all the countries presented in Table 1, only the Russian Federation is significantly increasing the volume of assistance to energy companies (the volume of tax expenditures increased from 0.52 to 1.1% of budget tax revenues over a three-year period).

Tax expenditures range from 0.002 to 0.04% of GDP (from 0.01 to 0.14% of tax revenues, respectively) in those OECD countries that provide tax support to the energy sector. The leader among the countries is Austria (Table 1), where fossil fuels are the main source of energy: oil ranks first with a share of 37.2% of the gross domestic consumption, followed by gas (22.1%) and coal (8.2%). However, the commitment to add more biofuels to fossil fuels and increased production of district heating from biomass have led to a record high use of renewable energy in Austria. Consequently, renewable energy currently accounts for 29.8% of the gross domestic consumption, with solid biomass being the most important renewable energy source (37%) followed by hydropower (34%). Other renewable energy sources include solar, wind, geothermal, biogas and biofuels, each of which accounts for less than 7% [39].

Tax expenditures for stimulating the energy development in India (a key OECD partner country) are significantly higher than in OECD countries (they amount to about 0.07–0.09% of GDP or 0.6% of tax revenues). Nevertheless, at present, the growth of the fossil fuel consumption in India is also gradually increasing. At the same time, the main energy consumption is coal—43.9%, oil—32.8% and natural gas—7.6%. Hence, there are high values of tax expenditures for companies in this area [40].

Of all the countries presented in Table 1, only the Russian Federation is significantly increasing the volume of assistance to energy companies (the volume of tax expenditures increased from 0.52 to 1.1% of budget tax revenues over a three-year period).

The following data (Table 2) let us draw several important conclusions about the role of tax expenditures for achieving environmental sustainability in OECD countries. The undisputed leader of tax expenditures for increasing renewable energy sources is Denmark (0.25% of GDP and 0.7–0.77% of tax revenues of the budget). Income tax incentives are applied here to support investments in electricity generation from renewable energy sources such as wind, solar, hydro and geothermal. The energy from renewable sources is expected to be a key factor in reducing emissions in developing countries and countries with economies in transition.

The countries with the most developed system of tax incentives for the energy efficiency are Finland and Sweden. Tax expenditures in Finland are about 0.3% of GDP (from 1.41 to 1.58% of tax revenues of the budget). Tax expenditures for the energy efficiency in Sweden are slightly lower than in Finland—0.16–0.25% of GDP (from 0.68 to 1.1% of tax revenues of the budget, respectively), but nevertheless they exceed the average values for OECD countries. Tax expenditures for environmental sustainability in terms of the renewable energy and energy efficiency increased in most countries between 2018 and 2020.

The ranking of countries in terms of the share of tax expenditures for increasing renewable energy sources and improving the energy efficiency in total tax expenditures for environmental sustainability is presented in Table 3. Among the leading countries in terms of "share of tax expenditures for increasing renewable energy sources" are Poland, Germany, Sweden and Italy (the last two countries share 3rd place). According to "share of tax expenditures for improving the energy efficiency", the places were distributed differently: South Korea, Ireland and Finland are in the top three.

As shown in Table 3, there are no figures for tax expenditures for increasing renewable energy sources in the Russian Federation. At the same time, according to "share of tax expenditures for improving the energy efficiency", our country, if included in the rating of OECD countries, will take 7th place (the value of the indicator is 12.5%). This is because a significant share of tax expenditures for environmental sustainability in Russia are tax expenditures for biodiversity conservation.

The grouping of countries by the level of tax expenditures for the energy efficiency and renewable energy sources, by the share in tax revenues of each country's consolidated budget, is presented in Table 4.

Table 4. Grouping of countries by the level of tax expenditures for the energy efficiency and renewable energy sources, by the share in tax revenues of each country's consolidated budget.

Level of tax expenditures for energy efficiency (b)	high		Finland (+/−)		
	average	Sweden (+)	France (c/−)		
	low	Spain (−) Ireland (c)	South Korea (c/+)	Netherlands (+/−)	
	na		Italy (+)	Germany (+) Poland (+) Mexico (+)	Denmark (−)
		na	low	average	high
		Level of tax expenditures for increasing renewable energy (a)			

Symbols: (−)—decrease; (+)—increase, (c)—constant level, (a/b). Source: compiled by the authors.

Sweden, Germany, Poland, Mexico and Italy are countries with a stable tax policy to support the energy efficiency and energy transition using tax incentives. The group with a high level of tax expenditures includes Denmark (in terms of supporting RESs) and Finland (in terms of supporting the energy efficiency).

The scale of tax expenditures indicates that Finland has the highest rating (large scale of tax expenditures as one of the tools for energy development) (the value of the multivariate average is 1.6179) (Table 5). The authors calculated the integrated indicator based on four indicators, because the country's legislation has no tax incentives to support the production and use of fossil fuels. However, there are extremely high (compared to other OECD countries) tax expenditures for energy efficiency improvements.

Table 5. Multivariate average indicator, reflecting the rating of each country in estimating the scale of tax incentives.

Country	Tax Expenditures Stimulating the Energy Sector Development		Tax Expenditures Related to Increased Use of Renewable Energy Sources		Tax Expenditures Related to Energy Efficiency Improvements		Number of Indicators	Integrated Indicator Reflecting Rating (Multivariate Average)
	% of GDP	% of Tax Revenue	% of GDP	% of Tax Revenue	% of GDP	% of Tax Revenue		
Spain	0.002	0.01	-	-	0.01	0.07	4	0.2030
South Korea	0.01	0.02	0.004	0.02	0.01	0.1	6	0.4954
France	0.01	0.1	0.01	0.02	0.05	0.3	6	1.0663
Sweden	0.005	0.01	-	-	0.25	1.1	4	1.3783
Netherlands	-	-	0.04	0.15	0.03	0.1	4	1.4583
Finland	-	-	0.01	0.02	0.29	1.41	4	1.6179
Average value	0.0068	0.0350	0.0160	0.0525	0.1067	0.5133	-	-

Source: compiled by the authors.

The Netherlands is in second place in the ranking (the multivariate average value is 1.4583) due to the highest values of tax expenditures for increasing renewable energy sources among the countries studied. The third place in terms of the scale of tax expenditures is occupied by Sweden (the multivariate average value is 1.3783).

Paradoxically, the bottom positions in the ranking are occupied by countries which, on the one hand, support the continued use of fossil fuels, but, on the other hand, have already begun a gradual transition to renewable energy technologies (for example, South Korea and France). This means that the calculation of the multivariate average for these countries was made based on all six indicators.

Note that not all six indicators are relevant for each country. For some countries, the multivariate average is calculated by only four indicators. At the same time, the higher the country's rating, the more actively it uses such tools as tax expenditures.

5. Discussion

The study shows that tax expenditures in the energy sector reflect tax incentives for companies and they are actively used tools for the energy development among developed countries. At the same time, tax expenditures contribute to the continued transition from fossil fuels to alternative energy sources and energy conservation.

Sweden is the leader in the OECD rating by the share of tax expenditures for the energy sector in total tax expenditures for developing priority sectors of the economy. Sweden's tax spending system in this area is very broad and specific, mainly including exemptions from various taxes or reduced tax rates for different companies. For example, natural gas and liquefied petroleum gas used as fuel in transport are exempt from the energy tax. Additionally, natural gas and liquefied petroleum gas used in transportation are subject to lower carbon tax rates. Any fuel used by companies in the agriculture, forestry and aquaculture sector for heating purposes receives a 24% reduction in the carbon tax. Industries outside the European Greenhouse Gas Emissions Trading Scheme (EU ETS) are granted a reduced carbon tax rate on all fossil fuels used for heating [41].

If we include data for the Russian Federation in the rating, then it will be in 9th place, even though it has the highest values of tax expenditures as a percentage of GDP and tax revenues among the analyzed countries. This is a consequence of the fact that the largest share of tax expenditures in Russia falls on the extractive sector of the economy (31.4%), the transport industry (15%) and science-intensive activities (12.3%), which are also a priority. That is, accounting for tax preferences provided is kept separately (which is not always typical for other countries) for mining companies and energy companies.

The amount of tax expenditures to support the energy industry in the Russian Federation is several times higher than the amount of tax expenditures in any of the analyzed countries. An example of tax incentives is a zero-property tax rate for gas pipeline facilities, gas production facilities, helium production and storage facilities. Organizations are also exempt from taxation in respect of newly commissioned facilities with high energy efficiency, in accordance with the list of such facilities established by the Government of the Russian Federation. In addition, taxpayers have the right to apply a special coefficient to the basic depreciation rate (but not higher than 2) in relation to depreciable fixed assets related to such objects when calculating the corporate income tax [42].

There are two types of tax expenditures for achieving environmental sustainability, according to their purpose—increasing the use of renewable energy sources and improving the energy efficiency. Moreover, in some of the considered countries there are both types of tax expenditures (the Netherlands, South Korea, Finland, France), and, in some, only one. For example, the Netherlands provides tax support for environmentally friendly investments through a combination of targeted income tax incentives and high carbon prices, including two investment incentives and a special accelerated depreciation schedule [43].

Ranking countries by estimating the share of tax expenditures for increasing renewable energy sources and improving the energy efficiency in total tax expenditures for environmental sustainability identified the leading countries: Poland, Germany, Sweden and Italy (for the first indicator) and South Korea, Ireland and Finland (for the first indicator). The results obtained can be explained by two reasons. The bottom-ranked countries, while providing tax incentives for environmental sustainability, do not focus only on the energy sector, using various types of tax expenditures, for example, biodiversity conservation, reduction of greenhouse gas emissions, support for climate change adaptation, etc. The leading countries have a wide range of tax benefits and preferences. For example, Polish tax legislation provides for a reduction in the property tax for wind farms. In addition, tax incentives to encourage renewable energy sources in Poland include exemption from the agricultural tax and exemption from the excise tax on electricity produced using renewable energy sources [44]. One component of tax expenditures for the energy efficiency in South Korea is a tax credit for investments in energy-saving facilities. The tax credit is provided for the purchase of appropriate new facilities and equipment to achieve energy savings and it is 1% for large companies, 3% for medium-sized companies and 7% for small and medium-sized enterprises.

The countries with the most developed system of tax incentives for the energy efficiency growth are Finland and Sweden. The system of tax incentives in Finland is quite wide. Thus, farmers are entitled to a tax refund, which is paid for electricity, light and heavy fuel oil and biofuels. Biogas is completely excluded from taxation when calculating the energy tax. At the same time, tax expenditures on peat are gradually reduced (since peat is a fossil fuel, the use of which does increase the energy efficiency for energy production) [45].

Currently, taxes form the backbone of Sweden's energy efficiency policy, as they are often the main driver for other policy instruments. However, taxes can have a detrimental effect on the competitiveness of Swedish industry. Therefore, there are several tax breaks for industrial enterprises, especially for those ones which take part in the European Emissions Trading Scheme. These enterprises only pay the energy tax, not the carbon tax, as the price of the carbon credits is considered to have the same effect as the tax. Biogenic fuels are exempt from both carbon and energy taxes. Thus, in practice, the carbon and energy taxes in Sweden perform the same functions—stimulating energy saving and switching to another type of fuel [46].

The scale of tax expenditures indicates that Finland has the highest rating, in second place is the Netherlands and in third place is Sweden. There are no tax incentives for renewable energy sources, but tax expenditures for the energy efficiency are almost as high as in Finland.

Paradoxically, the bottom positions in the ranking are occupied by countries that, on the one hand, support the continued use of fossil fuels, but, on the other hand, have already begun a gradual transition to renewable energy technologies (for example, South Korea and France). This means that the calculation of the multivariate average was based on all six indicators.

Like any exception to the general rule, tax breaks and privileges create economic distortions and cause distribution problems, which may be the subject of further research. In the context of the specifics of the energy opportunities and tax policy of each country, the finding of data for international comparisons, the calculation of the efficiency of tax expenditures and their convertibility into direct forms of budget financing are laborious, but promising.

Another promising area of research was proposed by a group of Italian scientists who are improving a new indicator that links anthropogenic impact on the environment with socio-economic goals—the Thermodynamic Human Development Index (THDI) [47]. As we noted, the quality of energy is an essential basic condition for sustainable development, the consistent principles of which are ecological balance, economic growth and social responsibility. The authors consider the use of rice straw, reviewed in [48], based on the THDI to reduce fossil fuels and greenhouse gas emissions. It seems to us that tax preferences for biofuels from renewable organic biomass can intensify the process of spreading this approach, especially for agricultural industries and territories. This can be a vector for further research and development of state policy to ensure sustainable development of agricultural territories.

If we keep tax incentives and emission targets, we can stimulate the transition to new hybrid forms of energy generation and optimization of electricity costs, and we can change consumer preferences. At the same time, in the short term, the dynamics of processes will be drastically influenced by factors caused by the global energy crisis, the features of which are characterized by the involvement of the entire set of energy sources (oil, natural gas, coal, biofuel, hydrogen, nuclear fuel).

6. Conclusions

The comparative analysis of tax expenditures for fossil fuels in OECD countries and key OECD partner countries has led to some important conclusions.

Based on the available statistics, many developed countries have now taken a course towards the transition to alternative energy sources, which involves moving away from investing in fossil fuels and refusing state (including tax) support for traditional energy. The conclusion is supported by data on the total absence of tax expenditures for stimulating fossil fuels in many countries. Only a few OECD countries have tax expenditures that are so significant that they can be identified as part of the GDP or part of tax revenues of the budget.

In those OECD countries that provide tax support to the energy sector, tax expenditures represent a small share. However, the commitment to add more biofuels to fossil fuels and increased production of district heating from biomass have led to a record high use of renewable energy in Austria.

Energy incentive expenditures in India (a key OECD partner country) are significantly higher than in OECD countries. India is undergoing an energy transition with a steady decline in the share of fossil fuels in its energy portfolio and this country is moving towards a reallocation of energy sources in favor of wind, solar and biomass, as well as greater use of electricity and hydrogen. The amount of tax expenditures to support the energy industry in the Russian Federation is many times higher than the amount of tax expenditures in any of the analyzed countries. The variety of tax preferences that exist in the energy sector is associated with increased attention to the energy industry as a priority for the country.

Between 2018 and 2020, there were no significant changes in the level of tax expenditures to support the energy complex in the countries studied. Most likely, this is a consequence of the economic recession that arose due to the COVID-19 pandemic, and it was in the form of a lack of budget funds for these purposes.

Author Contributions: Conceptualization, Y.T. and S.F.; methodology, Y.T.; validation, S.D., M.K. and A.K.; formal analysis, S.F.; investigation, S.D. and M.K.; data curation, S.D. and M.K.; writing—original draft preparation, Y.T., S.D. and M.K.; writing—review and editing, S.D. and M.K.; visualization, S.D. and M.K.; supervision, A.K.; project administration, S.F. All authors have read and agreed to the published version of the manuscript.

Funding: The manuscript was based on research carried out at the expense of budgetary funds under the state order of the Financial University.

Data Availability Statement: The data were obtained from free online databases and the information is provided in the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Tax Expenditures: Current Issues and Five-Year Budget Projections for Fiscal Years 1984–1988. The Congress of the United States. Congressional Budget Office; 25 October 1983. Available online: https://www.cbo.gov/sites/default/files/98th-congress-1983-1984/reports/doc26a.pdf (accessed on 15 January 2023).
2. Surrey, S.S.; McDaniel, P.R. The Tax Expenditure Concept: Current Developments and Emerging Issues. *Boston Coll. Law Rev.* **1979**, *20*, 225. Available online: https://www.semanticscholar.org/paper/The-Tax-Expenditure-Concept%3A-Current-Developments-Surrey-McDaniel/528ac53eaac085edb9761c0475569b4290d6ffab (accessed on 9 January 2023).
3. Thuronyi, V. Tax Expenditures: A Reassessment. *Duke Law J.* **1988**, *37*, 1182. Available online: https://scholarship.law.duke.edu/cgi/viewcontent.cgi?article=3057&context=dlj (accessed on 10 January 2023). [CrossRef]
4. Tyson, J. Reforming Tax Expenditures in Italy: What, Why, and How? *IMF Work.* **2014**, *14*, 4. Available online: http://reforming.it/doc/635/taxexpenditureinitaly.pdf (accessed on 15 January 2023). [CrossRef]
5. Best Practice Guidelines—Off Budget and Tax Expenditures. *OECD J. Budg.* **2004**, *4*, 121–142.
6. Sokolovska, A.; Zatonatska, T. Debatable aspects of the concept of tax expenditures. *Ekonomika* **2022**, *101*, 109–124. [CrossRef]

7. Grisolia, G.; Fino, D.; Lusia, U. Biomethanation of rice straw: A Sustainable perspective for the valorisation of a field residue in the energy sector. *Sustainability* **2022**, *14*, 5679. [CrossRef]
8. Demidova, S.; Balog, M.; Chircova, T.; Kulachinskaya, A.; Zueva, S.; Akhmetova, I.; Ilyashenko, S. Development of methodology and assessment of ecological safety of the EAEU and CIS regions in the context of sustainable development. *Economies* **2021**, *9*, 100. [CrossRef]
9. Villela, L.A. *Tax Expenditures Budgets: Concepts and Challenges for Implementation*; IDB Working Paper Series: 131. HJ4642.V55; Inter-American Development Bank: Washington, DC, USA, 2021.
10. Bertrand, L.; Caldeira, E.; Quatrebarbes, C.; Bouterige, Y. *Tax Expenditure Assessment: From Principles to Practice Methodological Guide*; under the supervision of Anne-Marie Geourjon; Fondation pour les Études et Recherches sur le Développement International (Ferdi): Clermont-Ferrand, France, 2018; ISBN 978-2-9550779-5-5.
11. Barrios, S.; Figari, F.; Gandullia, L.; Riscado, S. The Fiscal and Equity Impact of Tax Expenditures in the EU. JRC Working Papers on Taxation and Structural Reforms. 2016. Available online: https://joint-research-centre.ec.europa.eu/system/files/2016-12/jrc104176.pdf (accessed on 10 January 2023).
12. Kakaulina, M.O.; Gorlov, D.R. Assessment of the impact of tax incentives on investment activity in special economic zones of the Russian Federation. *J. Appl. Econ. Res.* **2021**, *21*, 282–324. [CrossRef]
13. Mosquera, I.; Lesage, D.; Lips, W. *Taxation, International Cooperation and the 2030 Sustainable Development Agenda*; Springer International Publishing: Cham, Switzerland, 2021; pp. 173–193. ISBN 978-3-030-64857-2. [CrossRef]
14. Haldenwang, C.; Redonda, A. Tax Expenditures: The Hidden Side of Government Spending, VoxEU.org—CEPR's Policy Portal. 2021. Available online: https://cepr.org/voxeu/columns/tax-expenditures-hidden-side-government-spending (accessed on 28 January 2023).
15. Redonda, A.; Sarralde, S.; Hallerberg, M.; Johnson, L.; Melamud, A.; Rozemberg, R.; Schwab, J.; Haldenwang, C. Tax expenditure and the treatment of tax incentives for investment. Economics: The Open-Access. *Open-Assess. E-J.* **2019**, *13*, 1–11. [CrossRef]
16. Beer, S.; Benedek, D.; Erard, B.; Loeprick, J. *How to Evaluate Tax Expenditures*; How to Note (International Monetary Fund); International Monetary Fund: Washington, DC, USA, 2022. Available online: https://www.imf.org/en/Publications/Fiscal-Affairs-Department-How-To-Notes/Issues/2022/11/How-to-Evaluate-Tax-Expenditures-525166 (accessed on 10 January 2023).
17. Fedorova, E.; Lapshina, N.; Borodin, A.; Lazarev, M. Impact of information in press releases on the financial performance of Russian companies. *Ekon. Polit.* **2021**, *3*, 138–157. [CrossRef]
18. *Inventory of Estimated Budgetary Support and Tax Expenditures for Fossil Fuels*; OECD Publishing: Paris, France, 2011. Available online: https://www.oecd.org/fossil-fuels/48805150.pdf (accessed on 9 January 2023).
19. Zehir, C.; Zehir, M.; Borodin, A.; Mamedov, Z.F.; Qurbanov, S. Tailored Blockchain Applications for the Natural Gas Industry: The Case Study of SOCAR. *Energies* **2022**, *15*, 6010. [CrossRef]
20. Borodin, A.; Zaitsev, V.; Mamedov, Z.F.; Panaedova, G.; Kulikov, A. Mechanisms for Tax Regulation of CO_2-Equivalent Emissions. *Energies* **2022**, *15*, 7111. [CrossRef]
21. Crippa, M.; Guizzardi, D.; Banja, M.; Solazzo, E.; Muntean, M.; Schaaf, E.; Pagani, F.; Monforti-Ferrario, F.; Olivier, J.; Quadrelli, R.; et al. *CO_2 Emissions of all World Countries*; EUR 31182 EN; Publications Office of the European Union: Luxembourg, 2022. [CrossRef]
22. Benzarti, Y.; Carloni, D. Who really benefits from consumption tax cuts? Evidence from a large VAT reform in France. *Am. Econ. J. Econ. Policy* **2019**, *11*, 38–63. [CrossRef]
23. Kronfol, H.; Steenbergen, V. *Evaluating the Costs and Benefits of Corporate Tax Incentives. Methodological Approaches and Policy Considerations*; World Bank: Washington, DC, USA, 2020. Available online: http://documents1.worldbank.org/curated/en/180341583476704729/pdf/Evaluating-the-Costs-and-Benefits-of-Corporate-Tax-Incentives-Methodological-Approaches-and-Policy-Considerations.pdf (accessed on 29 December 2022).
24. Shedding Light on Worldwide Tax Expenditures. GTED Flagship Report. 2021. Available online: http://www.GTED.net (accessed on 9 January 2023).
25. Ziyadin, S.; Streltsova, E.; Borodin, A.I.; Kiseleva, N.; Yakovenko, I.; Baimukhanbetova, E. Assessment of Investment Attractiveness of Projects on the Basis of Environmental Factors. *Sustainability* **2019**, *11*, 2544. [CrossRef]
26. *Energy Efficiency Trends and Policies in Austria*; Austrian Energy Agency: Vienna, Austria, 2021. Available online: https://www.odyssee-mure.eu/publications/national-reports/energy-efficiency-austria.pdf (accessed on 15 January 2023).
27. Renewable Energy Sources as a New Development Step for Oil and Gas Companies. 2019. Available online: www.assets.kpmg/content/dam/kpmg/ru/pdf/2019/12/ru-ru-renewable-energy-sources-for-oil-and-gas.pdf (accessed on 20 December 2022).
28. Makarova, A.A.; Mitrova, T.A.; Kulagina, V.A. (Eds.) *Forecast for the Development of Energy in the World and Russia 2019*; M.: ERI RAS—Moscow School of Management SKOLKOVO: Moscow, Russia, 2019; 210p, ISBN 978-5-91438-029-5.
29. Gole, I.; Dumitrache, V.-M.; Bălu, F.O. Assessment of a decade of greenhouse gas emissions. In *Proceedings of the International Conference on Economics and Social Sciences, Bucharest, Romania, 2020*; Springer: Berlin/Heidelberg, Germany, 2020; pp. 332–340. [CrossRef]
30. Kotlikoff, L.; Polbin, A.; Zubarev, A. Will Paris accord accelerate climate change? *Econ. Policy* **2021**, *16*, 8–37.
31. Valko, D. Impact of renewable energy and tax regulation on reducing greenhouse gas emissions in OECD Countries: CS-ARDL Approach. *Econ. Policy* **2021**, *16*, 40–61. (In Russian) [CrossRef]

32. Stepanov, I.A. Energy taxes and their contribution to greenhouse gas emissions reduction. *HSE Econ. J.* **2022**, *23*, 290–313. [CrossRef]
33. Golovanova, A.E.; Polaeva, G.B.; Nurmatova, E.A. European Union energy policy in renewable energy. *Innov. Investig.* **2018**, *11*, 52–55. (In Russian)
34. Kilsedar, C.; Patani, S.; Olsson, M.; Girardi, J.; Mubareka, S. *EU Bioeconomy Monitoring System Dashboards: Extended with Trade-Related Indicators*; Publications Office of the European Union: Luxembourg, 2022; ISBN 978-92-76-61625-2. [CrossRef]
35. A European Green Deal. Available online: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en#actions (accessed on 12 November 2022).
36. Statistical Pocketbook 2022. Available online: https://op.europa.eu/en/publication-detail/-/publication/7d9ae428-3ae8-11ed-9c68-01aa75ed71a1/language-en/format-PDF/source-279588540 (accessed on 15 January 2023).
37. *OECD Investment Tax Incentives Database—2022 Update: Tax Incentives for Sustainable Development (Brochure)*; OECD Publishing: Paris, France, 2022. Available online: www.oecd.org/investment/investment-policy/oecd-investment-tax-incentives-database-2022-update-brochure.pdf (accessed on 22 January 2023).
38. Steshenko, J.A.; Tikhonova, A.V. An integral approach to evaluating the effectiveness of tax incentives. *J. Tax Reform* **2018**, *4*, 157–173. [CrossRef]
39. Mamedov, Z.F.; Qurbanov, S.H.; Streltsova, E.; Borodin, A.; Yakovenko, I.; Aliev, A. Mathematical models for assessing the investment attractiveness of oil companies. *SOCAR Proc.* **2021**, *4*, 102–114. [CrossRef]
40. Country Profile—Sweden. European Environment Agency (Energy Support 2005–2012). Available online: https://webcache.googleusercontent.com/search?q=cache:GLvkJyidDjkJ:https://www.eea.europa.eu/publications/energy-support-measures/sweden-country-profile&cd=10&hl=ru&ct=clnk&gl=ru&client=safari (accessed on 15 January 2023).
41. Bashir, M.F.; Benjiang, M.A.; Bashir, M.A.; Radulescu, M.; Shahza, U. Investigating the role of environmental taxes and regulations for renewable energy consumption: Evidence from developed economies. *Econ. Res.-Ekon. Istraživanja* **2022**, *35*, 1262–1284. [CrossRef]
42. Ministry of Finance of the Russian Federation. The Main Directions of the Bbudget, Tax and Customs Tariff Policy for 2019 and the Planning Period of 2020 and 2021. Annex 1—Tax Expenditures of the Russian Federation 2015–2021. (In Russisan). Available online: https://minfin.gov.ru/ru/perfomance/budget/policy/osnov?id_65=124752-osnovnye_napravleniya_byudzhetnoi_nalogovoi_i_tamozhenno-tarifnoi_politiki_na_2019_god_i_na_planovyi_period_2020_i_2021_godov (accessed on 10 January 2023).
43. *Report of the Working Group on Energy Taxation Reform: A Proposal for Implementing the Intentions and Goals of the Government Program and for Further Development of Energy Taxation*; VN/11347/2019; Publications of the Ministry of Finance: Helsinki, Finland, 2021; ISBN 978-952-367-508-7. Available online: http://urn.fi/URN:ISBN:978-952-367-508-7 (accessed on 10 January 2023).
44. South Korea. Survey of Global Investment and Innovation Incentive. 2020. Available online: https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Tax/dttl-tax-survey-of-global-investment-and-innovation-incentives-southkorea-2020.pdf (accessed on 10 February 2023).
45. Holmberg, R. How Are the Swedish Taxes on Energy and Carbon Dioxide Related to Energy Efficiency? Odyssee-Mure Project. 2020. Available online: https://www.odyssee-mure.eu/publications/policy-brief/swedish-taxes-energy-carbon.pdf (accessed on 10 January 2023).
46. Ptak, M. Incentives to Promote the Development of Renewable Energy in Poland. Economic and Environmental Studies (E&ES). *Econ. Environ. Stud.* **2014**, *14*, 427–439. Available online: https://www.econstor.eu/bitstream/10419/178869/1/ees_14_4_05.pdf (accessed on 14 January 2023).
47. Lusia, U.; Fino, D.; Grisolia, G. A thermo-economic indicator for the sustainable development with social considerations: A thermo-economy for sustainable society. *Environ. Dev. Sustain.* **2021**, *24*, 2022–2036. [CrossRef]
48. Bressan, M.; Campagnoli, E.; Ferro, C.G.; Giaretto, V. Rice straw: A waste with a remarkable green energy potential. *Energies* **2022**, *15*, 1355. [CrossRef]

energies

Article

EU: The Effect of Energy Factors on Economic Growth

Ayaz Aliev [1,*], Madina Magomadova [2], Anna Budkina [3], Mustafa Harputlu [4] and Alagez Yusifova [3]

1 Department of Financial Sustainable Development, Plekhanov Russian University of Economics, 117997 Moscow, Russia
2 Department of Finance, Credit and Antitrust Regulation, Kadyrov Chechen State University, 364024 Grozny, Russia
3 Department of World Finance, Financial University under the Government of the Russian Federation, 125167 Moscow, Russia
4 Governor of Antakya, Antakya 31000, Turkey
* Correspondence: aliev.aao@rea.ru

Abstract: In this article, we investigate the effect of different energy variables on economic growth of several oil-importing EU member states. Three periods from 2000 to 2020 were investigated. Three different types of regression models were constructed via the gretl software. Namely, the OLS, FE, and SE approaches to panel data analysis were investigated. The FE approach was chosen as the final one. The results suggest the importance of the consumption of both oil and renewable energy on economic growth. Crises of certain periods also had a noteworthy effect as well.

Keywords: European Union; oil; renewable energy; coal; economic growth; gross domestic product; ordinary least squares; fixed effect; selection effect; econometrics; gretl software

Citation: Aliev, A.; Magomadova, M.; Budkina, A.; Harputlu, M.; Yusifova, A. EU: The Effect of Energy Factors on Economic Growth. *Energies* **2023**, *16*, 2908. https://doi.org/10.3390/en16062908

Academic Editor: Luigi Aldieri

Received: 9 February 2023
Revised: 13 March 2023
Accepted: 18 March 2023
Published: 22 March 2023

1. Introduction

The topic of oil importation to EU member states has always been a hot topic. And in light of recent events and sanctions on Russia, more and more attention is being paid to the effect that changes in the levels of energy consumption may have on the economy.

In this work, we aim to investigate the potential effect that different energy variables may have on the economic growth of several EU members states that are commonly identified as oil importers. Some of the variables chosen by us were influenced by past literature [1–9], which will be discussed in the next section. The main variable is GDP (in current USD). The explanatory variables are: oil price per barrel (USD), oil consumption, coal consumption, renewable energy consumption and, where appropriate, time dummies for significant shifts in GDP. All consumption variables are measured in exajoules. The chosen countries have been member states since 2000, and have not left the EU during the period from 2000 to 2020. The list of countries is as follows: Germany, France, Austria, Belgium, Romania, Spain, Portugal, Finland, Netherlands, and Sweden.

Based on obtained data for the period from 2000 to 2020, we created a panel data set. For this data set, we investigated the application of OLS, FE, and SE approaches [10–17] to regression. The results for all periods will be shown in a later section. Periods were chosen for the analysis: 2006–2013, 2014–2020, and 2006–2020. Models were constructed for all time periods. Further tests were also conducted for the final chosen model type.

Next, the main theoretical approaches taken will be discussed. This part will cover the general forms of econometric models being reviewed.

The analyzed articles allow us to find out the contribution of production to sustainable growth and development. For example, research [18] has identified the place of responsible production and consumption in many goals of sustainable development and growth. The study [19] allowed us to clarify the relationship between existing estimates and the need for transformations in panel data models in order to minimize errors. The AMT model presented in study [20] provides significant efficiency for sustainable and lean production, which is a practical help in making decisions on the choice of sustainable growth models.

The development of economic and mathematical tools for assessing the level of investment attractiveness on the example of oil companies is an important component, because the oil industry is a driver of the economic development of any country. The mathematical methods presented in article [21] make it possible to identify metrics and variables that characterize sustainable development trends on the example of oil companies and take them into account in further analysis.

After this, models for different time periods will be constructed. The most important information on chosen data and variables will also be discussed. Based on the tests conducted automatically by the gretl software, we will explain our final choice for the modeling approach.

As we get closer to the end, we turn to the final version of the model for our research. Yet again, all three periods will be covered. The results of the regression, as well as their interpretation, will be reviewed in this part.

Finally, we will turn to the conclusion for this research. Our findings for different periods will be summarized once again. Based on them, we will also mention the potential ways that information obtained in this research can be used in economic, social, and political scenarios.

In each of the studies, the authors focused on a specific aspect of the problem. For example, in study [10], the authors identified CO_2 as a central element of economic value. The study [11] focused on the volume of electricity generation. The study [12] is devoted to the impact of the life cycle on sustainable development in the field of clean and affordable energy.

Thus, a distinctive feature of this study is that previous studies have identified various indicators that affect the sustainable development of the analyzed countries. Our study reaches the results, clarifies the previously identified observations, and, on the basis of research methods, allows us to more accurately calculate the model that illustrates the impact of our results on economic growth.

Hypothesis 1. *Countries of EU must pay more attention to the area of renewable energy and the way it can be implemented in order to enforce the GDP growth in these countries*.

2. Materials and Methods

As our data covers dynamics for different variables for different countries. Over a period of time, we can confidently say that we are dealing with Panel Data. Therefore, the choice of models must also be appropriate. We limited ourselves to three main types, mainly: the Pooling (or Ordinary) regression (or Ordinary Regression) approach, the Fixed Effects (or "within") approach and the Random Effects approach. Their theoretical forms can be seen below:

Ordinary Linear Regression (OR) or Pooling regression:

$$y_{i,t} = \propto + \beta^T \cdot x_{i,t} + u_{i,t} \quad (1)$$

$$u_{i,t} \sim iif\left(0; \sigma^2\right)$$

(independent and identically distributed), where $\propto$—coefficient vector (the same for all objects); $\beta^T = (\beta_1; \beta_2; \ldots; \beta_k)$—the same (for all objects).

Fixed effects model (FE) or "within":

$$y_{i,t} = \propto_i + \beta^T \cdot x_{i,t} + u_{i,t} \quad (2)$$

$$u_{i,t} \sim iif\left(0; \sigma^2\right)$$

where $\propto_i$ is the coefficient vector with individual effect for each object, interpreted as a nonrandom constant; $\beta^T = (\beta_1; \beta_2; \ldots; \beta_k)$—the same (for all objects).

Random effect model (RE):

$$y_{i,t} = \propto + m_i + \beta^T \cdot x_{i,t} + v_{i,t} \quad (3)$$

$$v_{i,t} \sim iif\left(0;\sigma^2\right); m_i \sim iif\left(0;\sigma^2\right); E(v_{i,t} \cdot m_i) = 0$$

where m_i is an individual effect for each object, interpreted as a random variable that maintains a constant value for all $t, \alpha, \beta; \beta^T = (\beta_1; \beta_2; \ldots; \beta_k)$—the same (for all objects).

2.1. Building Models, Modelling, Testing Models

The article attempts to find out how much social, environmental, and human-centric indicators [22,23] affect the sustainability of economic development of the economy. How universal the GDP indicator is and whether its use is justified in making economic decisions was one of our considerations. Does it accurately reflect people's well-being? Long-term policies based on the GDP criterion are irrational to measure a country's overall progress. To assess a country's progress, the use of a GDP indicator is not sufficient. After extensive review, the authors found that GDP was intentionally designed to measure only economic activity, which cannot be equated with social or human well-being [24].

The analyzed studies, in particular [25], assess how renewable energy sources interact with international trade and environmental quality in the analyzed countries from 2001 to 2018 years. The results show that renewable energy is strongly and positively linked to international trade. In addition, the results show that the consumption of renewable energy has a positive effect on the quality of the environment. In addition, the results provide a theoretical framework for the formulation of clean and sustainable development policies to understand the role of renewable energy in stimulating international trade, which maintains a balance between eco-environmental sustainability at the macro and micro levels.

The data for energy variables was taken from BP's Statistical Review of World Energy 2021 [26]—being the latest one available. The data for GDP was taken from the World Bank and are shown in Figure 1.

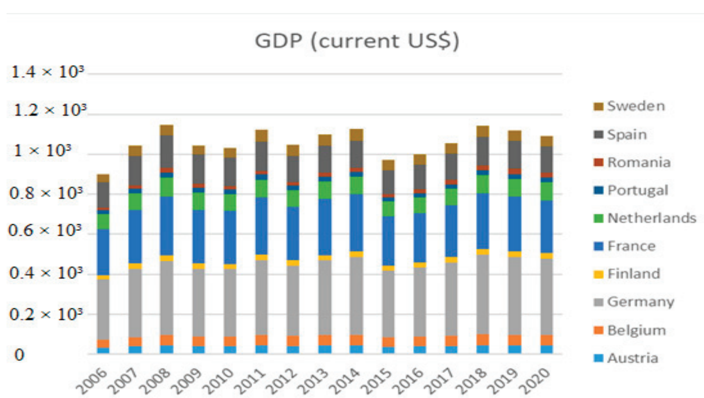


Figure 1. Data for GDP.

Below, the dynamics for GDP can be seen: In general, we observe similar dynamics for the reviewed member states. Germany seems to be the biggest one in terms of consumption, with Spain and France following behind it. Noteworthy changes can be associated with economic crises, such as the 2008 recession, or with oil-related shocks. We also see an increase in terms of the usage of renewable energy. However, it seems that coal is being gradually phased out.

As stated previously, three periods were chosen: 2006–2013, 2014–2020, and 2006–2020.

Our dependent variable is GDP, as it is the most common measure of economic growth. Our exogenous variables are:

Crude oil price per barrel.
Crude oil consumption (exajouls).
Coal consumption (exajouls).
Renewable energy consumption (exajouls).
Time dummy variable.

The first two were chosen to show the impact of oil consumption on economic growth. Coal consumption was added to show the effect of another type of fossil fuel. Renewable energy consumption was investigated, as it is very much the alternative to oil. Time dummies were added to account for crises and other major shifts. Initially, we also considered the inclusion of data on nuclear energy and natural gas consumption. However, the data on the former was missing for several countries, while the latter had troubling levels of correlation with other explanatory variables.

The Pooled regression model, Pooled weighted regression model, Fixed Effects, and Random Effects models were built for early 2000s, and they were compared with each other for accuracy and adequacy. The decision was made in favor of Fixed Effects model.

The main conclusions derived from this model are the following: it is important to mention that there was a multi-caliber in oil consumption between models of 2000–2008 and 2006–2020. This was due to the fact that the price of oil had rebounded strongly since 2005–2006, which did not have a negative impact on GDP. We believe that this situation caused multicollinearity in our model—this was a characteristic feature of the period 2000–2008, since, in the subsequent period 2006–2020, there was no such effect in this indicator.

Thus, start with testing the Pooled regression model [27] for EU countries for the period 2006–2013 period:

Pooled regression model was built, and some important tests were made (Figure 2):

```
Model 1: Pooled OLS, using 80 observations
Included 10 cross-sectional units
Time-series length = 8
Dependent variable: GDPblnUSD

                      coefficient  std. error  t-ratio   p-value
  -------------------------------------------------------------
  const                -486.802     166.665     -2.921   0.0046    ***
  CrudeoilpriceUSD~       4.15776     1.79594    2.315   0.0233    **
  Oilexajoules          610.845      36.8939    16.56    9.26e-027 ***
  Coalexajoules         138.097      72.9894     1.892   0.0623    *
  Renewablesexajou~     148.804     254.742      0.5841  0.5609

Mean dependent var   1054.277   S.D. dependent var   1104.923
Sum squared resid     6261397   S.E. of regression   288.9382
R-squared            0.935080   Adjusted R-squared   0.931617
F(4, 75)             270.0658   P-value(F)           1.05e-43
Log-likelihood      -564.2306   Akaike criterion     1138.461
Schwarz criterion    1150.371   Hannan-Quinn         1143.236
rho                  0.857739   Durbin-Watson        0.202333

Excluding the constant, p-value was highest for variable 7 (Renewablesexajoules)

White's test for heteroskedasticity -
  Null hypothesis: heteroskedasticity not present
  Test statistic: LM = 53.7158
  with p-value = P(Chi-square(14) > 53.7158) = 1.43654e-06
```

Figure 2. Pooled regression model.

We see that R^2 = 0.9316, which means that 93.16% of changes in the GDP level were explained by the changes in exogenous variables [28] (Crude oil price, Oil, Coal, and Renewables) within the linear regression model.

F_{test} shows us whether R^2 is random. We compared the value of the statistic with the critical value of the corresponding Fisher distribution at a significance level of 1% (Figure 3):

```
F(4, 75)
 right-tail probability = 0.01
 complementary probability = 0.99

 Critical value = 3.58011
```

Figure 3. Compare the value of the statistic with the critical value of the corresponding Fisher distribution at a significance level of 1%.

$F(4,75) = 270.07 > F_{crit} = 3.58$, which means that R^2 was not formed under the influence of random variables, and the quality of the specification model was high.

Now then tested our model for heteroscedasticity (Figure 4).

```
White's test for heteroskedasticity
OLS, using 80 observations
Dependent variable: uhat^2

                        coefficient     std. error   t-ratio  p-value
  ---------------------------------------------------------------------
  const                 378945          302395        1.253   0.2146
  CrudeoilpriceUSD~      -7715.17         7117.66    -1.084   0.2824
  Oilexajoules          -16924.7         71674.1     -0.2361  0.8141
  Coalexajoules         196735          150777        1.305   0.1966
  Renewablesexajou~         -1.11926e+06 659611      -1.697   0.0945  *
  sq_Crudeoilprice~         38.7508          40.2246   0.9634  0.3389
  X2_X3                    605.921          683.761    0.8862  0.3788
  X2_X4                  -2882.57          1425.48    -2.022   0.0473  **
  X2_X5                  10815.6           6018.80     1.797   0.0770  *
  sq_Oilexajoules         5607.01         11312.5      0.4956  0.6218
  X3_X4                 -18090.8          48694.7     -0.3715  0.7115
  X3_X5                 242710          152074         1.596   0.1153
  sq_Coalexajoules      -14650.6          48517.4     -0.3020  0.7636
  X4_X5                  61925.2        159168         0.3891  0.6985
  sq_Renewablesexa~    -838470          461840        -1.815   0.0741  *

  Unadjusted R-squared = 0.671448

Test statistic: TR^2 = 53.715837,
with p-value = P(Chi-square(14) > 53.715837) = 0.000001
```

Figure 4. Testing the model for heteroscedasticity.

There was heteroscedasticity in the model. The most significant variable was Renewables. We built a weighted least squares model to remove heteroscedasticity.

The Pooled weighted regression model then looked as it does in Figure 5.

```
Model 5: WLS, using 80 observations
Dependent variable: GDPblnUSD
Variable used as weight: Renewablesexajoules

                      coefficient  std. error  t-ratio   p-value
  ------------------------------------------------------------
  const               -906.748     222.029     -4.084   0.0001     ***
  Oilexajoules         634.792      45.7803    13.87    2.17e-022 ***
  Coalexajoules        228.433      58.6854     3.892   0.0002     ***
  Renewablesexajou~   -214.160     209.663     -1.021   0.3103
  CrudeoilpriceUSD~      8.62512     2.23655    3.856   0.0002     ***

Statistics based on the weighted data:

Sum squared resid     1716556   S.E. of regression   151.2859
R-squared            0.947549   Adjusted R-squared   0.944752
F(4, 75)             338.7297   P-value(F)           3.58e-47
Log-likelihood      -512.4672   Akaike criterion     1034.934
Schwarz criterion    1046.845   Hannan-Quinn         1039.710

Statistics based on the original data:

Mean dependent var   1054.277   S.D. dependent var   1104.923
Sum squared resid     6854681   S.E. of regression   302.3173

Excluding the constant, p-value was highest for variable 7 (Renewablesexajoules)
```

Figure 5. Testing Pooled regression models.

$R^2 = 0.9448$, which means that 94.48% of changes in the GDP level were explained by the changes in exogenous variables within the linear regression model.

p-value (F) = 3.58×10^{-47}—the value was also very small, which means that R^2 was not formed under the influence of random variables, and the quality of the specification model was high [29].

In the Pooled regression model, rho = 0.86, which was close to 1, which means there was a huge chance of having individual effects.

Now then compared Fixed Effects model with Pooled regression model (Figure 6).

```
Model 3: Fixed-effects, using 80 observations
Included 10 cross-sectional units
Time-series length = 8
Dependent variable: GDPblnUSD

                         coefficient   std. error   t-ratio   p-value
  -----------------------------------------------------------------
  const                   469.174      252.125       1.861    0.0672   *
  Oilexajoules            227.037      122.774       1.849    0.0689   *
  Coalexajoules          -139.940      134.867      -1.038    0.3032
  Renewablesexajou~       536.659      180.746       2.969    0.0042   ***
  CrudeoilpriceUSD~         1.68001      0.642709    2.614    0.0111   **

Mean dependent var   1054.277   S.D. dependent var   1104.923
Sum squared resid    592077.2   S.E. of regression   94.71466
LSDV R-squared       0.993861   Within R-squared     0.311348
LSDV F(13, 66)       821.9378   P-value(F)           1.28e-67
Log-likelihood      -469.8897   Akaike criterion     967.7794
Schwarz criterion    1001.128   Hannan-Quinn         981.1497
rho                  0.027463   Durbin-Watson        1.482783

Joint test on named regressors -
  Test statistic: F(4, 66) = 7.45986
  with p-value = P(F(4, 66) > 7.45986) = 5.08258e-05

Test for differing group intercepts -
  Null hypothesis: The groups have a common intercept
  Test statistic: F(9, 66) = 70.2189
  with p-value = P(F(9, 66) > 70.2189) = 2.51686e-30
```

Figure 6. Compare Fixed Effects and Pooled regression models.

We tested the Fixed Effects model using the Joint test on named regressors. *p*-value = 5.08258×10^{-5}—the value was very small compared with the alpha value, so we chose the Fixed effects model from these two models.

Next, we checked the 3rd premise of the Gauss–Markov theorem—the presence of autocorrelation. We performed the Durbin–Watson statistic test with the 5% significance level. We obtained the critical values $d_L = 1.5337$ and $d_U = 1.7430$. The DW statistic was 1.4827. As we see, there was an autocorrelation. However, it will be explained further.

Now let's check our model for adequacy, for this we calculate $\hat{y}_{max_{it}}$, $\hat{y}_{min_{it}}$:

$$\hat{y}_{max_{it}} = a_{0_{max}} + a_{1_{max}} \times x_{it} + \cdots + a_{i_{max}} \times x_{it} \tag{4}$$

$$\hat{y}_{min_{it}} = a_{0_{min}} + a_{1_{min}} \times x_{it} + \cdots + a_{i_{min}} \times x_{it}, \tag{5}$$

Now, let us consider the Stochastic Effects model (Figure 7).

We looked through the Breusch–Pagan test and then the Hausman tests.

Using the results of Breusch–Pagan test [30] we compared the Pooled regression model with the Stochastic Effects model (Pooled vs. SE). *p*-value = 7.75515×10^{-40} < alpha value, respectively; from the two models, we chose the Stochastic Effects model.

Let us compare the Stochastic Effects model with the Fixed Effects model using the Houseman test: *p*-value = 0.00791073, which was also less than the alpha value, respectively. We selected the Fixed Effects model from these two models.

In the end, it turns out that, for the period 2006–2013, the Fixed Effects model corresponded best. Testing on the adequacy for the Fixed Effects model are shown. (Figure 8).

```
Model 4: Random-effects (GLS), using 80 observations
Included 10 cross-sectional units
Time-series length = 8
Dependent variable: GDPblnUSD

                      coefficient  std. error     z      p-value
  -------------------------------------------------------------
  const               -164.304     161.674     -1.016   0.3095
  Oilexajoules         501.324      71.0564     7.055   1.72e-012 ***
  Coalexajoules        -23.4666    109.261     -0.2148  0.8299
  Renewablesexajou~    885.315     132.934      6.660   2.74e-011 ***
  CrudeoilpriceUSD~      1.78220     0.668940   2.664   0.0077    ***

Mean dependent var   1054.277  S.D. dependent var   1104.923
Sum squared resid     8061736  S.E. of regression   325.6923
Log-likelihood      -574.3396  Akaike criterion     1158.679
Schwarz criterion    1170.589  Hannan-Quinn         1163.454
rho                  0.027463  Durbin-Watson        1.482783

'Between' variance = 93681.8
'Within' variance = 8970.87
theta used for quasi-demeaning = 0.891242
corr(y,yhat)^2 = 0.925627

Joint test on named regressors -
  Asymptotic test statistic: Chi-square(4) = 126.298
  with p-value = 2.40909e-26

Breusch-Pagan test -
  Null hypothesis: Variance of the unit-specific error = 0
  Asymptotic test statistic: Chi-square(1) = 174.485
  with p-value = 7.75515e-40

Hausman test -
  Null hypothesis: GLS estimates are consistent
  Asymptotic test statistic: Chi-square(3) = 11.8512
  with p-value = 0.00791073
```

Figure 7. Breusch–Pagan test, followed by the Hausman tests.

```
t(66, 0.025) = 1.997

      VARIABLE         COEFFICIENT      95% CONFIDENCE INTERVAL

          const         469.174         -34.2098       972.558
   Oilexajoules         227.037         -18.0891       472.163
  Coalexajoules        -139.940        -409.210        129.330
Renewablesexajo~        536.659          175.788       897.529
CrudeoilpriceUS~          1.68001        0.396795      2.96322
```

Figure 8. Testing on adequacy for the Fixed Effects model.

Now we check our model for adequacy. For this purpose, we calculate $\hat{y}_{max_{it}}$, $\hat{y}_{min_{it}}$: based on Equations (4) and (5).

Since $\hat{y}_{max_{it}} = 1785.189$, $\hat{y}_{min_{it}} = 0.545961$ and our forecast GDP = 586.8418 lay in this interval, our model was adequate, which means that the fourth premise of the Gauss–Markov theorem was satisfied, and the coefficients of the model were unbiased, consistent, and efficient.

We began analysis with the Pooled regression model for countries included in European Union for the period from 2014 to 2020.

We considered the influence of oil prices, oil, gas, coal, nuclear energy, and renewables consumption on economic growth of mentioned countries, specifically on GDP.

Build Pooled regression model and implement appropriate tests (Figure 9).

```
Pooled OLS, using 70 observations
Included 10 cross-sectional units
Time-series length = 7
Dependent variable: GDPbln

                      coefficient  std. error  t-ratio   p-value
  -------------------------------------------------------------
  const                -110.324     370.736     -0.2976  0.7670
  dt_15                 -84.8282    190.045     -0.4464  0.6568
  Crudeoilprice           0.799673    3.61931    0.2209  0.8258
  Oilexajoules          638.136      53.0648    12.03    4.49e-018 ***
  Coalexajoules         -61.4635     93.2946    -0.6588  0.5124
  Renewablesexajou~     560.190     184.441      3.037   0.0035    ***

Mean dependent var   1071.836   S.D. dependent var   1141.294
Sum squared resid     5513776   S.E. of regression   293.5179
R-squared            0.938651   Adjusted R-squared   0.933859
F(5, 64)             195.8437   P-value(F)           2.13e-37
Log-likelihood      -493.9250   Akaike criterion     999.8499
Schwarz criterion    1013.341   Hannan-Quinn         1005.209
rho                  0.889990   Durbin-Watson        0.153697

Excluding the constant, p-value was highest for variable 5 (Crudeoilprice)

White's test for heteroskedasticity -
  Null hypothesis: heteroskedasticity not present
  Test statistic: LM = 59.7203
  with p-value = P(Chi-square(18) > 59.7203) = 2.27033e-06
```

Figure 9. Output statistics for Pooled regression model in period 2014–2020.

To understand how well GDP is explained by given indicators, we should look at R-squared modified—0.9386. It means that 93.86% of changes in GDP volume were explained by changes in oil prices, consumption of oil, gas, coal, nuclear energy, and renewables [31].

It was assumed that the equation of model contained a random perturbation, which means that the formula contained randomness. That is why we looked at *p*-value (F). It was equal to 2.13×10^{-63} (less than 2.36, see Figure 10), which means that R^2 was not random, it was not formed under the influence of random variables, and the quality of the model specification was high.

```
F(5, 64)
 right-tail probability = 0.05
 complementary probability = 0.95

 Critical value = 2.35832
```

Figure 10. Critical value for Fisher test.

The next step is testing the model for heteroscedasticity (investigate the second hypothesis of the Gauss–Markov theory). It is obvious that there was no heteroscedasticity in the model, the second premise was fulfilled, the residuals of the model were homoscedastic, and the coefficients of the model were not biased, consistent, and efficient (Figure 11).

In the Pooled regression model, the rho = 0.89 parameter was quite close to 1, so we still checked for the presence of individual effects, and we needed to consider other models.

Let us compare the Fixed Effects and Pooled regression models (Figure 12).

We tested the Fixed Effects model by Joint test. *p*-value = P(F(5,55)) = 2.422×10^{-6}—the value was very small, so we chose the Fixed effects model from two models (Pooled regression model and Model with Fixed Effects). We also conducted the Durbin–Watson test. *Stat. Darbin–Watson = 1.77.* The value was low, so we needed to find critical values according to the Darbin–Watson test:

5% critical values for Durbin–Watson test:

n = 70, k = 6

dL = 1.43

dU = 1.80

It turns out that the value did not fall into the dU interval, but was quite close to the critical value. Presumably, there was no autocorrelation in the model. It was probably necessary to introduce an additional variable that had an impact on our dependent variable GDP [32]. Nevertheless we first looked at the Random Effects model (see Figure 13).

```
White's test for heteroskedasticity
OLS, using 70 observations
Dependent variable: uhat^2
Omitted due to exact collinearity: X2_X3

                        coefficient    std. error   t-ratio  p-value
  ------------------------------------------------------------------
  const               -118068          162650       -0.7259  0.4712
  dt_15                128239          156041        0.8218  0.4150
  Crudeoilprice          -4500.51        9555.15    -0.4710  0.6396
  Oilexajoules         106947          122286        0.8746  0.3859
  Coalexajoules        734343          452722        1.622   0.1110
  Renewablesexajou~    256704          502011        0.5114  0.6113
  X2_X4                -76203.9         58422.0     -1.304   0.1980
  X2_X5               -227202          212149       -1.071   0.2892
  X2_X6                187608          280649        0.6685  0.5068
  sq_Crudeoilprice         42.7337         84.2995   0.5069  0.6144
  X3_X4                   700.743        1118.27     0.6266  0.5337
  X3_X5                 -2328.20         3417.75    -0.6812  0.4988
  X3_X6                 -3248.75         4905.78    -0.6622  0.5108
  sq_Oilexajoules      -31523.1         16293.5     -1.935   0.0586   *
  X4_X5               -349694          114986       -3.041   0.0037   ***
  X4_X6                436967           96308.5      4.537   3.49e-05 ***
  sq_Coalexajoules      20350.4         60757.6      0.3349  0.7390
  X5_X6                603427          304518        1.982   0.0529   *
  sq_Renewablesexa~        -1.00108e+06 203396      -4.922   9.38e-06 ***

  Unadjusted R-squared = 0.853147

Test statistic: TR^2 = 59.720293,
with p-value = P(Chi-square(18) > 59.720293) = 0.000002
```

Figure 11. White's test.

```
Fixed-effects, using 70 observations
Included 10 cross-sectional units
Time-series length = 7
Dependent variable: GDPbln

                       coefficient  std. error  t-ratio   p-value
  ----------------------------------------------------------------
  const                 749.768     193.401      3.877    0.0003   ***
  dt_15                  68.7495     58.7346     1.171    0.2468
  Crudeoilprice           3.75304     1.05607    3.554    0.0008   ***
  Oilexajoules            3.67377   109.648      0.03351  0.9734
  Coalexajoules        -147.407      99.3564    -1.484    0.1436
  Renewablesexajou~     228.417     210.897      1.083    0.2835

Mean dependent var   1071.836   S.D. dependent var   1141.294
Sum squared resid    312669.8   S.E. of regression   75.39831
LSDV R-squared       0.996521   Within R-squared     0.452322
LSDV F(14, 55)       1125.329   P-value(F)           2.94e-62
Log-likelihood      -393.4800   Akaike criterion     816.9599
Schwarz criterion    850.6874   Hannan-Quinn         830.3569
rho                 -0.119916   Durbin-Watson        1.778010

LR test for rho = 0
  Test statistic: F(5, 55) = 9.08479
  with p-value = P(F(5, 55) > 9.08479) = 2.42244e-06

Test for differing group intercepts -
  Null hypothesis: The groups have a common intercept
  Test statistic: F(9, 55) = 101.655
  with p-value = P(F(9, 55) > 101.655) = 5.37331e-31
```

Figure 12. Model with Fixed Effects.

```
Random-effects (GLS), using 70 observations
Included 10 cross-sectional units
Time-series length = 7
Dependent variable: GDPbln

                        coefficient  std. error     z     p-value
  ---------------------------------------------------------------
  const                   96.7430    181.753      0.5323  0.5945
  dt_15                  -57.3426     57.6645    -0.9944  0.3200
  Crudeoilprice            1.87513     1.09423    1.714   0.0866   *
  Oilexajoules           350.196      87.4103     4.006   6.17e-05 ***
  Coalexajoules           15.1469     85.6726     0.1768  0.8597
  Renewablesexajou~      830.959     142.537      5.830   5.55e-09 ***

Mean dependent var   1071.836   S.D. dependent var   1141.294
Sum squared resid     9696650   S.E. of regression   386.2373
Log-likelihood      -513.6835   Akaike criterion     1039.367
Schwarz criterion    1052.858   Hannan-Quinn         1044.726

Breusch-Pagan test -
  Null hypothesis: Variance of the unit-specific error = 0
  Asymptotic test statistic: Chi-square(1) = 163.766
  with p-value = 1.70151e-37

Hausman test -
  Null hypothesis: GLS estimates are consistent
  Asymptotic test statistic: Chi-square(5) = 23.6212
  with p-value = 0.000256692
```

Figure 13. Random Effects model.

Let us test the model using the Brish–Pegan Test and the Hausman test [33].

Let us compare the random effects model with the united regressions model (Pooled) based on the Brish–Pegan test. *p*-value = $1.7015 \times 10^{-37} < 0.01$, respectively. We chose the Stochastic Effects model from two mentioned models [34].

Let us compare the Stochastic Effects model with the Fixed Effects model using the Hausman test: *p*-value = 0.00026. It was less than alpha (0.01), respectively. We chose the Fixed Effects model from two models. Taking into account that the Fixed Effects model corresponded for the period 2000–2020 and for the period that we recently considered (2014–2020) too, we can state with full confidence that the Fixed Effects model is the most effective for forecasting.

2.2. Analysis of the Model Received

LSDV R-squared and R-squared in limits take high values. A total of 45% of changes in GDP were explained by changes in independent variables under Fixed Effects model [35].

p-value was extremely small = 2.94×10^{-62}. So, the value of R-squared was not random, and the quality of the model specification was high.

2.3. Simulation Results and Their Discussion

As Fixed Effect was our choice for the model, the following equation was created to illustrate the effects that our chosen variables had on GDP (Figure 14).

```
                     coefficient  std. error  t-ratio   p-value
  --------------------------------------------------------------
  const                749.768     193.401      3.877    0.0003  ***
  dt_15                 68.7495     58.7346     1.171    0.2468
  Crudeoilprice          3.75304     1.05607    3.554    0.0008  ***
  Oilexajoules           3.67377   109.648      0.03351  0.9734
  Coalexajoules       -147.407      99.3564    -1.484    0.1436
  Renewablesexajou~    228.417     210.897      1.083    0.2835

Mean dependent var   1071.836   S.D. dependent var   1141.294
Sum squared resid    312669.8   S.E. of regression   75.39831
LSDV R-squared       0.996521   Within R-squared     0.452322
LSDV F(14, 55)       1125.329   P-value(F)           2.94e-62
Log-likelihood      -393.4800   Akaike criterion     816.9599
Schwarz criterion    850.6874   Hannan-Quinn         830.3569
rho                 -0.119916   Durbin-Watson        1.778010
```

Figure 14. Equation effects that our chosen variables had on GDP.

$$GDP_{it} = 749.77 + 3.75*OilPrice_{it} + 3.7*Oil(ex)_{it} - 147.4*Coal(ex)_{it} + 228.4*Renewables(ex)_{it} + 68.8*dt15_{it} + e_{it} \quad (6)$$

where:

Oilprice—Crude oil price.
Oil(ex)—oil consumption (exajoules).
Coal(ex)—coal consumption (exajoules).
Renewables (ex)—renewable energy consumption (exajoules).
Dt15—time dummy variable (for 2020 COVID pandemic).

In order to understand the significance of the explanatory variables, gretl automatically performs the *t*-test and shows its results, which can be seen next to the variables in the table for the FE model.

The regression results suggest that all explanatory variables, with the exception of coal consumption, were significant on the 1% level, with time dummy being another exception (significant on the 10% level instead). The conclusion that can be drawn is that, while renewable energy does have a significant effect on economic growth, oil dynamics still play an important role in the economic wellbeing of the selected states. Coefficients for both of them, respectively, had a positive sign. Moreover, due to the phase-out of coal consumption, its importance similarly diminished, and its coefficient was negative. The results for the time dummy also indicate that the the COVID-19 pandemic did have a significant effect on GDP. However, it is interesting to observe that the effect was positive. This may be associated with a greater shift towards renewable energy during the pandemic [36,37].

In order to check the adequacy of the model, prerequisites for the Gauss–Markov theorem were checked.

Prerequisite 1: Multicollinearity.

Correlation matrix for the variables (with the exception of the time dummy) can be seen in Figure 15.

```
          GDP   Crudeoilprice    Oilexajoules    Coalexajoules
       1.0000          0.0220          0.9567           0.7959 GDP
                       1.0000          0.0120           0.0410 Crudeoilprice
                                       1.0000           0.7846 Oilexajoules
                                                        1.0000 Coalexajoules

Renewablesexaj~
       0.8088 GDP
      -0.1030 Crudeoilprice
       0.7553 Oilexajoules
       0.7800 Coalexajoules
       1.0000 Renewablesexaj~
```

Figure 15. Correlation matrix for the variables.

As can be seen, while there are some cases of correlation over 0,75, there were no dramatically high values for correlation between exogenous variables. Moreover, given that the signs of coefficients for other periods were the same, we can conclude that there was no multicollinearity present here.

Prerequisite 2: homoskedasticity.

According to the Wald test [38] for heteroskedasticity, we can reject the H0 that the units have a common error variance. Thus, we had heteroskedasticity in the residuals, which fulfilled this premise of the Gauss–Markov theorem.

Prerequisite 3: autocorrelation.

Gretl [39] automatically gives out the test values for the Darbin–Watson statistic. In this case, dW = 1.778, dL = 1.43, and dU = 1.7672. Accordingly, a table for acceptable values can be seen in Figure 16.

-	**-**	**4-dU**	**-**	**dU**	**-**	**-**
0	dL	dU	2	4-dU	4-dL	4
0	1.43	1.7672	-	2.2328	2.57	4

Figure 16. Acceptable values.

As can be seen, our given value lay in the "green zone", indicating the absence of autocorrelation. This means that the residuals were free from autocorrelation, and the coefficients of the model were not biased, consistent, and efficient.

In order to test for adequacy (Figure 17), the prediction interval was constructed based on the confidence interval for the coefficients:

```
t(55, 0.025) = 2.004

      VARIABLE         COEFFICIENT      95% CONFIDENCE INTERVAL

         const          749.768         362.184       1137.35
         dt_15           68.7495        -48.9571      186.456
   Crudeoilprice          3.75304         1.63664       5.86945
    Oilexajoules          3.67377      -216.066       223.413
   Coalexajoules       -147.407        -346.521        51.7079
  Renewablesexajo~      228.417        -194.230       651.065
```

Figure 17. Test for adequacy.

Now, let us check our model for adequacy; for this, we calculate $\hat{y}_{max_{it}}$, $\hat{y}_{min_{it}}$: Now we check our model for adequacy. For this purpose, we calculate $\hat{y}_{max_{it}}$, $\hat{y}_{min_{it}}$: based on Equations (4) and (5).

Since $\hat{y}_{max_{it}} = 1963.9$, $\hat{y}_{min_{it}} = 158$, and our forecast GDP = 541 lay in this interval, our model was adequate, which means that the fourth premise of the Gauss–Markov theorem was satisfied. and the coefficients of the model were not biased, consistent, and efficient.

Thus, we see that the economy of countries exporting oil depends on oil and non-oil factors only by 32%, which means that it is not surprising that we missed a significant variable, and, because of which, we have autocorrelation and heteroscedasticity in the model. It can be concluded that the economy of the studied countries, among other things, depends on such factors as: unemployment, population, level of education, investment, etc.

Conclusions for the model:

- In the period from 2014 to 2020, alternative energy played a higher role, and therefore it was a significant variable. At the same time, the volatility of oil prices and its consumption were still important for the economic growth of countries.
- Changes in oil prices, consumption of oil, and renewables positively influenced the value of GDP of given countries (Austria, Belgium, Germany, Finland, France, Netherlands, Portugal, Romania, Spain, Sweden).

The negative value for the variable "Gas Consumption" can be explained by the fact that the increase in gas prices from 2014 to 2020 was a consequence of the increase in the costs of its extraction and processing. That is, in principle, the increase in gas consumption could not lead to an increase in the country's GDP, but on the contrary, it led to a decrease in GDP.

2006–2020 period:

In articles [40–43], the authors investigated the relationship between the unemployment rate and oil prices, oil price uncertainty, and interest rates. The paper used the method of autoregressive distributed lag (ARDL). A fully modified conventional least squares regression (FMOLS) was also applied to find optimal estimates of long-term coefficients for regressions. All these tests were conducted in Sweden, Norway, Denmark, and Finland based on monthly data from January 2008 to February 2020. The relationship was found for Sweden, Norway, and Denmark. Long-term FMOLS regression coefficients have shown that an increase in oil prices leads to an increase in the unemployment rate in Sweden and Denmark. All countries, with the exception of Denmark, showed evidence of a causal relationship between oil prices and unemployment, thus indicating a strong relationship between these two variables.

Firstly, we built a Pooled regression model and made some important tests (Figure 18):

```
Model 29: Pooled OLS, using 149 observations
Included 10 cross-sectional units
Time-series length: minimum 14, maximum 15
Dependent variable: GDP

                      coefficient  std. error  t-ratio   p-value
  ----------------------------------------------------------------
  const                -301.853     94.4422    -3.196   0.0017    ***
  Crudeoilprice           2.16990    1.10193    1.969   0.0509    *
  Oilexajoules          611.091     28.5168    21.43    1.72e-046 ***
  Coalexajoules          34.1476    49.8835     0.6845  0.4947
  Renewablesexajou~     493.473    102.272      4.825   3.55e-06  ***
  dt_15                 191.463    110.636      1.731   0.0857    *

Mean dependent var   1065.970   S.D. dependent var   1121.237
Sum squared resid    12074626   S.E. of regression   290.5821
R-squared            0.935104   Adjusted R-squared   0.932835
F(5, 143)            412.1061   P-value(F)           5.01e-83
Log-likelihood      -1053.471   Akaike criterion     2118.942
Schwarz criterion    2136.965   Hannan-Quinn         2126.264
rho                  0.904715   Durbin-Watson        0.151870

Excluding the constant, p-value was highest for variable 7 (Coalexajoules)

White's test for heteroskedasticity -
  Null hypothesis: heteroskedasticity not present
  Test statistic: LM = 111.432
  with p-value = P(Chi-square(18) > 111.432) = 1.70229e-15
```

Figure 18. Pooled regression model. For 2006–2020 period.

The adjusted R-squared was quite high, with low *p*-value of F, thus indicating that it was not formed due to random chance. The rho criterion was also close to 1, thus indicating a presence of significant individual effects.

Next, we looked at panel models (Figure 19) and compared them against OLS and each other.

If we are to look at the joint test on named regressors (Figure 20), we can see that its *p*-value was very close to 0. This means that the FE approach was preferable to OR.

The *p*-value in case of the Breusch–Pagan was very close to 0, which means that we could choose the RE model over the OR. In case of the Hasusman test, the *p*-value was similarly low. This, on the other hand, signified that we choose the FE approach.

As can be seen, according to the results of the tests, the FE approach was the best one in this case. Therefore, it was used as the final modelling choice.

```
Model 30: Fixed-effects, using 149 observations
Included 10 cross-sectional units
Time-series length: minimum 14, maximum 15
Dependent variable: GDP

                       coefficient   std. error   t-ratio   p-value
  --------------------------------------------------------------
  const                  518.935      123.290       4.209   4.67e-05 ***
  Crudeoilprice            2.08844      0.333394    6.264   4.75e-09 ***
  Oilexajoules           189.064       55.4346      3.411   0.0009   ***
  Coalexajoules          -80.4627      65.1032     -1.236   0.2186
  Renewablesexajou~      351.425       66.0862      5.318   4.28e-07 ***
  dt_15                   69.5762      37.0832      1.876   0.0628   *

Mean dependent var   1065.970   S.D. dependent var   1121.237
Sum squared resid     1018947   S.E. of regression   87.20139
LSDV R-squared       0.994524   Within R-squared     0.404586
LSDV F(14, 134)      1738.189   P-value(F)           5.0e-144
Log-likelihood      -869.2817   Akaike criterion     1768.563
Schwarz criterion    1813.623   Hannan-Quinn         1786.870
rho                  0.134107   Durbin-Watson        1.450197

Joint test on named regressors -
  Test statistic: F(5, 134) = 18.2107
  with p-value = P(F(5, 134) > 18.2107) = 9.22418e-14

Test for differing group intercepts -
  Null hypothesis: The groups have a common intercept
  Test statistic: F(9, 134) = 161.546
  with p-value = P(F(9, 134) > 161.546) = 2.01536e-67

Distribution free Wald test for heteroskedasticity -
  Null hypothesis: the units have a common error variance
  Asymptotic test statistic: Chi-square(10) = 2403.61
  with p-value = 0
```

Figure 19. Panel models.

```
Model 32: Random-effects (GLS), using 149 observations
Included 10 cross-sectional units
Time-series length: minimum 14, maximum 15
Dependent variable: GDP

                       coefficient   std. error     z       p-value
  --------------------------------------------------------------
  const                   97.5975     144.286      0.6764   0.4988
  Crudeoilprice            2.20943      0.356131   6.204    5.51e-010 ***
  Oilexajoules           356.190       46.4623     7.666    1.77e-014 ***
  Coalexajoules           50.7998      59.6277     0.8519   0.3942
  Renewablesexajou~      539.005       55.3086     9.745    1.93e-022 ***
  dt_15                  124.919       37.6934     3.314    0.0009    ***

Mean dependent var   1065.970   S.D. dependent var   1121.237
Sum squared resid    29799904   S.E. of regression   454.9107
Log-likelihood      -1120.774   Akaike criterion     2253.548
Schwarz criterion    2271.572   Hannan-Quinn         2260.871
rho                  0.134107   Durbin-Watson        1.450197

'Between' variance = 107452
'Within' variance = 7604.08
mean theta = 0.931236
corr(y,yhat)^2 = 0.928154

Joint test on named regressors -
  Asymptotic test statistic: Chi-square(5) = 152.452
  with p-value = 4.01375e-31

Breusch-Pagan test -
  Null hypothesis: Variance of the unit-specific error = 0
  Asymptotic test statistic: Chi-square(1) = 771.581
  with p-value = 8.14526e-170

Hausman test -
  Null hypothesis: GLS estimates are consistent
  Asymptotic test statistic: Chi-square(4) = 26.9194
  with p-value = 2.06389e-05
```

Figure 20. Joint test on named regressors.

3. Simulation Results

Since FE is our choice for the model, the following equation was created to illustrate the effects that our chosen variables have on GDP:

$$\begin{aligned} GDP_{it} = 518.93 + 2.08 \, * \, oilprice_{it} + 189.064 \, * \, Oil(ex)_{it} - 80.4627 \, * \, Coal(ex)_{it} + 351.425 \\ * \, Renewables(ex)_{it} + 69.57 \, * \, dt15_{it} + e_{it} \end{aligned} \quad (7)$$

where:

Oilprice—Crude oil price.
Oil(ex)—oil consumption (exajoules).
Coal(ex)—coal consumption (exajoules).
Renewables (ex)—renewable energy consumption (exajoules).
Dt15—time dummy variable (for 2020 COVID pandemic).

In order to understand the significance of the explanatory variables, gretl automatically performs the *t*-test and shows its results, which could be seen next to the variables in the table for the FE model.

The regression results suggest that all explanatory variables, with the exception of coal consumption, were significant on the 1% level, with time dummy being another exception (significant on the 10% level instead).

The conclusion that can be drawn is that, while renewable energy does have a significant effect on economic growth, oil dynamics still play an important role in the economic well-being of the selected states. Coefficients for both of them, respectively, had a positive sign. Moreover, due to the phase-out of coal consumption, its importance has similarly diminished, and its coefficient was negative. The results for the time dummy also indicate that the COVID-19 pandemic did have a significant effect on GDP. However, it is interesting to observe that the effect was positive. This may be associated with a greater shift towards renewable energy during the pandemic.

In order to check the adequacy of the model, the prerequisites for the Gauss–Markov theorem were checked.

Prerequisite 1—Multicollinearity.

In Figure 21, a correlation matrix for the variables (with the exception of the time dummy) can be seen.

```
           GDP  Crudeoilprice    Oilexajoules   Coalexajoules
        1.0000         0.0220          0.9567          0.7959 GDP
                       1.0000          0.0120          0.0410 Crudeoilprice
                                       1.0000          0.7846 Oilexajoules
                                                       1.0000 Coalexajoules

 Renewablesexaj~
        0.8088 GDP
       -0.1030 Crudeoilprice
        0.7553 Oilexajoules
        0.7800 Coalexajoules
        1.0000 Renewablesexaj~
```

Figure 21. Correlation matrix for the variables for 2006–2020 period.

As can be seen, while there were some cases of correlations over 0.75, there were no dramatically high values for correlations between exogenous variables. Moreover, as the signs of coefficients for other periods were the same, we can conclude that there was no multicollinearity present here.

Prerequisite 2—homoskedasticity.

According to the Wald test for heteroskedasticity, we could reject the H0 that the units had a common error variance. Thus, we had heteroskedasticity in the residuals, which fulfilled this premise of the Gauss–Markov theorem.

Prerequisite 3—autocorrelation.

Gretl automatically gives out the test values for the Darbin–Watson statistic. In this case, DW = 1.450197, dL = 1.6635, and dU = 1.8020. Accordingly, a table for acceptable values can be seen in Figure 22.

-	-	4-dU	-	dU	-	-
0	dL	dU	2	4-dU	4-dL	4
-	1.6635	1.8020	-	2.1980	2.34	-

Figure 22. Test values for the Darbin–Watson statistic.

As can be seen, our given value lay in the "red zone", thus indicating the presence of autocorrelation. However, this can be explained by the fact that we are only looking at the variables from the energy sectors. It is only to be expected that some significant variables (such as consumption and net trade, for example) are to be omitted.

In order to test for adequacy, the prediction interval was constructed based on the confidence interval for the coefficients (Figure 23).

VARIABLE	COEFFICIENT	95% CONFIDENCE	INTERVAL
const	518.935	275.089	762.782
Crudeoilprice	2.08844	1.42904	2.74783
Oilexajoules	189.064	79.4237	298.704
Coalexajoules	-80.4627	-209.225	48.3000
Renewablesexajo~	351.425	220.718	482.132
dt_15	69.5762	-3.76779	142.920

Figure 23. Confidence interval for the coefficients.

The minimum value for the GDP in this case was 3,898,729, while the maximum was 1,298,872,633. The real value (GDP for Sweden in 2020) was 54,122 bln USD. As the real value fell within the obtained interval, we can conclude that the model was adequate.

4. Discussion

We took an approach to solving the question that was raised at the beginning of the work: how oil prices, consumption of oil, coal, and renewable energy sources affect the GDP of the main EU oil and gas importing countries differs in the utmost accuracy of conclusions compared to other methods of assessing such a relationship.

In this article, several models for estimating the relationship between independent variables and a dependent variable (the GDP of European countries) were analyzed. The analysis has shown that the best model for identifying the correct relationship is a model with Fixed Effects.

The advantage of the model is that the model with Fixed Effects is as close to reality as possible. It is worth noting two important details that make it so accurate:

The second premise requires that the values of regressors related to different objects are independent of each other. However, it is important to emphasize that it admits the existence of a relationship between the values of regressors related to the same object, but different points in time: for example, it admits that xi3 can be correlated with xi2, and that, in turn, can be correlated with xi1. In other words, the future values of the regressor for a given object may depend on its past values. This is a realistic assumption. For example, oil consumption in this region today is probably related to its consumption in the past. Similarly, oil prices in Europe today are likely to affect the future European oil price.

The fourth premise requires that the regressor be exogenous in the sense that it should not be associated with a random error of the model. However, it admits the existence of a correlation between the value of the regressor xit and the fixed effect μi. This is also a realistic premise. As part of our example about energy consumption, the cultural characteristics of a given region (which are precisely characterized by its fixed effect) can influence the decision to change the price of this energy source (that is, the value of xit).

This study made an attempt to take into account the most significant factors influencing sustainable growth within the macro level. The use of mathematical tools made it possible not only to increase the accuracy of the conclusions compared to other methods, but also to identify its fixed effects in each analyzed period, which increases the accuracy of the models that describe the impact of the variables we have chosen on the GDP and sustainable growth of countries. At the same time, it should be noted that the unsustainable development of the global economy imposes its effect on the development model.

5. Conclusions and Recommendations

To sum it up, there were observed three periods of GDP growth and other variables influencing those periods. In all of these time periods, the best model for evaluating the significance of factors in GDP growth became the Fixed Effects model. The results of analysis were approximately the same: renewable energy did have a significant effect on economic growth, while oil dynamics still played an important role in the economic well-being of the selected states. Coefficients for both of them, respectively, had a positive sign [44,45].

Nevertheless, the only difference in these time intervals is the following fact: It is important to mention that there was a multi-caliber in oil consumption between models of 2000–2008 and 2006–2020. This is due to the fact that the price of oil rebounded strongly since 2005–2006, which did not have a negative impact on GDP. We believe that this situation caused multicollinearity in our model—this was a characteristic feature of the period 2000–2008, since, in the subsequent period 2006–2020, there was no such effect in this indicator.

In conclusion, we can say that the value of renewable energy has increased significantly over the years. It is not surprising that many countries, especially ones from the EU, are pushing for it. Our recommendation is that they stay the course. More attention must be paid to the area of renewable energy, as well as the ways that it can be implemented.

On the other hand, oil still has a significant impact on the economy of many states. Thus, while renewable energy is good for the future, the shift from fossil fuels to alternative sources of energy must be gradual, so as to escape major ramifications that such sharp hits may have. Coal is of much lesser importance, so it is advisable to move away from it.

In the future, this analysis could be expanded to provide a more detailed description of the effect of specific types of renewable energy, as well as the effect on nuclear energy.

Author Contributions: Conceptualization, A.B.; methodology, A.Y.; software, A.B.; formal analysis, A.A.; writing—original draft preparation, M.M.; writing—review and editing, M.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Burcu, O. Nuclear Energy-Economic Growth Nexus in OECD Countries: A Panel Data Analysis. *Int. J. Econ. Perspect.* **2017**, *11*, 138–154.
2. Dynan, K.; Sheiner, L. GDP as a Measure of Economic Well–being. In *Hutchins Center Working Paper 43*; The Brookings Institution: Washington, DC, USA, 2018; p. 4.
3. Rehman Khan, Z.Y.; Belhadi, A.M. Investigating the effects of renewable energy on international trade and environmental quality. *J. Environ. Manag.* **2020**, *272*, 15.
4. Raduzzi, R. The macroeconomics outcome of oil shocks in the small Eurozone economies. *World Econ.* **2019**, *43*, 191–211. [CrossRef]

5. Rafindadi, A. Impacts of renewable energy consumption on the German economic growth: Evidence from combined cointegration test. *Renew. Sustain. Energy Rev.* **2017**, *75*, 1130–1141. [CrossRef]
6. Awrejcewicz, J.; Krysko, V.A.; Kutepov, I.E.; Vygodchikova, I.Y. Quantifying chaos of curvilinear beam via exponents. *Commun. Non-Linear Sci. Numer. Simul.* **2015**, *27*, 81–92. [CrossRef]
7. Vazquez, P.V. Estimation of the potential effects of offshore wind on the Spanish economy. *Renew. Energy* **2017**, *111*, 815–824. [CrossRef]
8. Baldoni, E.; Coderoni, S.; di Giuseppe, E.; D'orazio, M.; Esposti, R.; Maracchini, G. A software tool for a stochastic life cycle assessment and costing of buildings' energy efficiency measures. *Sustainability* **2021**, *13*, 7975. [CrossRef]
9. Borodin, A.; Zaitsev, V.; Mamedov, Z.F.; Panaedova, G.; Kulikov, A. Mechanisms for Tax Regulation of CO2-Equivalent Emissions. *Energies* **2022**, *15*, 7111. [CrossRef]
10. Tong, D.; Zhang, Q.; Zheng, Y.; Caldeira, K.; Shearer, C.; Hong, C.; Qin, Y.; Davis, S.J. Committed Emissions from Existing Energy Infrastructure Jeopardize 1.5 °C Climate Target. *Nature* **2019**, *572*, 373–377. [CrossRef]
11. Sobamowo, G.M.; Ojolo, S.J. Techno-economic analysis of biomass energy utilization through gasification technology for sustainable energy production and economic development in Nigeria. *Energy* **2018**, *2018*, 4860252. [CrossRef]
12. Levi-Oguike, J.; Sandoval, D.; Ntagwirumugara, E. A Comparative Life Cycle Investment Analysis for Biopower Diffusion in Rural Nigeria. *Sustainability* **2022**, *14*, 1423. [CrossRef]
13. Breusch, T.S.; Pagan, A.R. A Simple Test for Heteroscedasticity and Random Coefficient Variation. *Econometrica* **1979**, *47*, 1287–1294. [CrossRef]
14. Subbotin, Y.; Shevaldin, V. On one method of constructing local parabolic splines with additional nodes. *Proc. Inst. Math. Mech. Ural. Branch Russ. Acad. Sci.* **2019**, *25*, 205–219.
15. Halunga, A.; Orme, C.; Yamagata, T. A Heteroskedasticity Robust Breusch-Pagan Test for Contemporaneous Correlation in Dynamic Panel Data Models. *J. Econom.* **2017**, *198*, 209–230. [CrossRef]
16. Tao, L.; Chen, Y.; Liu, X.; Wang, X. An integrated multiple criteria decision making model applying axiomatic fuzzy set theory. *Appl. Math. Model.* **2012**, *36*, 5046–5058. [CrossRef]
17. Büscher, C.; Ufer, U. The (Un)availability of Human Activities for Social Intervention: Reflecting on Social Mechanisms in Technology Assessment and Sustainable Development Research. *Sustainability* **2022**, *14*, 1394. [CrossRef]
18. Powell, D.J.; Romero, D.; Gaiardelli, P. New and Renewed Manufacturing Paradigms for Sustainable Production. *Sustainability* **2022**, *14*, 1279. [CrossRef]
19. Arellano, M.; Bover, O. Another look at the instrumental variables estimation of error components models. *J. Econom.* **1995**, *68*, 29–51. [CrossRef]
20. Lu, T. A Fuzzy Network DEA Approach to the Selection of Advanced Manufacturing Technology. *Sustainability* **2021**, *13*, 4236. [CrossRef]
21. Mamedov, Z.F.; Qurbanov, S.H.; Streltsova, E.; Borodin, A.; Yakovenko, I.; Aliev, A. Mathematical models for assessing the investment attractiveness of oil companies. *SOCAR Proc.* **2021**, *4*, 102–114. [CrossRef]
22. Wu, Z.; Zhao, Z.; Niu, G. *Introduction to the Popular Open Source Statistical Software (OSSS)*; Open Source Software for Statistical Analysis of Big Data; Bryant University: Smithfield, RI, USA, 2020.
23. Borodin, A.; Panaedova, G.; Ilyina, I.; Harputlu, M.; Kiseleva, N. Overview of the Russian Oil and Petroleum Products Market in Crisis Conditions: Economic Aspects, Technology and Problems. *Energies* **2023**, *16*, 1614. [CrossRef]
24. Kisswani, A.; Kisswani, K. Modeling the employment–oil price nexus: A non-linear cointegration analysis for the U.S. market. *J. Int. Trade Econ. Dev.* **2019**, *28*, 1–17. [CrossRef]
25. Fatima, T.; Mentel, G.; Doğan, B.; Hashim, Z.; Shahzad, U. Investigating the role of export product diversifcation for renewable, and non-renewable energy consumption in GCC (gulf cooperation council) countries: Does the Kuznets hypothesis exist? *Environ. Dev. Sustain.* **2022**, *24*, 8397–8417. [CrossRef] [PubMed]
26. Alzaid, A.; Al-Osh, M.A. First-Order Integer-Valued Autoregressive (INAR (1)) Process: Distributional and Regression Properties. *Stat. Neerl.* **1988**, *42*, 53–61. [CrossRef]
27. Brown, R.P.C.; Carmignani, F.; Fayad, G. Migrants' remittances and financial development: Macro- and micro-level evidence of a perverse relationship. *World Econ.* **2013**, *36*, 636–660. [CrossRef]
28. Steutel, F.W.; van Harn, K. Discrete Analogues of Self-Decomposability and Stability. *Ann. Probab.* **1979**, *7*, 893–899. [CrossRef]
29. Lima, V.; Souza, T.; Cribari-Neto, F.; Fernandes, G. Heteroskedasticity-robust inference in linear regressions. *Comm. Statist. Simulation Comput.* **2009**, *39*, 194–206. [CrossRef]
30. Sovacool, B.K.; Schmid, P.; Stirling, A.; Walter, G.; MacKerron, G. Differences in carbon emissions reduction between countries pursuing renewable electricity versus nuclear power. *Nat. Energy* **2020**, *5*, 928–935. [CrossRef]
31. Değirmen, S.; Saltık, Ö. *Could Nuclear Energy Production and Economic Growth Relationship for Developed Countries Be an Incentive for Developing Ones?: A Panel ARDL Evidence Including Cointegration Analysis*; GELISIM-UWE 2019 Special Issue, İstanbul Gelişim Üniversitesi Sosyal Bilimler Dergisi; Mersin University: Mersin, Turkey, 2019; pp. 1–28. [CrossRef]
32. Hausman, J.A. Specification Tests in Econometrics. *Econometrica* **1978**, *46*, 1251–1271. [CrossRef]
33. Greene, W. Fixed and Random Effects in Stochastic Frontier Models. *J. Product. Anal.* **2005**, *23*, 7–32. Available online: http://www.jstor.org/stable/41770178 (accessed on 8 February 2023). [CrossRef]

34. deHaan, E. Using and Interpreting Fixed Effects Models. 2021. Available online: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3699777 (accessed on 8 February 2023).
35. Lepore, D.; Micozzi, A.; Spigarelli, F. Industry 4.0 Accelerating Sustainable Manufacturing in the COVID-19 Era: Assessing the Readiness and Responsiveness of Italian Regions. *Sustainability* **2021**, *13*, 2670. [CrossRef]
36. Basu, A.; Mandal, A.; Mart´ın, N.; Pardo, L. Generalized Wald-type tests based on minimum density power divergence estimators. *Statistics* **2016**, *50*, 1–26. [CrossRef]
37. Borodin, A.; Mityushina, I.; Harputlu, M.; Kiseleva, N.; Kulikov, A. Factor Analysis of the Efficiency of Russian Oil and Gas Companies. *Int. J. Energy Econ. Policy* **2023**, *13*, 172–188. [CrossRef]
38. Lee, C. Adkins, Using gretl for Monte Carlo experiments. *J. Appl. Econom.* **2010**, *5*, 880–885.
39. Segarra-Blasco, A.; Teruel, M.; Cattaruzzo, S. The economic reaction to non-pharmaceutical interventions during Covid-19. *Econ. Anal. Policy* **2021**, *72*, 592–608. [CrossRef]
40. COVID-19. European Centre for Disease Prevention and Control. Published 2021. Available online: https://www.ecdc.europa.eu/en (accessed on 14 January 2022).
41. Hale, T.; Angrist, N.; Goldszmidt, R.; Kira, B.; Petherick, A.; Phillips, T. A global panel database of pandemic policies (Oxford COVID-19 Government Response Tracker). *Nat. Hum. Behav.* **2021**, *5*, 529–538. [CrossRef]
42. Claeson, M.; Hanson, S. COVID-19 and the Swedish enigma. *Lancet* **2021**, *397*, 259–261. [CrossRef]
43. Olagnier, D.; Mogensen, T.H. The COVID-19 pandemic in Denmark: Big lessons from a small country. *Cytokine Growth Factor Rev.* **2020**, *53*, 10–12. [CrossRef]
44. Mamedov, Z.F.; Qurbanov, S.H.; Streltsova, E.; Borodin, A.; Yakovenko, I.; Aliev, A. Assessment of the potential for sustainable development of electric power enterprises: Approaches, models, technologies. *SOCAR Proc.* **2022**, *2*, 15–27. [CrossRef]
45. Borodin, A.; Natocheeva, N.; Khominich, I.; Kulikov, A.; Shchegolevatykh, N. The Impact of the Business Environment on the Effectiveness of the Implementation of the Financial Strategy of the Oil and Gas Company. *Int. J. Energy Econ. Policy* **2021**, *11*, 13–21. [CrossRef]

energies

MDPI

Article

Methodology for an Audit of Institutional Projects in the Energy Sector

Elena Fedchenko [1], Lyubov Gusarova [1], Timur Timkin [1], Natalie Gryzunova [2], Michał Bilczak [3] and Svetlana Frumina [4,5,*]

1 Department of Financial Control and Treasury, Financial University under the Government of the Russian Federation, 49 Leningradskiy Ave., 125993 Moscow, Russia
2 Department of Sustainable Development Finance, Plekhanov Russian University of Economics, 36 Stremyanny Lane, 117997 Moscow, Russia; gryzunova.n@rea.ru
3 Department Economic Sciences, University of Warmia and Mazury in Olsztyn, 10719 Olsztyn, Poland
4 Department of Public Finance, Financial University under the Government of the Russian Federation, 49 Leningradskiy Ave., 125993 Moscow, Russia
5 Department of World Financial Markets and Fintech, Plekhanov Russian University of Economics, 36 Stremyanny Lane, 117997 Moscow, Russia
* Correspondence: frumina@mail.ru

Abstract: Auditing activity, in the last decade, is one of the most dynamically changing types of economic activity, on the one hand, due to an increase in the number of state projects implemented by many countries, and on the other hand, due to technological innovations and digitalization. Russian auditing practices are also being actively reformed. For example, the Ministry of Energy is updating their audit methodology. The subject of this study is to ensure the efficiency of spending public funds for the implementation of strategic projects. The object of this study is the methodology of a state audit. An analysis of the currently used Russian and international standards for public audits shows that there are many opportunities to improve the methodology for conducting financial, strategic and performance audits. First of all, there is a need to solve methodological problems in monitoring the efficiency of investment developments, since partnerships between private investors and government bodies for the implementation of strategic projects have expanded. The main difficulty of audit methodology is the definition of a system of target criteria in long-term projects. Quite often it is difficult to determine the main expected result, for example, financial, or social efficiency or the adequacy of multi-unit tariffs. All these circumstances determine the relevance of methodological changes. The aim of this study is to develop a new audit methodology as, first of all, a management technology. We use a result-oriented approach that is based on the developed system of indicators, to evaluate the effectiveness of an institutional project and to evaluate the effectiveness of environmental costs and technological innovations to reduce anthropogenic emissions and to create a single Asian energy space.

Keywords: state audit; climate policy; institutional projects; modeling; energy

Citation: Fedchenko, E.; Gusarova, L.; Timkin, T.; Gryzunova, N.; Bilczak, M.; Frumina, S. Methodology for an Audit of Institutional Projects in the Energy Sector. *Energies* **2023**, *16*, 3535. https://doi.org/10.3390/en16083535

Academic Editors: Peter V. Schaeffer, Elena Lucchi and Charisios Achillas

Received: 5 February 2023
Revised: 22 March 2023
Accepted: 12 April 2023
Published: 19 April 2023

1. Introduction

The COP26 international climate conference in Glasgow, held in November 2021, showed how difficult it is for the world community to reach agreement on a number of key issues, in particular, on the decommissioning of coal-fired generation facilities, the need to reduce methane emissions and deforestation. However, significant progress has been made on some important areas of climate policy that have been neutralized by sanctions. For example, there is an agreement on the mechanisms for international carbon trading under Article 6 of the Paris Agreement, which is expected to lead to increased interactions between countries to achieve climate goals. Despite the global trend towards increased electricity generation from renewable energy sources (RESs), fossil fuels account for more than 80% of the world's primary energy consumption. The sharp increase in gas prices in Europe in 2021 clearly indicates that the dependence of industrialized countries on fossil energy resources remains high.

The Russian Federation has implemented 14 national projects (programs) in various areas: demography, health, education, housing and the urban environment, ecology, safe and high-quality roads, labor productivity and employment support, science, digital economy, culture, small- and medium-sized businesses and support for individual entrepreneurial initiative, international cooperation and export [1,2]. Each national project consists of a number of federal, regional and institutional projects aimed at achieving national development goals. The system of project management of budget expenditures in the Russian Federation consists of the following elements:

1. National projects that ensure the achievement of priority areas for accelerated development.
2. Federal projects as part of national projects that ensure the achievement of goals, objectives and target indicators of national projects.
3. Federal projects outside of national projects, ensurng the achievement of other indicators on behalf of the President, the Government of the Russian Federation.
4. Regional projects that ensure the achievement of goals, objectives and target indicators of national projects in the areas of jurisdiction of the constituent entities of the Russian Federation.
5. Institutional projects that ensure the achievement of goals, objectives and target indicators of departments.

The Ministry of Energy is implementing four strategic projects "Digital Energy"; "Unified Technical Policy—Reliability of Electricity Supply"; "Improving the Processes for Collecting, Processing, Storing and Using Information Resources of the Fuel and Energy Complex and Development of the State Information System of the Fuel and Energy Complex"; and "Organization of project activities in the Ministry of Energy of Russia", which are being implemented as part of the national project "Digital Economy of the Russian Federation", adopted by the Russian government in 2017 [3–7]. These projects have caused changes in the methodology of a state audit of budget spending.

One of the main requirements for the methodology is the definition of criteria for efficiency, productivity and effectiveness. The auditor should communicate, in a transparent manner, assurance regarding the outcome of the audit in relation to the subject matter. In addition, it is very important to form a conclusion that the results are based on sufficient and appropriate evidence. If there is any error in the evidence, the results and conclusions will also be erroneous [8]. New technology is based on mathematical modeling of investment dynamics.

As part of this study, scientific articles by authors who have studied audit (control) issues of project activities have been analyzed [9–15]. By analyzing the standards of project activities, it can be noted that the generally accepted international methodologies PMBoK and PRINCE2, despite some fundamental differences in individual stages of projects, contain requirements for monitoring their implementations and the need to know all risk factors. The authors of [16] identified high-quality planning and consistent monitoring at all stages of project implementation as key factors for the success of project activities. The author of [17] pointed out the need for qualitative selection of projects during their initiation. The importance of good planning as an analytical basis for evaluating the results of each project was emphasized in [18]. The authors in [19] noted that public projects are complex structures that require too many criteria, which sometime contradict each other; and therefore, create difficulties in assessing the quality of their implementation and achieving the final goals. Some authors have emphasized the need to determine the contribution of the project to the achievement of national development goals [20]. The work by [21] was devoted to the issues of project activities in the energy sector.

2. Materials and Methods

A systems-oriented approach, according to GUID 3910, Article 54, is an approach that does not primarily focus on public policies or goals, but focuses on properly functioning governance systems as a condition for effective and efficient public policies. During the process of developing the audit methodology, provisions to consider include the regulatory legal acts and methodological documents in the field of project activities, INTOSAI international standards and other internal regulatory documents used by the Accounts Chamber of the Russian Federation in the process of controlling state property.

The audit of institutional projects should cover the following issues:

- The purpose of the system;
- Responsible participants;
- Responsibilities of each participant;
- The rules, regulations and procedures that will matter;
- Relevant information flows.

In addition to the questions specified in GUID 3910, the following is advisable:

- Identification and analysis of the tasks to be solved by the project;
- Identification of executors and beneficiaries of the project;
- Analysis of the transformational mechanism of the project;
- Assessment of the sufficiency of resource support for the implementation of the project and the validity of the distribution of resources for project activities;
- Analysis of the quality of planning project targets;
- Checking of the compliance of the project passport with the established requirements for the project development procedure;
- Checking of the implementation of project milestones;
- Checking of the implementation of project activities;
- Assessment of the achievement of project targets;
- Analysis of the quality of project implementation;
- Evaluation of the cost effectiveness of the project implementation [22].

The identified tasks to be solved by the project should be ranked according to the degree of technical and financial significance, with the assignment of weighting coefficients, which are determined by the internal audit standards of the self-regulatory organization of auditors (SRO) working with energy companies on institutional projects. For each project, a goal is identified and a network of interrelated tasks is formed that form a network graph, as well as a list of criteria for monitoring managerial impacts. The network graph (or goal tree) assumes that all elements are distributed over resources and over time. Each task (or event of this graph) has different technical and financial characteristics (Figure 1).

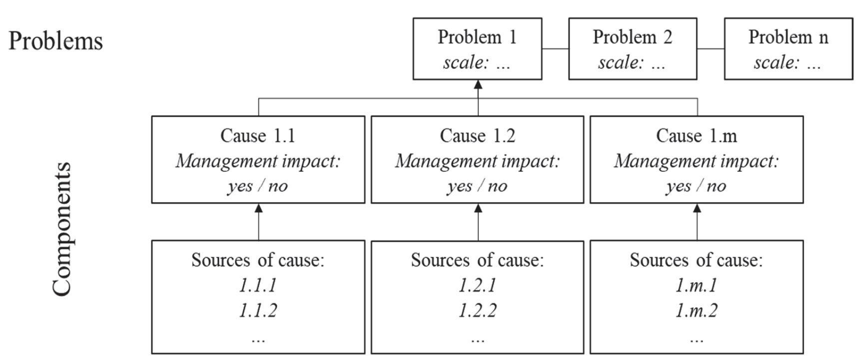


Figure 1. "Network graph" of the tasks to be solved within the framework of the national project, compiled by the authors.

A "task tree" is the basis for the subsequent analysis of the content of an institutional project using the criterion of completeness of coverage of all tasks and their components by the tasks set in the project. If the project tasks are not aimed at eliminating individual causes of tasks that can be managed, this is qualified as the cause of the risk of not achieving the project goals. The "task tree" as a tool is widely used in the choice of investment alternatives, in the tax control of affiliated persons.

The information necessary to build a "tree of tasks" is formed on the basis of regulatory legal and methodological information, official statistics, results of scientific research, the results of previously conducted control and expert analytical activities on the analyzed topic and information obtained during their implementation.

In addition, based on a comparison of the "reference" and actual parameters of a project, an analysis of its transformational mechanism is performed: An assessment is made of the coverage of the identified tasks and components by the project activities as a whole and in the context of activities that can be adjusted taking into account the conclusion that the expected results (project activities) correspond to the identified tasks. An analysis of the sufficiency of resource support for the implementation of the project and the validity of the distribution of resources for individual activities is performed.

The results of the analysis are summarized in the form of a roadmap or project results map (Figure 2).

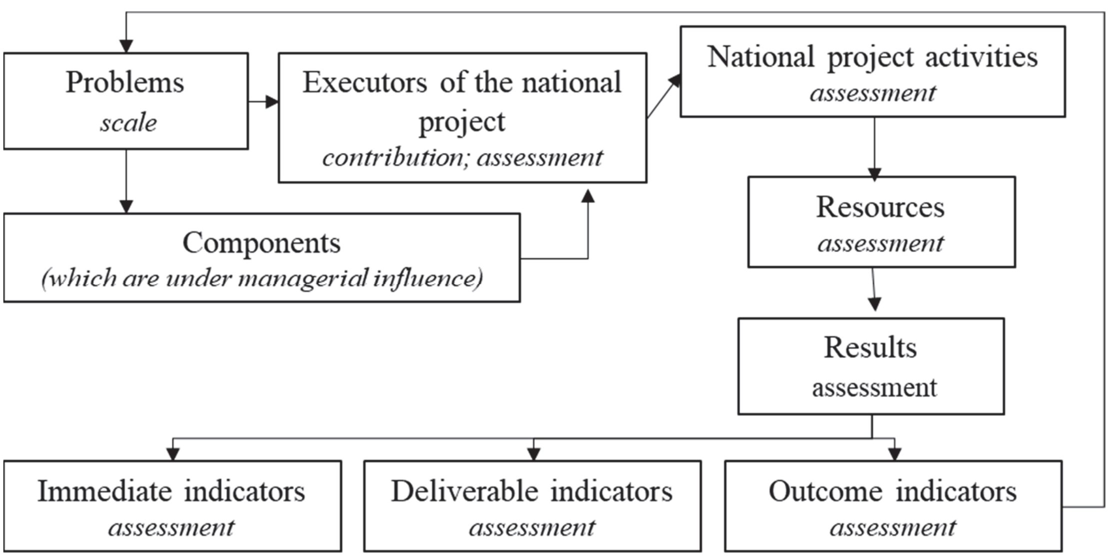


Figure 2. Map of the results of the project.

On the basis of the project results map, an analysis of the quality of planning a project's target indicators is performed according to the following criteria: compliance of the target indicators with the goals and objectives of the project; consideration of the ability of performers to exert managerial influence on the solution of identified tasks when planning the values of target indicators; consideration of the resource constraints of the project when planning the values of target indicators; completeness of the reflection of the expected results in the context of indicators of immediate results, indicators of final results and indicators of the final effect.

Such an in-depth and complete analysis of the formation of a project will allow, in the future, an evaluation of its implementation not only from the point of view of the achievement of milestones, activities and indicators of cash execution for budget expenditures, but also from the point of view of the expected contributions to the achievement of national development goals of the country. One of the key conditions for implementing a promising approach to a project audit is a high level of digitalization of control and analytical activities. A systematic approach, automation tools and integration with government information systems will ensure sufficient coverage and relevance of information for analytical work within the framework of the project audit. Thus, in-depth systemic analyses of the formation and implementation of projects, aimed at assessing the expected achievement of national development goals, is of great importance in the professional activities of state auditors [23–25].

The main directions for the methodology of a state audit of institutional projects are defined as:

(1) An audit of the formation of the project (determination of the limit of capital investments and financial performance indicators);
(2) An audit of the project implementation (control of the distribution of resources and work in time).

The audit of project formation includes several stages, which are presented in Table 1.

Table 1. Audit of the formation of an institutional project.

No	Audit Stages	Content of Audit Procedures
1	Identification and analysis of the tasks of the region, which the project is aimed at solving	An indicator of the distribution of resources between the project executors in terms of their potential contribution to the solution of each task
2	Identification of performers, investors and beneficiaries	The coefficient of involvement of investors and performers in the solution
3	Analysis of the transformational mechanism of the project	Distribution of weighting coefficients of tasks between the activities of the institutional project with the assumption that they fully cover each identified task.
4	Creating a project results map	The works are adjusted in accordance with the coefficients of sufficiency of the resource provision for the implementation of the institutional project and the coefficients of coverage of tasks and components by the activities of the institutional project in the context of activities.
5	Analysis of the quality of planning indicators	The quality factor of planning the targets of the institutional project.
6	Checking the compliance of the project passport with the established requirements	The quality coefficient of the project passport compilation.
7	Summary assessment of the quality of project formation	Summary coefficient of the quality of project formation.

Source: compiled by the authors.

The methodology for auditing the implementation of institutional projects provides for the sequential implementation of two stages of the state audit in accordance with the recommendations of INTOSAI includes:

(1) Analysis of the achievement of the expected results of the project (Table 2);
(2) Evaluation of the effectiveness of the project.

Table 2. Recommended methodology for analyzing the achievement of expected results of an institutional project.

Indicator	Formula
Assessment of project milestones (Q).	$Q = \frac{Q_f}{Q_p}$, where Q_f—actual number of milestones completed within the established time limit at the end of the reporting period; Q_p—number of milestones planned for the reporting period.
Achievement of project target indicators P_i	$P_i = \frac{P_i^f}{P_i^p}$, where P_i^f—actual value of the i-th indicator at the end of the reporting period; P_i^p—planned value of the i-th indicator, set for the corresponding reporting period.
Achievement of immediate target indicators ($P_{\text{immediate}}$)	$P_{i(\text{immediate})} = \frac{\sum_{i(\text{immediate})}^{n1} P_{i(\text{immediate})}}{n1}$ where $P_{i(\text{immediate})}$—assessment of the achievement of the i-th target indicator of immediate target indicators; $n1$—number of immediate target indicators.
Achievement of deliverable target indicators ($P_{\text{deliverable}}$).	$P_{i(\text{deliverable})} = \frac{\sum_{i(\text{deliverable})}^{n2} P_{i(\text{deliverable})}}{n2}$ where $P_{i(\text{deliverable})}$—assessment of the achievement of the i-th target indicator of deliverable target indicators; $n2$—number of deliverable target indicators.
Achievement of outcome target indicators (P_{outcome}).	$P_{i(\text{outcome})} = \frac{\sum_{i(\text{outcome})}^{n3} P_{i(\text{outcome})}}{n3}$ where $P_{i(\text{outcome})}$—assessment of the achievement of the i-th target indicator of outcome target indicators; $n3$—number of outcome target indicators.
Final assessment of the achievement of target indicators (P).	$P = \min(P_{\text{immediate}}; P_{\text{deliverable}}; P_{\text{outcome}}) \times P'$, where P'—full data ratio to assess the achievement of target indicators, calculated as the ratio of the number of target indicators for which actual data on implementation is available to the total number of target indicators set in the national project.
Assessment of national project expenditures R_j	$R_j = \frac{R_j^f}{R_j^p}$, where R_j^f—actual volume of expenditures from the j-th source to implement the national project at the end of the reporting period; R_j^p—planned volume of expenditures from the j-th source to implement the national project at the end of the reporting period;
Final assessment of expenditures from all sources to implement the national project (R).	$R = \frac{\sum_j^{n4} R_j \times v_j}{n4}$, where v_j—volume of the j-th source; $n4$—amount of sources.

3. Results

The world is witnessing a change in trends in climate policy, a reorientation of export flows of energy resources and an expansion of investors in state energy financing programs in accordance with the concept of a multipolar world. An analysis of the methodology for auditing projects in the energy sector, both in the public administration sector and in the corporate sector in many countries, makes it possible to determine common methodological approaches for its implementation. In general, the audit of projects should be primarily aimed at identifying inefficient activities and projects. To do this, it is important to define key performance criteria during the planning stages. This procedure is recommended by all internal auditing standards and the INTOSAI recommendations. Then, benchmarking is appropriate—project management practices are generalized, systematized, and risks are identified and assessed. In Russia, there are now 18 self-regulatory organizations of auditors operating in the energy sector in different geographical areas, which form internal standards for assessing the quality of management and provision of goods in the energy sector.

In connection with the spread of the illegal practice of nationalization and the withdrawal of investments and property, there is a need to establish legal documents and obtain guarantees and pledges to pay off debts. Modern digital technologies expand the possibilities of modeling the relationship between resources and the properties of all types of beneficiaries, since an energy product can now be a multicomponent product and the created energy product can now be stored (this was not possible before). In a state audit of projects, the assessment of quality planning of needs is of key importance. Currently, for example, in Russia, China and Australia, the process of identifying consumers is being conducted. Energy consumers have changed the structure, volumes of consumption and requirements for energy resources. It is the analysis of needs in terms of strategic goal setting, reliability, safety and the optimal distribution of resources over time that makes it possible to implement an integrated approach.

The first stage of the recommended methodology for auditing an institutional project is to identify and analyze the tasks that the project is aimed at solving. The result of this stage is the construction of a "task tree" (Figure 2).

The indicator of the distribution of resources between the project executors in terms of their potential contribution to the solution of each task is defined as:

$$\sum_{i=1}^{n} V_i = \sum_{g=1}^{m} C_g^l = 1 \tag{1}$$

where V_i is the weighting coefficient of the i-th task and is the potential contribution of the g-th executor to solving problems.

At the second stage of an audit of the formation of an institutional project, the executors, investors and beneficiaries are identified by sectors of the economy. The list of performers is determined on the basis of a competition; in Russia and China, this competition is held in the form of a state order. In Russia, often in energy projects, you can find a mixed form of ownership and a wide variety of investors. Therefore, now they take into account the coefficient of involvement of investors and performers in solving problems:

$$E_1 = \frac{\sum_{k=1}^{m} C_g^p}{\sum_{k=1}^{m} C_g^l} \tag{2}$$

where E_1 is the coefficient of investment participation;

- planned contribution of the g-th performer to the solution of the task;
- the potential contribution of the g-th performer to the solution of the tasks set.

The individual coefficient of a performer's involvement in solving tasks is:

$$E_1^g = \frac{C_g^p}{C_g^l} \tag{3}$$

where E_1^g is the coefficient of involvement of the g-th performer in solving the task, C_g^p is the planned contribution of the g-th executor to the solution of the planned task, C_g^l is the potential contribution of the g-th executor in solving the problem.

The list of project executors is correlated with the "task tree" in order to determine the potential contribution of executors (individual organizations) to the solution of the identified tasks (E_i). When calculating the potential contribution, only those components of the tasks that have the ability to exert managerial influence are taken into account.

The list of project beneficiaries should be strictly regulated. The choice of performers should be based on an analysis of the achievements of the performers, the results of previously implemented projects and expert analytical activities on the subject under analysis.

Based on the list of beneficiaries of the project and the "task tree", certain needs are correlated with the tasks, activities and results.

The quantitative indicator of the second stage of an audit of an institutional project is the coefficient of involvement of performers in solving the tasks set (E_i), which, if necessary, is adjusted taking into account the conclusion that the project can satisfy the needs of all groups of beneficiaries by the value (ki):

- Equal to 1, if it is concluded that the institutional project can meet the needs of all groups of beneficiaries;
- Equal to 0.85, if it is concluded that the institutional project has a limited ability to meet the needs of all groups of beneficiaries;
- Equal to 0.7, if there are doubts about the possibility of an institutional project to sufficiently meet the needs of all groups of beneficiaries.

Based on the results of identifying the executors and beneficiaries of a project and the analysis performed, the reasons for possible failures are determined, as well as the ability of the institutional project to sufficiently satisfy the needs of all groups of beneficiaries, for which individual coefficients of involvement of executors in solving the identified tasks (E_i^g) are calculated. The coefficient (E_i^g) if necessary, is adjusted by the value (E_i^g), taking into account the conclusion that the institutional project can satisfy the needs of all groups of beneficiaries, similarly to the order determined for the coefficient of involvement of performers (E_i).

At the third stage of an audit of the formation of an institutional project, an analysis of the transformational mechanism of the project is performed. To do this, task weights (V_i) are distributed among the activities of the institutional project with the assumption that they fully cover each identified task. The distribution of task weights (V_i) between institutional project activities, assuming full coverage of each identified task, is:

$$\sum_{i=1}^{n} V_i = \sum_{j}^{n'} S_j^l = 1, \tag{4}$$

where V_i is the weighting factor of the *i*-th problem and S_j^l is the value of the full coverage of the tasks by the *j*-th event.

The coefficient of coverage of the task components by the activities of the institutional project is:

$$E_2 = \frac{\sum_{j=1}^{n'} S_j^p}{\sum_{j=1}^{n'} S_j^l} \tag{5}$$

where E_2 is the coefficient of coverage of tasks and components by the activities of the institutional project, S_j^p is the planned coverage of the *j*-th event of tasks and components, and S_j^l is the complete coverage of the *j*-th event of tasks and components.

In order to correlate the tasks, activities and expected results of the implementation of the institutional project with the "task tree", an expert assessment is performed:

- ✓ Coverage of the identified tasks and components by the activities of the institutional project;
- ✓ Compliance of the expected results of the institutional project with the identified tasks.

Based on the results of the assessment, the coefficient of coverage of the identified tasks and components by the activities of the institutional project (E_i) is calculated, which, if necessary, is adjusted, taking into account the conclusion that the expected results of the national project correspond to the identified tasks by the value (ki):

Equal to 1, if it is concluded that the expected results of the institutional project correspond to the identified tasks;

Equal to 0.85, if it is concluded that the expected results of the institutional project meet the identified tasks in a limited way;

Equal to 0.7, if there are doubts about the compliance of the expected results of the institutional project with the identified tasks.

Based on the results of the analysis of the transformational mechanism of the institutional project, the reasons for the failure to fully cover the identified tasks and components by each activity, as well as the discrepancy between the expected results of the national project and the identified tasks, are determined, for which the coefficients for covering the identified tasks and components by the activities of the institutional project in the context of activities E_j^2 are calculated. The coefficient E_j^2 is adjusted, if necessary, by the value k_j^2 taking into account the conclusion that the expected results of the project correspond to the identified tasks in the order determined for the coefficient ($k2$).

At the fourth stage of an audit of the formation of an institutional project, the results of the previous analysis are summarized in the form of a project results map in order to establish:

Sufficiency of resource support for implementation of the institutional project;

The validity of the distribution of resources for the activities of the national project.

The sufficiency of resource support for implementation of the national project is determined based on the number and content of the activities of the institutional project with the assumption that they fully cover each identified task (V_i).

The sufficiency of collateral can be assessed using several coefficients:

$$E_3 = \frac{\sum_{j=1}^{n'} C_j^p}{\sum_{j=1}^{n'} C_j^l} \tag{6}$$

where E_3 is the coefficient of sufficiency of the resource provision for the implementation of the national project, C_j^p is the planned amount of resource support for the implementation of the j-th event of the national project, C_j^l is the required amount of resource support for the implementation of the j-th event of the national project.

The following is the coefficient of sufficiency of resource provision for the implementation of the j-th event of the institutional project:

$$E_3^j = \frac{C_j^p}{C_j^l} \tag{7}$$

where E_3^j is the coefficient of sufficiency of resource support for the implementation of the j-th measure of the institutional project, C_j^p is the planned volume of resource support for the implementation of the j-th measure of the institutional project, and C_j^l is the required amount of resource support for the implementation of the j-th measure of the institutional project.

Based on the results of assessing the planned cost of the activities of the institutional project, the coefficient of sufficiency of resource support for the implementation of the institutional project (E_3) is calculated, based on the results of which, in order to determine the reasons for the insufficiency of resources, the corresponding coefficients are determined in the context of the activities of the institutional project (E_3^j). The validity of the distribution of resources for the activities of the institutional project implies the maximization of the coefficient (E_3^j) depending on the weighting coefficients (V_i).

In order to determine the validity of the allocation of resources for project activities, the activities are ranked by the weighting coefficients of the tasks to be solved by the corresponding activities. If the values of the coefficients (E_3^j) do not reflect the resulting distribution, a conclusion is made about the unreasonable distribution of resources among the activities of the institutional project.

The residuality coefficient of resource support for the implementation of the institutional project, if necessary, is adjusted by the value (k3):

Equal to 1, if a conclusion is made about the reasonableness of the distribution of resources for the activities of the institutional project;

Equal to 0.85, if it is concluded that the allocation of resources for the activities of the institutional project is insufficiently justified;

Equal to 0.7, if there are doubts about the validity of the distribution of resources for the activities of the institutional project.

The coefficient (E_3^j) in relation to individual activities of the institutional project, taking into account the conclusion about the reasonableness of the distribution of resources for the activities of the institutional project, is not adjusted.

At the fifth stage of an audit of the formation of a national project, based on the results map of the national project, an analysis of the quality of planning the target indicators of the national project is performed.

The institutional project target planning quality factor (E_4) is the sum of the following four criteria:

- Compliance of target indicators with the goals and objectives of the project (weight 0.25);
- The ability of performers to exert managerial influence on the solution of problems when planning the values of target indicators (weight 0.25);
- Availability of resource limitations of the national project when planning the values of target indicators (weight 0.25);
- Completeness of reflection of the expected results in the context of indicators of immediate results, indicators of final results and indicators of the final effect (weight 0.25).

Based on the analysis, the value of the quality factor for planning the target indicators of the institutional project (E_4) is determined as the sum of the above four criteria.

At the sixth stage of an audit of the formation of an institutional project, the compliance of the institutional project passport with the established requirements for the procedure for developing institutional projects is checked, as well as checking the timely updating of the project passport. The project passport quality factor (E_5) is:

- Equal to 1, in the absence of significant comments on the content and (or) timely updating of the project passport;
- Equal to 0.5, if there are significant comments on the content and (or) timely updating of the project passport.

Based on the results of the check, the value of the quality factor for compiling an institutional project passport (E_5) is determined, which takes the following values:

✓ Equal to 1, in the absence of significant comments on the content and (or) timely updating of the project passport;
✓ Equal to 0.5, if there are significant comments on the content and (or) timely updating of the project passport.

At the seventh stage of an audit of the formation of an institutional project, the results obtained at the previous stages are summarized. The summary coefficient of the project formation quality is calculated by:

$$E_{\text{result}} = 0.8 \times \frac{E_{1 \times k_1 + E_{2 \times k_2} + E_{3 \times k_3}}}{3} + 0.2 \frac{E_{4 + E_5}}{2} \times M \quad (8)$$

where E_1 is the coefficient of involvement of performers in solving problems; k_1 is the value of the adjustment, taking into account the conclusion that the institutional project can meet the needs of all groups of beneficiaries (k_1 takes the values: equal to 1 if it is concluded that the national project can meet the needs of all groups of beneficiaries, equal to 0.85 if a conclusion is made about the limited ability of the national project to meet the needs of all groups of beneficiaries, equal to 0.7 if there are doubts about the ability of the national project to sufficiently meet the needs of all groups of beneficiaries); E_2 is the coefficient of coverage of tasks and components by the activities of the institutional project; k_2 is the amount of adjustment, taking into account the conclusion about the compliance of the expected results of the project with the identified tasks (k_2 takes the values: equal to 1 if it is concluded that the expected results of the institutional project correspond to the identified tasks, equal to 0.85 if it is concluded that the expected results of the institutional project meet the identified tasks in a limited way, equal to 0.7 if there are doubts about the compliance of the expected results of the institutional project with the identified tasks); E_3 is the coefficient of adequacy of resource support for the implementation of the project; k_3 is the value of the adjustment, taking into account the conclusion about the validity of the distribution of resources for project activities (k_3 takes the values: equal to 1 if a conclusion is made about the reasonableness of the distribution of resources for the activities of the institutional project, equal to 0.85, if it is concluded that the allocation of resources for the activities of the institutional project is not sufficiently justified, equal to 0.7, if there are doubts about the reasonableness of the allocation of resources for the activities of the institutional project); E_4 is thequality factor for planning project targets; E_5 is the quality coefficient of the project passport compilation; M is the maturity level of drawing up a national project passport.

For the project as a whole, an assessment of the quality of project formation (E_{result}) is calculated. The maturity level of drawing up an institutional project passport takes values in accordance with the criteria presented in Table 3.

Table 3. Criteria for the maturity level of the project.

Level of Maturity	Criteria	Value
Level 0: lack of indicators or baseline data	Achievement of goals is not characterized by indicators or indicators do not have target values, or justification is not provided to achieve target values of indicators.	0.5
Level 1: explicit assumptions	Assumptions used in justification are clearly stated; Acceptable and reliable statistical data are used; Starting points and inertial scenarios are available only for some indicators.	0.5
Level 2: realistic assumptions and sound methods	Assumptions used in justification are realistic; Methods used for forecasting are reasonable (in particular, expected changes in indicators are calculated directly or follow national and/or international examples).	0.75
Level 3: manageable contingencies	There is a plan of action in case of risks; The most significant risks are correctly identified, assessed and managed.	1

In relation to an institutional project activity, the evaluation of the quality of the formation of the project activity (E_{result}) is calculated. If the assessment of the quality of the formation of an institutional project and (or) the assessment of the quality of the formation of an individual project event takes a value of 0.8 or higher, it is concluded that the institutional project can contribute to the achievement of the national development goals of the Russian Federation for the period up to 2050.

If the assessment of the quality of the formation of an institutional project and (or) the assessment of the quality of the formation of an individual project event takes a value below 0.8, it is concluded that it is necessary to finalize the institutional project in order to contribute to the achievement of the national development goals of the Russian Federation for the period up to 2030 and up to 2050 of the year.

An assessment of the quality of the formation of an institutional project and project activities, as well as conclusions and proposals based on the results of the audit, are used when conducting a state audit of the implementation of institutional projects.

An audit of the implementation of an institutional project is aimed at assessing the achievement of the expected results of the institutional project, as well as the effectiveness of its implementation. When conducting a state audit of the implementation of institutional projects, the reliability of the information contained in the information analytical system for the implementation of institutional projects is also verified.

The first stage of an audit of the implementation of an institutional project is the analysis of the achievement of the expected results of the project. In order to analyze the achievement of expected results, the following are assessed:

- Fulfillment of institutional project milestones;
- Achievement of target indicators of the institutional project;
- Cash execution for the costs of the implementation of the institutional project [26].

The assessment of the degree of implementation of an institutional project milestones (Q) is conducted on the basis of a comparison of the actual number of milestones completed on time at the end of the reporting period and their planned number. When evaluating the degree of fulfillment of control points, the following scale is used:

"High level" of performance is assigned when the value of the score is more than 0.9;

"Average level" of performance is assigned when the score value is more than 0.7;

"Low level" of performance is assigned when the score is 0.7 or less.

If it is impossible to achieve a high level of implementation of the control points of the institutional project, an analysis of the reasons for non-fulfillment is performed, and the risk of non-fulfillment of the expected results of the institutional project is assessed. The assessment of the risk of non-fulfillment of the expected results is conducted taking into account the calculated value of the coefficient of involvement of performers in solving the identified tasks (Ei), adjusted for the conclusion that the institutional project can satisfy the needs of all groups of beneficiaries (ki).

In the case of failure to achieve a high level of implementation of the project milestones with the value of the adjusted coefficient (Ei $\times$ ki) below 0.8, it is concluded that there are significant risks of not obtaining the expected results of the institutional project.

The assessment of the achievement of the target indicators of the institutional project (Pi) is conducted on the basis of a comparison of the actual values of the indicators at the end of the reporting period and the planned values of the corresponding indicators. For a group of target indicators for direct results, the degree of achievement of target indicators for direct results (P_{direct}) is calculated. For the group of target indicators of the final results, the degree of achievement of the target indicators of the final results (P_{final}) is calculated. For the group of target indicators of the final effect, the degree of achievement of the target indicators of the final effect (P_{result}) is calculated. When assessing the degree of achievement of target indicators for each group, a single scale is used:

- "High level" of performance is assigned when the value of the score is more than 0.9;
- "Average level" of performance is assigned when the score value is more than 0.7;
- "Low level" of performance is assigned when the score is 0.7 or less.

The final assessment of the degree of achievement of the target indicators is based on the smallest of the three estimates of the groups of target indicators (P). If it is impossible to achieve a high level of target indicators, all causes are analyzed and the risk of non-fulfullment of the expected results of the project is assessed. The assessment of the risk of non-fulfillment of the expected results of the national project is conducted taking into account the calculated coefficients (E2) and (k2). If the value of the adjusted coefficient (E2× k2) is below 0.8, it is concluded that there are significant risks of non-fulfillment of the expected results of the project.

The assessment of the degree of cash execution for the costs of implementing the institutional project (R_j) is based on a comparison of the actual costs of implementing the project at the end of the reporting period and their planned level. When assessing the degree of cash execution for the costs of project implementation, a single scale is used:

- "High level" of performance is assigned when the value of the score is more than 0.9;
- "Average level" of performance is assigned when the score value is more than 0.7;
- "Low level" of performance is assigned when the score is 0.7 or less.

The final assessment of the degree of cash execution for expenses (R) from all sources for the implementation of the institutional project is based on the lowest of the estimates for each source of expenses.

If it is impossible to achieve a high level of cash execution for expenses from all sources for project implementation, the reasons for the impossibility of failures are analyzed, taking into account the calculated value of the resource adequacy ratio for project implementation (E3), adjusted by taking into account the conclusion about the reasonableness of the distribution of resources for project activities (k3).

If it is impossible to achieve a high level of cash execution for expenses from all sources for the implementation of an institutional project with the value of the adjusted coefficient (E3 × k3) below 0.8, it is concluded that there are significant risks of non-fulfillment of the expected results of the project.

The second stage of an audit of the implementation of an institutional project is the assessment of the effectiveness of its implementation. In order to assess the effectiveness of project implementation, information on the results of the analysis of the implementation of the expected results of the project, the existing significant risks of non-fulfillment of the expected results of the project, is summarized in Table 4.

Table 4. Evaluation of the effectiveness of the implementation of the institutional project.

(Q)/(P)/(R)	$E_1 \times k_1/E_2 \times k_2/E_3 \times k_3$	
	Less than 0.8	**0.8 and More**
Low level	Efficiency is low, there are significant risks of non-fulfillment of expected results of the departmental project, a revision of the content of the national project is required	Efficiency is low, there are significant risks of non-fulfillment of expected results of the departmental project
Average level	Efficiency is average, there are risks of non-fulfillment of expected results of the departmental project, a revision of the project content is required	Efficiency is average, there are risks of non-fulfillment of expected results of the departmental project
High level	Efficiency is high, risks of non-fulfillment of expected results of the departmental project are minimal, a revision of the project content is required	Efficiency is high, risks of non-fulfillment of expected results of the departmental project are minimal

As can be seen, the proposed methodology differs significantly from the traditional one [16] in the gradation of risks and the level and status of beneficiaries.

If it is possible to achieve a high level of efficiency in all areas of the assessment, a conclusion is made about the expediency of the project and its inclusion in the national plan for the period up to 2050.

4. Discussion

During this study, we conclude that there is a need to develop an integrated approach to auditing (control) the efficiency of project activities of executive authorities, which, as part of project activities, initiate and implement institutional projects, the targets of which should be aimed at achieving national development goals provided by federal and national projects. At the same time, the planning stage and the stage of analysis of the project execution are singled out as the main stages of an audit (control) of an institutional project. The main goal of the first stage is an independent assessment of the validity of goal setting and the volume and the timing of expenditures on the institutional project. At the second stage, the efficiency of budgetary resources is estimated.

The need to assess quality planning of a project was emphasized by Mark Velasquez and Patrick T [27], who paid considerable attention in their works to the need for quality selection at the stage of project initiation.

We agree with the conclusions of Primadhika M., Teguh R., Matos S. and Lopes E., who attached great importance to the pre-investment phase when assessing the quality planning of a project, and proposed using such variables as: compliance with quality characteristics, social responsibility, stake-holder satisfaction, costs, timing and reliability. This approach was considered in terms of identifying and analyzing the tasks that an institutional project is aimed at, determining executors and beneficiaries of the project, while developing individual ratios for the involvement of executors in solving identified tasks, which allows assessing the ability of the institutional project to sufficiently satisfy the needs of all groups of beneficiaries [28].

Cordoş, G. S. and Fülöp, M. T. [29] rightly believe that when estimating the efficiency of the project, it is necessary to assess the achievement of desired project results, which is consistent with the conclusion about the need to evaluate the outcome as the final effect of the institutional project.

George-Silviu, C. and Melinda-Timea, F. [30] attached great importance to project activities in the public sector, considering it to be a powerful catalyst for economic recovery and state renewal. The authors noted the need for a subsequent assessment of the results of a project's implementation, which can be both direct (immediate) and indirect (side). At the same time, the authors noted that side effects can cause a negative effect, and performance should be assessed not only in the short term, but also in the long term. As performance indicators, the authors proposed using such criteria as relevance (retaining the need for the project), sustainability (saving benefits throughout the entire implementation period) and benefit costs (cost-benefit analysis). This approach is consistent with the results of this study in terms of the need to cover the entire cycle of using public resources—from project planning to obtaining the outcome.

5. Conclusions

The presented methodology for a state audit of institutional energy projects is universal and can be used for any country. It is recommended that a state audit of institutional projects be performed in the following areas: an audit of the formation of the national project and implementation of the national project.

The methodology focuses on assessing the possibility of each institutional project providing a significant contribution to the achievement of a country's national development goals for the period up to 2050 and on identifying the risks accompanying each project.

Author Contributions: Conceptualization, E.F.; methodology, L.G.; software, T.T.; formal analysis, S.F.; writing—original draft preparation, M.B.; writing—review and editing, N.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ermolaev, K.A.; Kuzmin, M.S. Problems of modernization and transition to innovative economy. *Probl. Mod. Econ.* **2017**, *4*, 85–97.
2. Sakharov, G.V.; Kvasov, I.A. Evaluation of investment projects in the field of energy. *Sci. Work. Free. Econ. Soc. Russ.* **2021**, *156*, 283–298.
3. Borodin, A.; Mityushina, I.; Harputlu, M.; Kiseleva, N.; Kulikov, A. Factor Analysis of the Efficiency of Russian Oil and Gas Companies. *Int. J. Energy Econ. Policy* **2023**, *13*, 172–188. [CrossRef]
4. Zehir, C.; Zehir, M.; Borodin, A.; Mamedov, Z.F.; Qurbanov, S. Tailored Blockchain Applications for the Natural Gas Industry: The Case Study of SOCAR. *Energies* **2022**, *15*, 6010. [CrossRef]
5. Borodin, A.; Panaedova, G.; Frumina, S.; Kairbekuly, A.; Shchegolevatykh, N. Modeling the Business Environment of an Energy Holding in the Formation of a Financial Strategy. *Energies* **2021**, *14*, 8107. [CrossRef]
6. Mamedov, Z.F.; Qurbanov, S.H.; Streltsova, E.; Borodin, A.; Yakovenko, I.; Aliev, A. Assessment of the potential for sustainable development of electric power enterprises: Approaches, models, technologies. *Econ. Oil Gas Ind.* **2022**, *2*, 15–27. [CrossRef]
7. Degtyareva, V.V.; Kamchatova, E.Y. Development of medium and small business in the sphere of energy: Features of development of highly intelligent projects. *Econ. Soc. Mod. Model. Dev.* **2018**, *8*, 57–64.
8. Guidance GUID 3910 [Electronic Resource]. Available online: https://www.issai.org/wp-content/uploads/2019/08/GUID-3910-Central-Concepts-for-Performance-Auditing.pdf (accessed on 26 February 2023).
9. Kerzner, H. *Project Management Metrics, KPIs, and Dashboards: A Guide to Measuring and Monitoring Project Performance*; John Wiley & Sons: Hoboken, NJ, USA, 2017. Available online: https://www.amazon.com/Project-Management-Metrics-KPIs-Dashboards/dp/1119427282 (accessed on 4 November 2022).
10. Samset, K.; Christensen, T. Ex ante project evaluation and the complexity of early decision -making. *Public Organ. Rev.* **2017**, *17*, 1–17. [CrossRef]
11. Matos, S.; Lopes, E. Prince2 or PMBOK—A Question of Choice. *Procedia Technol.* **2013**, *9*, 787–794. [CrossRef]
12. Kahalnikov, M.V. Risks of energy digitalization projects under reducing carbon foorprint. *Econ. Entrep.* **2021**, *1*, 230–233.
13. Dorokhina, E.Y. Benefits and risks of green energy projects. *Probl. Sci. Thought* **2022**, *1*, 11–15.
14. Konnov, I.A. Development of a model of risk management of innovative projects in nuclear energy. *Colloq. J.* **2020**, *11*, 20–22.
15. Kulapin, K.I. Strategic development of the Russian fuel and energy complex in the light of the adoption of the Paris climate agreement. *Energy Policy* **2019**, *3*, 18–25.
16. Famuwagun, O.S. Knowledge in Contemporary Global Projects. 2020, p. 11. Available online: https://www.researchgate.net/publication/345742503_Project_Management_Methodologies_and_Bodies_of_Knowledge_in_Contemporary_Global_Projects (accessed on 15 January 2023).
17. Gasik, S. National public projects implementation systems: How to improve public projects delivery from the country level. *Procedia—Soc. Behav. Sci.* **2016**, *226*, 351–357. [CrossRef]
18. Belcher, B.M.; Claus, R.; Davel, R.; Ramirez, L.F. Linking transdisciplinary research characteristics and quality to effectiveness: A comparative analysis of five research-for-development projects. *Environ. Sci. Policy* **2019**, *101*, 192–203. [CrossRef]
19. Abanda, F.H.; Chia, E.L.; Enongene, K.E.; Manjia, M.B.; Fobissie, K.; Pettang, U.J.M.N.; Pettang, C. A systematic review of the application of multi-criteria decision-making in evaluating Nationally Determined Contribution projects. *Decis. Anal. J.* **2020**, *5*, 100–140. [CrossRef]
20. Soloviev, A.I. About the method of system modeling of the stable economic agents (using the example of the rocket and space industry). In *The Collection: Economic Security of Russia: Problems and Prospects. Materials of the III International Scientific-Practical Conference*; Nizhny Novgorod State Technical University: Nizhny Novgorod, Russia, 2015; pp. 409–415.
21. Dorzhieva, V.V. Digital transformation of the Russian fuel and energy complex: Priorities and development targets. *Kreat. Ekon.* **2021**, *15*, 4079–4094. [CrossRef]
22. *State Audit Standard 104*; External State Audit (Control) Standard; Performance Audit, Approved. Resolution of the Collegium of the Accounts Chamber of the Russian Federation: Moscow, Russia, 9 February 2021; No. 2PK.
23. *State Audit Standard 105*; External State Audit (Control) Standard; Strategic Audit, Approved. Resolution of the Board of the Accounts Chamber of the Russian Federation: Moscow, Russia, 10 November 2020; No. 17PK.
24. Gryzunova, N.; Vedenyev, K.; Manuylenko, V.; Keri, I.; Bilczak, M. Distributed Energy as a Megatrend of Audit of Investment Processes of the Energy Complex. *Energies* **2022**, *15*, 9225. [CrossRef]

25. *No. 11K (1536)*; Methodology for Assessing the Quality of the Formation and Implementation of the RF GP as Part of the Follow-Up Control over the Execution of the Federal Budget. Board of the Accounts Chamber of the Russian Federation: Moscow, Russia, 9 March 2022.
26. Głodzińsk, E. Project assessment framework: Multidimensional efficiency approach applicable for project-driven organizations. *Procedia Comput. Sci.* **2018**, *138*, 731–738. [CrossRef]
27. Velasquez, M.; Patrick, T. An Analysis of Multi-Criteria Decision-Making Methods. *Int. J. Oper. Res.* **2013**, *10*, 56–66.
28. Marnada, P.; Raharjo, T.; Hardian, B.; Prasetyo, A. Agile project management challenge in handling scope and change: A systematic literature review. *Procedia Comput. Sci.* **2021**, *197*, 290–300. [CrossRef]
29. Cordoş, G.S.; Fülöp, M.T. Understanding audit reporting changes: Introduction of Key Audit Matters. *Account. Manag. Inf. Syst. Contab. Inform. Gestiune* **2015**, *14*, 128–152.
30. George-Silviu, C.; Melinda-Timea, F. New audit reporting challenges: Auditing the going concern basis of accounting. *Procedia Econ. Financ.* **2015**, *32*, 216–224. [CrossRef]

energies

Article

Mitigating Market Power and Promoting Competition in Electricity Markets through a Preventive Approach: The Role of Forward Contracts

Dzikri Firmansyah Hakam

School of Business and Management, Institut Teknologi Bandung, Bandung 40132, Indonesia; dzikri.hakam@sbm-itb.ac.id

Abstract: This paper proposes a novel approach to optimizing the structure of the electricity market by mitigating market power through the use of forward contracts. The IEEE 30 node test system is used as a case study for the paper, which employs nodal pricing and a Cournot model with recursive optimization. The findings show that forward contracts can reduce market power and lead to a more competitive market structure with fewer participants. The study emphasizes the importance of successor companies having a well-balanced mix of generation technology. Six players with a different generational mix are optimal in the constrained nodal pricing scenario, while five players with slightly different mixes are optimal in the Cournot case study. These findings have important implications for policymakers and industry stakeholders involved in the design and implementation of efficient electricity markets. Market power can be reduced by using forward contracts and establishing an appropriate number of market participants, resulting in more efficient and sustainable electricity markets. Overall, this study provides useful insights for improving electricity market structures and increasing competition in the electricity sector.

Keywords: forward contract; nodal pricing; Cournot; market power; market structure

Citation: Hakam, D.F. Mitigating Market Power and Promoting Competition in Electricity Markets through a Preventive Approach: The Role of Forward Contracts. *Energies* **2023**, *16*, 3543. https://doi.org/10.3390/en16083543

Academic Editor: Alex Borodin

Received: 2 March 2023
Revised: 8 April 2023
Accepted: 14 April 2023
Published: 19 April 2023

1. Introduction

In recent years, many countries have undergone electricity market restructuring in order to achieve competitive pricing and maximize welfare. Despite the significant resources invested in this process, market power has emerged as a significant issue, with the potential to keep electricity prices above competitive market levels. A crucial step in establishing a competitive electricity market is the division of the monopoly generation company (GenCo) into multiple competitive successor companies. As noted by [1], an adequate number of competing generators is crucial for mitigating market power and ensuring that wholesale markets are reasonably competitive. The regulatory reform and development of a competitive electricity market depend on creating an efficient number of competitors to mitigate market power and ensure that wholesale markets are reasonably competitive. In light of this, during the early stages of the restructuring phase, the state-owned GenCo should be restructured into several competitive successor enterprises that consist of multiple types of power plants. This split aims to create a competitive environment without the existence of dominant and pivotal players in the market that could exercise market power, and competition among generating companies will also ensure a sufficient mix of energy balance in the power system. As suggested by [1], it is advisable to address potential market power structurally before restructuring, in order to mitigate the potential adverse effects on prices and welfare.

Many countries have undergone electricity market restructuring with the goal of achieving competitive pricing and maximizing welfare. However, market power has emerged as a significant issue, resulting in market failure and preventing the attainment of maximum potential welfare gains. According to the authors of [2], market prices are often susceptible to unilateral market power, with pivotal successor companies exercising market power through strategic behaviors. To mitigate these effects, it is crucial for electricity regulators to design and implement a market structure that promotes competition and ensures efficient functioning of the market, while minimizing the influence of political considerations in decision-making processes. One crucial aspect of this is creating competitive successor companies in the wholesale electricity market through divestiture, as seen in the case of England and Wales [3]. However, it is important to note that simply divesting state-owned generation companies does not guarantee competitive behavior in the market, and efforts should also be made to design an optimal electricity market structure and generation technology mix to minimize market power through market power modeling.

Mitigating market power in the design of electricity markets is crucial for ensuring competitive pricing and maximizing welfare [2,4–6]. A crucial step in achieving this is the division of the monopoly GenCo into multiple competitive successor companies, as an adequate number of competing generators is essential for mitigating market power and ensuring that wholesale markets are reasonably competitive [1]. The configuration of players post-generation split should minimize market power, which can be achieved through ex-ante simulations prior to restructuring. Traditional measures of market power, such as the Herfindahl–Hirschman Index (HHI), may not accurately capture the dynamics of competition behavior in the wholesale electricity market due to factors such as inelastic demand, significant short-term capacity constraints, and high storage costs. Therefore, an alternative method, such as the Residual Supply Index (RSI), which was developed by the California Independent System Operator (CAISO), is considered more effective for market power mitigation in the electricity market [7–9]. The RSI is more effective because it considers the supply-side response to a market change, taking into account supplier behavior in relation to available capacity. Because it captures the incentives of suppliers to adjust their supply based on market conditions, this approach allows the RSI to provide a more realistic assessment of market power. As a result, in the design of electricity markets, the RSI is a better measure of market power and more effective in mitigating market power [10]. It is important for government and electricity authorities to take these considerations into account in determining the optimal configuration of the wholesale electricity market from a state-owned electricity company.

A review of the literature on market power mitigation reveals that most studies focus on corrective measures to address market power after it has already emerged, rather than preventive strategies to minimize its potential exercise. This is especially true for countries in the early stages of restructuring their electricity markets. A preventive approach to minimize market power is crucial for achieving maximum welfare for society and can serve as a more efficient approach towards establishing a competitive electricity market. The study by [11–14] presents a preventive approach to creating optimal successor companies prior to electricity market restructuring, but it does not incorporate the use of forward contracts as a tool to mitigate market power and optimize market structure. This present research aims to extend the work of [11,13,14] by incorporating the application of forward contracts in the proposed algorithm, which can potentially optimize the market structure with fewer market participants, thus reducing the exercise of market power. As such, this research makes a significant contribution to the literature by offering a novel and preventive approach to electricity market restructuring that accounts for the use of forward contracts as a tool to mitigate market power.

This research developed a bottom-up electricity market model that incorporates significant economic features and uses an ex-ante modeling approach to provide a realistic power system analysis. The model includes various market pricing structures such as locational marginal pricing and zonal pricing, taking into account the market boundaries and grid limitations of the specific power system. The computational simulation also includes strategic market behaviors, such as imperfect and perfect competition strategic interactions, and uses the Cournot model for ease of analysis. Incorporating the Residual Supply Index (RSI) and modeling the dynamics of the power system, where each node represents a load serving entity (LSE) and a supplier, present a novel approach to mitigating market power. This simplifies the calculations for load flow simulation. The model calculates load flow using a direct current approach and models marginal cost as a linear function based on heat rate curves, resulting in a more accurate calculation of generation costs. The model also employs a restricted-stylized approach for large-scale power system simulation, in which the transmission network model is based on the actual power system topology and one node represents a single high or extra high voltage power substation.

This research presents a novel algorithm for mitigating market power in electricity market restructuring by utilizing a balance of granular and easily accessible data. The algorithm, which can be implemented by any market designer in any state, utilizes publicly available datasets and takes into account the unique characteristics of the power network, grid code, and legal features. The economic modeling combines microeconomics, power engineering, law, policy, and mathematics, and incorporates forward contracts as a tool to reduce the number of market participants and create an optimal market structure in different competition scenarios. The algorithm can be applied in electricity markets that are still in a state of monopoly and considers the unique features of the power system topology. The ultimate goal of this research is to provide a practical solution for policymakers and market designers to mitigate market power and optimize market structure, building on previous research by [5,11,12,15].

The first chapter gives an overview of the research problem, objectives, and contribution. The literature review in Section 2 is thorough, covering relevant theories and models related to electricity market restructuring, market power, and forward contracts. The methodology section is detailed in Section 3, and it includes a bottom-up electricity market model that incorporates significant economic features and employs an ex-ante modeling approach for a realistic power system analysis. The section also discusses how forward contracts can be used to reduce market power and optimize market structure, as well as the Cournot model for strategic market behaviors. The study's findings are presented in the results section in Section 4, including the optimal ownership structure and mix of successor companies, as well as the impact of forward contracts on mitigating market power. The results are analyzed in the discussion section of Section 5. Finally, the conclusions section in Section 6 summarizes the main findings, emphasizes the research contribution, and suggests future research directions.

2. Literature Review

2.1. Market Power and Preventive Antitrust Law

In his essay, the author of ref. [16] highlights the importance of economics in shaping antitrust policy, noting that economic theory plays a crucial role in shaping an economist's perspectives on competition policy. He argues that antitrust laws are designed to promote competition among market players with the ultimate goal of reducing prices and increasing consumer welfare. Stigler also explains the distinction between preventive and corrective antitrust laws, noting that most US antitrust laws are corrective in nature and aimed at eliminating existing monopolies. However, he emphasizes the importance of antimerger statutes as a tool for preventing the formation of monopolies. This aligns with the argument in [17] that US antitrust policy is not designed to regulate or approve market structures and firm behavior across the economy; instead, the system relies on case law developed through enforcement actions which may have limitations in performing complex economic evaluations.

The European Commission's approach to competition law, specifically with regard to merger policy, is focused on improving the structure of national markets through reactive measures. This means that the Commission only evaluates proposed mergers and assesses whether they will result in a better market structure than the current state. However, this approach has its limitations as the Commission cannot enforce a competitive market structure unless a merger proposal is brought forth. Additionally, the EU's competition tools, such as directives, are flexible and rely on member states to take action and implement them. As a result, these tools may not be sufficient to create a truly competitive market, as argued by the authors of [18].

Effective antitrust provisions and institutions are crucial for maintaining a competitive market. Antitrust rules provide a legal framework for enforcing action and punishment for illegal activities, while antitrust agencies have the power to ensure compliance through enforcement actions. To achieve this, it is essential to have a solid economic foundation for antitrust laws and policies. An economics-based approach allows for the development of clear and understandable antitrust provisions and enables courts to evaluate and implement antitrust policy designs. This helps ensure that market players receive clear signals and guidelines regarding allowed and prohibited strategic actions.

Creating optimal antitrust laws, as outlined in [19], involves identifying and addressing anticompetitive behaviors in the market, while also considering the impact on market welfare. By assessing these behaviors and conducting law enforcement to intervene in harmful effects, the antitrust institution also creates a deterrent for misconduct behaviors. This approach not only addresses harmful market effects but also helps maintain a competitive market by preventing future misconduct.

Antitrust law is guided by two main theories of value: an efficiency-based theory, which prioritizes the maximization of welfare and efficient allocation of resources; and a standard for permissible strategic behavior, which aims to protect weaker economic entities and consumers from the market power of monopolies. Fines and sanctions play a crucial role in enforcing competition law prohibitions. According to the authors of [20], sanctions can prevent antitrust violations in three ways: by creating a deterrent effect, by having a moral effect, and by raising the cost of setting up and engaging in anticompetitive behavior. The threat of prosecution and fines can deter companies from violating antitrust laws, create a sense of moral commitment to compliance, and increase the cost of engaging in anticompetitive behavior, such as setting up and running cartels.

2.2. Forward Contract to Mitigate Market Power

The strategic interaction of market firms can be studied using game theory and industrial organization concepts. Firms' strategic behavior is determined by their ability to predict the price and quantity decisions of other players. We chose the Cournot strategy for our study because of its simplicity and compatibility with power system characteristics such as generation and transmission constraints, voltage and stability conditions, generation ramp-up and ramp-down, contingency analysis, and commodity flow PTDF. The Cournot model involves quantity gaming, in which the strategic interaction is based on the supply provided by the company. This is in contrast to the Bertrand model, in which the quantity is the only decision variable, and each firm accepts the fixed price, resulting in no market power. While the Stackelberg model considers quantity gaming, it assumes a "leader" firm whose decisions correctly consider the reaction of "followers", who are unaware of how their reactions affect the leader's decision. This assumption may not hold true in practice, making the Cournot model a better fit for our research. Overall, by incorporating the effects of anticipation and strategic behavior among firms, the Cournot model with forward contracts can help to reduce market power in the electricity market and produce more realistic prices.

The matching of power supply with electricity demand is essential in the electricity market. To maintain this balance, power systems have objectives such as maintaining a stable frequency and voltage level. Power system dispatchers plan the export and import of electricity based on transmission characteristics and PTDF load flow. Additionally, the restructured electricity market is characterized by price volatility, particularly in the spot market. To mitigate this risk, forward contracts are important for retailers and suppliers [21].

In cases where market settings heavily rely on the spot market, as seen in the California crisis of 2000–2001, electricity market crises may occur. At the time, the system reserve margin was tight and there was a lack of forward contracts. The authors of ref. [22] suggest that implementing forward markets could have reduced or prevented the crisis. Forward contracts address three main issues in the wholesale market: investment, risk, and market power. In tight and scarce conditions, generator owners may accept profits below the true electricity price due to price cap regulations and adjustments from operators. Forward markets provide reliable payments and investment incentives for efficient entry, thus reducing this risk.

The use of forward contracts in the electricity market can help to reduce the market power of key players, as demonstrated by studies such as [23,24]. The Cournot model, which is widely used in the electricity market due to its simplicity and compatibility with power system characteristics such as generation and transmission constraints, voltage and stability conditions, and commodity flow PTDF, can be easily integrated with forward contracts. Additionally, the Cournot model is known to produce prices that are higher than would be expected with realistic demand elasticity, and forward contracts can help to make the model more realistic.

Forward contracts play a crucial role in reducing the ability of key market players to exercise market power, as demonstrated in [23] in their analysis of Cournot oligopoly behavior and in [24] in his study of the supply function equilibrium. In the electricity market, modelers often use the Cournot framework due to its simplicity and compatibility with power system characteristics, such as generation and transmission constraints, voltage and stability conditions, generation ramp-up and ramp-down, contingency analysis, and commodity flow PTDF. Incorporating forward contracts into large-scale Cournot power systems is also a convenient option. However, the Cournot equilibrium price is considered too high and output too low, when compared to realistic demand elasticity. Therefore, forward contracts can help make the model more realistic, as per [25].

In the long run, contracts can also increase new entry and competitive behavior, especially in the power plant investment sector, particularly in gas power plants. For example, in the first year after the establishment of the OFGEM (Office of Gas and Electricity Markets) in 1998, there was a significant investment of five GW gas power plants from IPPs and five GW from existing companies. This was due to the support provided by long-term forward contracts in the gas and electricity commodity market. However, as per the [24] model, contracts may also deter entry in cases where such deterrence is necessary for increasing efficiency.

3. Research Methodology

The optimized electricity market structure is based on the preventive approach developed by the authors of [11–14].

The conceptual algorithm outlines a four-step process for achieving the optimal market structure.

- The first step is to create a model of the nodal market using market characteristics and constraints. We developed perfect and imperfect (Cournot) competition models of the IEEE 30 nodes system by incorporating generation and transmission constraints. The perfect competition model is grounded in research conducted in [13–15,26–30]. The research on Cournot competition modeling served as the basis for our implementation of this approach in the study. Specifically, we relied on the work of [4,11,13,31,32]. The constraints related to generation include capacity, energy mix, and reserve margin, whereas transmission constraints encompass DC load flow, transmission limits, and line connections.
- The model is then calibrated to match the actual conditions of the power system in the second step. This includes examining market power behavior during peak loads. This step is critical for ensuring that the model accurately reflects the power system's real-world conditions.
- The third step is to use a power plant merger analysis to examine potential market structure configurations. We assume that companies that own multiple power plants behave as multi-plant monopolists [33]. This step takes into account things such as

the initial generation structure and the presence of independent power plants. The goal is to determine the best ownership structure and succession company mix.

- The final step is to assess market power using the Residual Supply Index (RSI) and consider any additional capacity investments that may be required. This step ensures that the market structure is competitive, and that welfare is maximized while addressing any issues with generation capacity and reserve margin. Based on the empirical study in [7–9], we used a screening process to determine the optimal market structure for each configuration. The screening process was based on an RSI threshold of 110%.

It should be noted that each cascading optimization in the study calculates various factors such as nodal price, nodal demand, nodal supply, nodal consumer surplus, nodal producer surplus, and power flow for each market configuration. However, for the purpose of our analysis, we primarily focus on the Residual Supply Index (RSI) calculation for each market setting. Specifically, we select the highest RSI value among all possible market settings as our main point of emphasis. This algorithm's overarching goal is to achieve a competitive market structure that maximizes welfare while addressing any issues with generation capacity and reserve margin. Policymakers and market designers can follow this four-step process.

The methodology used in this study is a single-shot game methodology in which generating firms submit fixed supply functions to the ISO while taking into account their competitors' bid functions. This is used for a single bidding period, and once all firms have submitted bids, the ISO clears the market, resulting in a market-clearing price. This price is determined by the ISO based on the market's generation and transmission network structure, as well as the balance of supply and demand for electricity. The ISO pays the bus nodal price to all generating firms based on the amount of electricity sold to the pool in this model, and consumers pay the ISO the electricity price based on the active power load received.

3.1. Nodal Pricing and DC Power Transmission System

The concept of nodal pricing, as established by [34,35], is a fundamental theory used to determine optimal electricity prices that achieve welfare maximization under specific constraints. In this research, we perform a nodal pricing analysis based on Optimal Power Flow (OPF) and a marginal cost calculation at each node. The authors of ref. [36] incorporated transmission constraints and optimized electricity prices as a dual value in the program's implementation of nodal pricing in the England and Wales market. The authors of ref. [27] expanded on this implementation by accounting for transmission losses in the optimal power flow (OPF) in order to apply nodal pricing in the same market. However, in this study, transmission losses are assumed to be minimal, and the load flow formulation is approximated into the DC load flow. The equilibrium structure is then used to calculate the Nash equilibrium for specific bid functions and the electricity network [37].

Kirchhoff's law is a fundamental principle that governs power flow in power systems. The vector sum of the currents at any node in a circuit must be zero. This law governs all electrical circuits, including power grids. Kirchhoff's law can be restated in terms of power flow in a grid as the vector sum of a node's input and output being equal to the electricity injection at that node. This means that the power flow through any node in the system must be balanced, with the power flowing in equaling the power flowing out. Kirchhoff's law must be followed to ensure the stability and reliability of the power system, as any deviation from this principle can cause power flow imbalances and potential power outages. To ensure the accuracy and stability of our power flow calculations, we use Kirchhoff's law as a fundamental principle in our bottom-up electricity market model in this study.

We assume that bus i is the sending node and j is the receiving node, connected by transmission line ij. V_m is the voltage magnitude, V_θ is the voltage angle, and θ is the phase angle. G_{ij} and B_{ij}, respectively, are conductance and susceptance of transmission line ij. The AC power flow from bus i to j is defined as $P_{ij}(AC)$:

$$P_{ij}(AC) = V_m V_\theta \left[G_{ij}\cos(\theta_i - \theta_j) + B_{ij}\sin(\theta_i - \theta_j)\right] - V_m^2 G_{ij} \quad (1)$$

If P_{ij} is positive, then the power is flowing from bus i to bus j, and vice versa.

Using the AC power flow equation, the DC power flow $P_{ij}(DC)$ assumes that voltage magnitudes bus i and j equal to 1 p.u. (per unit) and $(\theta_i - \theta_j) < \frac{2\pi}{9}$, which implies that $\cos(\theta_i - \theta_j) \approx 1$ and $\sin(\theta_i - \theta_j) \approx (\theta_i - \theta_j)$ for a normal operating condition in the power system.

$$P_{ij}(DC) = B_{ij}(\theta_i - \theta_j) \quad (2)$$

In power system theory, the susceptance B_{ij} is the imaginary part of admittance Y_{ij} and could be denoted as $\frac{1}{X_{ij}}$ where X_{ij} is the reactance of the transmission lines. Thus, the DC power flow could be stated as:

$$(\theta_i - \theta_j) = X_{ij} P_{ij}(DC) \quad (3)$$

We assume a power setting with m transmission lines and n nodes. X is a vector of reactance ($m \times m$). P_F is a vector of DC power flow ($m \times 1$). M is the node–branch incidence matrix for the angle phase vector matrix ($n - 1 \times m$) excluding the reference node (slack bus), i.e., the node with phase angle is zero. P is the power injection matrix ($n - 1 \times 1$). B is the susceptance matrix. PTDF is the power transfer distribution factor. The DC power flow vector equation could be expressed in a matrix form as PTDF vector multiplies the power injection vector:

$$\begin{gathered} PTDF = X^{-1} M^T B^{-1} \\ M^T \theta = X P_F \\ P_F = X^{-1} M^T \theta \\ P = M P_F = M X^{-1} M^T \theta = B\theta \\ P_F = X^{-1} M^T B^{-1} P = PTDF\ P \\ P_F = \sum_i PTDF(\, q_{si} - q_{di}) \end{gathered} \quad (4)$$

The power injection at node n is calculated using the DC power flow assumption as the difference between power generation production q_{Si} and consumer demand q_{li}. As a result, the transmission line's power flow can be represented as a linear function of PTDF and $q_{si} - q_{di}$.

3.2. Supply and Demand

The GenCo generates electricity based on the actual cost of the generator, while the consumer provides demand functions that represent the amount of electricity consumed. The demand function is the derivative of the benefit function, while the marginal cost function is the derivative of the total cost function. The consumer utility function is an inverse quadratic function as follows:

$$UD_i(q_{di}) = a_i q_{di} - b_i {q_{di}}^2; i = 1, \ldots, I \quad (5)$$

The load demand coefficient and active load demand at node i are represented by a_i, b_i, and q_{di}, respectively. The coefficient a_i is a positive value, and I indicates the number of consumers.

The demand function's slope is negative, and it follows a linear form in the inverse.

$$p_i(q_{di}) = a_i - b_i q_{di}; i = 1, \ldots, I \quad (6)$$

Total generation cost $TC_i(q_{si})$ consists of fixed (f_i) and variable cost $C_i(q_{si})$

$$TC_i(q_{si}) = f_i + c_i q_{si} + \frac{1}{2} d_i {q_{si}}^2; i = 1, \ldots, I \tag{7}$$

$$C_i(q_{si}) = c_i q_{si} + \frac{1}{2} d_i {q_{si}}^2;\ i = 1, \ldots, I \tag{8}$$

$$UD_i(q_{li}) = c_i q_{li} - \frac{1}{2} d_i {q_{li}}^2; i = 1, \ldots,\ I \tag{9}$$

The bid or marginal cost function $MC_i(q_{si})$ of a generating firm is represented as a linear function because a constant marginal cost does not fully capture the true cost of generation in the power sector. We defined c_i as the intercept of the marginal cost, while d_i was the slope of the marginal cost which reflected the true cost of the Genco.

$$MC_i(q_{si}) = c_i + d_i q_{si};\ i = 1, \ldots, I \tag{10}$$

Consumer surplus is defined as the net benefit of consumers. The total consumer surplus is computed by adding the individual consumer surpluses based on the price. The consumer surplus in each region is determined by a variety of factors, including the structure of the power network, the location of generators and consumers, and transmission constraints. Let $D_i(p_i)$ represent consumer i's electricity demand at price (p_i). The consumer surplus for the inverse linear demand function is expressed as follows:

$$CS_i(p_i) = \frac{1}{2}(a_i - p_i) D_i(p_i);\ i = 1, \ldots, I \tag{11}$$

The producer surplus is the profit earned by a generator from selling electricity to the power pool and can be expressed as $PS_i(p_i)$.

$$PS_i(p_i) = \frac{1}{2}(p_i - c_i) q_{si}(p_i);\ i = 1, \ldots, I \tag{12}$$

3.3. ISO Problem in Nodal Pricing

The system operator balances electricity supply and demand using a mechanism known as the balancing mechanism. The ISO's goal is to maximize total welfare, denoted by $\pi_i\ (p)$, by selecting a single price for each bus I (1, ... , *I*) in the network while taking the network's limits (generation and transmission) into account as both inequality and equality constraints. Let $P_i(q_{di})$ represent the benefit from electricity consumption, $MC_i(q_{si})$ represent the total cost of generators at node i, q_{si} represent the active load supply from the generator at bus i, and $\overline{q}_{si}$ represent the available capacity of the generator at node i. The problem of maximizing ISO welfare can be expressed as follows:

$$\begin{gathered} \underset{q_{di}}{max} \left(\sum_i P_i(q_{di}) q_{di} - \sum_i MC_i(q_{si}) \right) \\ \text{Subject to/constraints :} \\ \text{Electricity demand balance } \sum_i q_{si} - \sum_i q_{di} = 0 \\ \text{Transmission constraint } \sum_l PTDF(\ q_{si} -\ q_{di}) \le T_l, -T_l\ \le \sum_l PTDF(\ q_{si} -\ q_{di}) \\ \text{Generation constraint } q_{si} \le \overline{q}_{si} \\ \text{Non} - \text{negativity } q_{di} > 0, q_{si} > 0 \end{gathered} \tag{13}$$

3.4. Cournot Equilibrium Determination

We assume each node has a unique inverse linear demand function and the total demand function is defined as:

$$P(Q) = \alpha - \beta Q \tag{14}$$

where Q is the total demand for a particular interconnected power system and P is the Cournot equilibrium price.

In a competitive electricity market, generating firms make decisions on the amount of electricity they wish to produce and sell, based on market conditions and their own costs. This output decision, in turn, affects the market price level through the inverse demand relationship. In a single-shot game, firms assume that their rivals' outputs are constant and use this information to calculate their own profit function, which is the difference between their benefit function and total cost function. The role of the independent system operator (ISO) is to ensure that this profit function is maximized for all players, taking into account the constraints imposed by the power network. In a Cournot equilibrium, the profit function for each firm (i) is given by a specific mathematical equation that takes into account the output decisions and costs of all firms in the market.

$$\pi_i = \left(\alpha - \beta\left(\sum_{i=1}^{i=I} q_i\right)\right)q_i - \left(f_i + c_i q_i + \frac{1}{2}d_i {q_i}^2\right) \tag{15}$$

The above profit function is in quadratic form and concave. Hence, the derivative solution for ISO profit maximization is easy to calculate.

$$\frac{d\pi_i}{dQ_i} = \alpha - \beta\left(\sum_{i=1}^{i=I} q_i\right) - \beta q_i - (c_i + d_i q_i) \tag{16}$$

Taking the function's derivative with respect to each node and setting it to zero yields a matrix equation with the variable subject to the total demand and cost function coefficients. The array's size is determined by the number of participants in the electricity network.

When the derivative function is set to zero in each node, a matrix equation with q_i as the subject variable and subject to the total demand and cost function coefficient is obtained. The array's size is determined by the number of participants in the electricity network.

$$\begin{bmatrix} -2\beta - d_1 & -\beta & \dots & -\beta & -\beta \\ -\beta & -2\beta - d_2 & \dots & -\beta & -\beta \\ \dots & \dots & \dots & \dots & \dots \\ -\beta & -\beta & \dots & -2\beta - d_{I-1} & -\beta \\ -\beta & -\beta & \dots & -\beta & -2\beta - d_I \end{bmatrix} \begin{bmatrix} q_1 \\ q_2 \\ \dots \\ q_{I-1} \\ q_I \end{bmatrix} = \begin{bmatrix} c_1 - \alpha \\ c_2 - \alpha \\ \dots \\ c_{I-1} - \alpha \\ c_I - \alpha \end{bmatrix}$$
$$\begin{bmatrix} q_1 \\ q_2 \\ \dots \\ q_{I-1} \\ q_I \end{bmatrix} = \begin{bmatrix} 2\beta + d_1 & \beta & \dots & \beta & \beta \\ \beta & 2\beta + d_2 & \dots & \beta & \beta \\ \dots & \dots & \dots & \dots & \dots \\ \beta & \beta & \dots & 2\beta + d_{I-1} & \beta \\ \beta & \beta & \dots & \beta & 2\beta + d_I \end{bmatrix}^{-1} \begin{bmatrix} \alpha - c_1 \\ \alpha - c_2 \\ \dots \\ \alpha - c_{I-1} \\ \alpha - c_I \end{bmatrix} \tag{17}$$

The FOC profit maximization has diagonal function $2\beta + d_i$ with $0 < \beta < 1$ and $0 < d_i < 1$; therefore, the coefficient of the matrix is positive and will give a unique solution for each q_i.

The object variable q_i is the Cournot best response function in the network and could be defined as q_i^*.

$$q_i^* = \frac{(\alpha - c_i) - \left(\beta \sum_{i \neq j}^{j} q_j\right)}{2\beta + d_I} \tag{18}$$

In a case where the generating firms are symmetric, i.e., produce electricity in a uniform marginal cost, c_i and d_i coefficients are equivalent for all firms.

The power system is composed of numerous subnetworks in the actual power system topology, with each node representing a single load serving entity (LSE) and one or more power plant technologies. Each power plant technology, such as the base, intermediate, and peaking power plants, has a distinct linear marginal cost that reflects its distinct generation characteristics. The power system's power plant technology mix can be classified based on the power plant's ability to ramp-up and ramp-down to adjust to fluctuations in LSE aggregate electricity demand. Peak-load power plants have high ramping rates, low fuel costs, and relatively short construction times, whereas base-load power plants have low ramping rates, low fuel costs, and relatively short construction times.

When a GenCo operates multiple power plants, it behaves similarly to a monopolist with multiple plants, with the marginal cost of each plant determining the cost of generating electricity. When two power plants merge, their marginal cost functions are added horizontally. The efficiency constant used in the merger process is 1, which means that the GenCo's efficiency before and after the merger is the same ($e_{pre-merger} = e_{post-merger}$).

To describe the system with two power plants that have a linear marginal cost $mc_1 = c_1 + d_1q_1$ and $mc_2 = c_2 + d_2q_2$, the combining marginal cost is mc_{12}, where $c_{12} = \left[\frac{c_1d_2+c_2d_1}{d_1+d_2}\right]$ and $d_{12} = \left[\frac{d_1d_2}{d_1+d_2}\right]$. The merger of the power plants results in changes to both the original marginal costs mc_i and the supplier capacity k where $k_{12} = k_1 + k_2$. Note that for uniform power plant capacity, the combined generation capacity is the maximum supplier capacity $k_{max} = k_{12}$.

The application of forward contract in this study is following the work by the authors of [23]. The producers could supply electricity in the forward market by determining a definite quantity as contract coverage, and then bid in the spot market. The system operator clears the market according to the Cournot game. Based on [23], we assume two players x and y with inverse demand function $q(z) = (a - z)$. The cost functions are $c(x) = bx$ and $d(y) = by$ with forward contracts f and g, respectively. The profit functions in the Cournot equilibrium for x and y with a constant marginal cost and forward sales are $\pi_x = (a - x - y)(x - f) - bx)$ and $\pi_y = (a - x - y)(y - g) - by$. Solving FOC for both equations above leads to reaction function $x(y) = \frac{a-b+f-y}{2}$. The quantity's Nash equilibriums are $x = \frac{a-b+2f-g}{3}$ and $y = \frac{a-b+2g-f}{3}$, while the Cournot price is $q = \frac{a-b-f-g}{3}$.

The authors of ref. [21] conducted a forward contract study using the RSI and proving that the RSI is suitable for a competition analysis and has an ability to determine the potential of generators to raise prices considering contracts and non-price-responsive supplies. Incorporating the forward contract, the RSI formula is $r_i = \frac{k^T-k_i}{Q}$, where k^T is the total installed capacity, Q is the total demand equilibrium, and k_i is the relevant capacity (capacity—forward contract). Based on this equation, the forward contract reduces the GenCo's relevant capacity. Therefore, the contract mitigates the market power by increasing the residual supply faced by the market.

4. Case Study and Numerical Results

4.1. Case Study: Modified IEEE 30 Bus

In this study, we use a modified IEEE 30 bus power system to gain insights into power system analysis and economics. The system comprises 132 and 33 kV transmission lines with a combination of single, parallel, and phi line configurations. This test system is composed of five power producer nodes, twelve load serving entities nodes, eight power producer–load serving entities nodes, and the remaining nodes are null nodes with zero supply and demand. We have assumed the presence of 13 power plants located at nodes (1, 2, 3, 8, 11, 13, 14, 15, 18, 22, 23, 27, 30). To determine the optimal ownership structure and the mix of successor companies, we model the IEEE 30 bus electricity system into three types of power plant technology: base, intermediate, and peak power plants. As seen in Figure 1, base-load power plants are located at nodes 2, 11, 14, 22, and 23, and are represented in green. Intermediate power plants are located at nodes 1, 13, 18, and 27 and are represented in blue. Lastly, peak power plants are located at nodes 3, 8, 15, and 30 and are represented in yellow. The marginal cost is a linear function, as can be seen in Table 1.

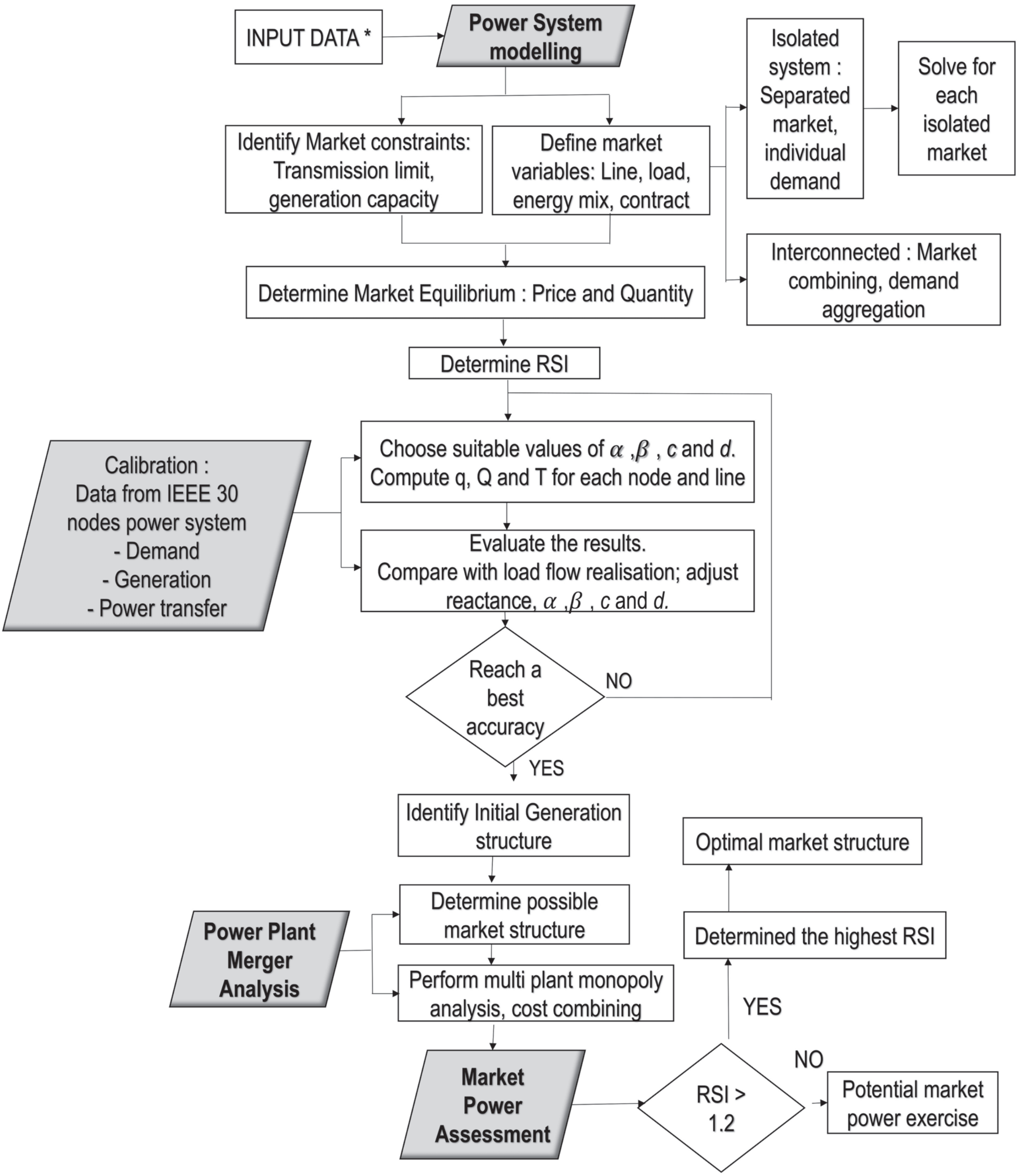


Figure 1. IEEE 30 bus test power system.

Table 1. Marginal cost function.

Type	PP	c_i	d_i
Base	Coal PP	30	0.1
Intermediate	Gas	35	0.15
Peaking	Diesel	40	0.2

The IEEE 30 bus power system is distinguished by its radial structure, with power flowing from the source to the loads via a single path, as well as its interconnection with other power systems. These characteristics must be taken into account when analyzing the behavior of the power system and optimizing its performance. The arrangement of components in the power system, including generators, transmission lines, transformers, and loads, is one of the unique features of the power system topology. The topology of the IEEE 30 nodes system includes the specific types of components used, the system layout and design, and the specific operating conditions under which the system operates. The system, for example, includes a mix of base-, intermediate-, and peaking-load power plants, and the transmission lines vary in length and capacity. These characteristics influence the behavior of the power system and must be considered when analyzing its performance.

The IEEE 30 bus power system is chosen as the test system in this study due to its widespread acceptance in the power system community and well-documented properties. The modified IEEE 30 bus power system used in this study includes a variety of transmission line configurations, load serving entities, and power producer nodes. It consists of a mix of base, intermediate, and peak power plants, which are the most common types of power plants in the electricity industry. We can gain valuable insights into the optimal ownership structure and the mix of successor companies by modeling this system, which can help policymakers and market designers create a competitive electricity market structure. Additionally, by using a well-known and well-documented system, we can ensure the replicability and generalizability of our results. Overall, the use of the IEEE 30 bus power system in this study is justified as it provides a realistic and well-documented test bed for a power system analysis and economics.

The marginal cost function for each type of power plant, which includes base-load PP, intermediate PP, and peaking PP, is displayed in Table 1. c_i and d_i represent the intercepet and slope of the marginal cost function, respectively. Table 2 lists the nodal information, including the generation capacity and load demand for each node in MW. The total demand in the system is 1530 MW, which is equivalent to the total supply. The demand and marginal cost functions are based on real-world data and have been calibrated to align with actual nodal and aggregated demand and supply. The nodal demand in this test system is characterized by an inelastic demand curve, which remains unchanged for the Cournot case study. In addition, we use transmission line capacity data as specified in Table 3 to accurately represent the transmission constraints in the system. This information is crucial for understanding the power flow dynamics and economic behavior of the market participants in the simulation.

Table 2. Load and installed capacity (MW).

n	k_i (MW)	q_{di} (MW)	n	k_i (MW)	q_{di} (MW)
1	100	10	16	0	9
2	200	0	17	0	0
3	50	20	18	100	35
4	0	0	19	0	17
5	0	85	20	0	60
6	0	0	21	0	34
7	0	50	22	150	0
8	130	25	23	150	85

Table 2. *Cont.*

n	k_i (MW)	q_{di} (MW)	n	k_i (MW)	q_{di} (MW)
9	0	0	24	0	9
10	0	190	25	0	9
11	120	0	26	0	0
12	0	50	27	120	0
13	120	20	28	0	27
14	160	50	29	0	35
15	100	50	30	30	0

Table 3. Transmission line characteristics in IEEE 30 bus power system.

From i	to j	X_{ij} (p.u)	T_l (MW)	From i	to j	X_{ij} (p.u)	T_l (MW)
1	2	0.06	130	15	18	0.22	100
1	3	0.19	130	18	19	0.13	100
2	4	0.17	65	19	20	0.07	132
3	4	0.04	130	10	20	0.21	64
2	5	0.2	130	10	17	0.08	64
2	6	0.18	90	10	21	0.07	64
4	6	0.04	90	10	22	0.15	64
5	7	0.12	140	21	22	0.02	64
6	7	0.08	130	15	23	0.2	64
6	8	0.04	132	22	24	0.18	96
6	9	0.21	96	23	24	0.27	100
6	10	0.56	96	24	25	0.33	64
9	11	0.21	65	25	26	0.38	130
9	10	0.11	65	25	27	0.21	65
4	12	0.26	65	28	27	0.4	65
12	13	0.14	65	27	29	0.42	64
12	14	0.26	64	27	30	0.6	64
12	15	0.13	132	29	30	0.45	18
12	16	0.2	64	8	28	0.2	32
14	15	0.2	64	6	28	0.06	32
16	17	0.19	100				

4.2. Numerical Results

This section presents the results of a power system simulation that was conducted to explore the impact of different market structures on the overall performance of the system. We use the IEEE 30 bus power system model as the basis for our simulation and apply it to three different scenarios: (1) locational marginal pricing (LMP) with transmission constraints as a base case, (2) Cournot modeling, and (3) Cournot with forward contracts. The main objective of this numerical analysis is to determine the optimal mix and structure for each case study, the minimum number of players needed to create a competitive market, and the optimal contract coverage. To achieve this, we use a deterministic approach and provide ad-hoc configurations for each market structure. Through this simulation, we aim to gain valuable insights into the effects of different market structures on the performance of the power system and identify the most efficient and effective market design for ensuring a competitive and well-functioning electricity market.

4.2.1. Base Case: Nodal Pricing with Transmission Constraint

The load flow for the base case power system can be seen in Figure 2 below. As illustrated in the figure, congestion arises at lines 1–4, 2–9, 3–12 and 4–14, indicating that transmission constraints are limiting the ability of local power producers with low marginal costs in certain regions to transfer their cheap power to other areas. This results in market power, higher electricity prices, and lower welfare. Furthermore, in real power systems, these transmission bottlenecks can lead to forced system outages where the load flow exceeds its transfer limit and causes damage to the cables. This further enables power producers to exercise market power. Table 4 below illustrates the four congested transmissions in the IEEE 30 bus power system, providing a clear picture of the transmission constraints that are impacting the power system.

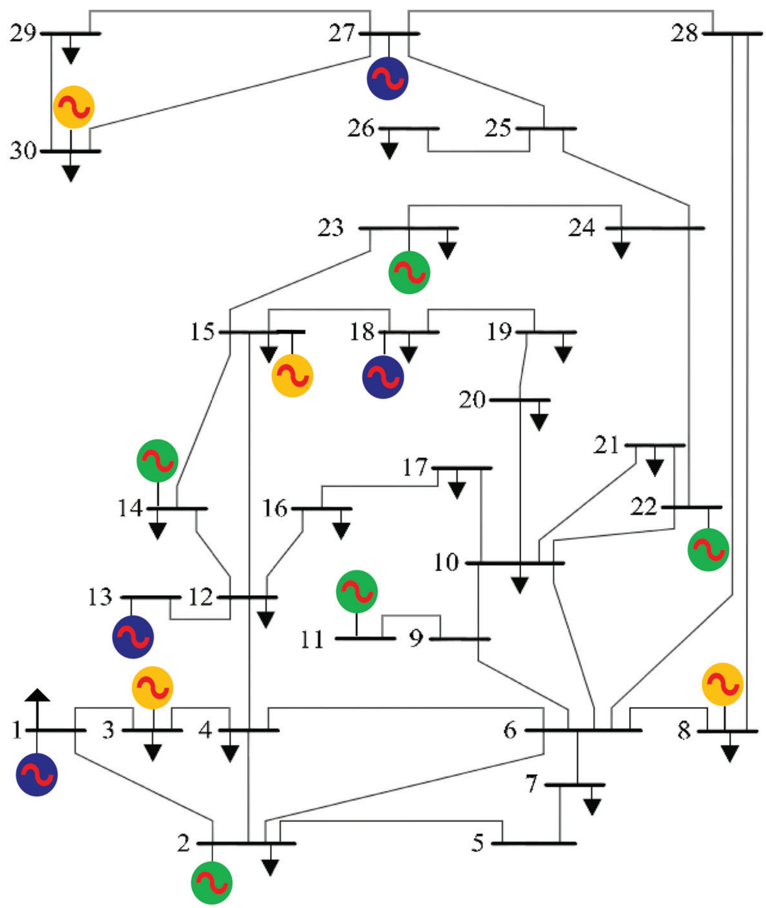


Figure 2. IEEE 30 bus test power system.

Table 4. Congested transmission lines IEEE 30 bus.

No	From i	To j	$P_{ij}(DC)$ (MW) Case 1: Perfect Competition
1	4	6	90
2	9	10	65
3	12	13	−65
4	14	15	64

The shift factor matrix, as shown in Table 5, is a crucial tool in determining the optimal load flow for each transmission line in the base case scenario. This matrix represents the proportion of the load on each line that is shifted to other lines in order to alleviate transmission congestion and improve overall system performance. By analyzing the shift factors, it is possible to identify which lines are the most congested and in need of additional capacity or upgrades. Furthermore, the shift factors can be used to determine the most cost-effective solutions for addressing transmission constraints, such as building new transmission lines or upgrading existing ones. Additionally, this information can also be used to inform pricing mechanisms and market design, as it can help to identify which generators are most affected by transmission constraints and therefore may be able to exercise more market power. Overall, the shift factor matrix is an essential tool for understanding and improving the performance of power systems in a competitive market environment.

The pre-model market configuration consists of 13 firms with a total capacity of 1530 MW. Through the application of a merger analysis in the model, we have determined the optimal market structure for 12 players as can be seen in Table 6 and Figure 3. This optimal structure is achieved when the power plant in node 15 is combined or merged with the power plant in node 30. The merger results in a Residual Supply Index (RSI) of 1.526, indicating that the combined firm's market power is reduced, and competition is enhanced. A merger analysis is a common approach used in antitrust policy to assess the potential effects of a merger on competition in a market. By analyzing the market structure and the impact of a merger on the concentration of market power, regulators can make informed decisions on whether to approve or reject a proposed merger. In this case, the merger of the two power plants in nodes 15 and 30 is deemed to be optimal as it results in a more competitive market, with reduced market power and increased welfare for consumers.

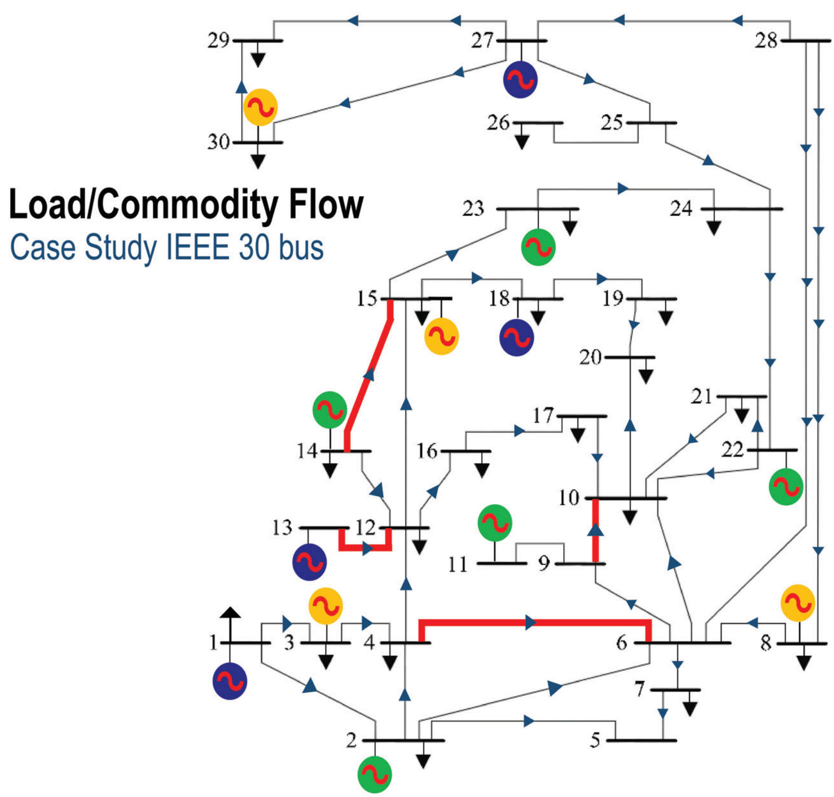


Figure 3. Load flow for base case IEEE 30 bus power system.

Table 5. Shift factor matrix IEEE 30 test bus.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	0.662	−0.177	0.152	0.045	−0.092	−0.007	−0.041	−0.007	0.002	0.006	0.002	0.024	0.024	0.021	0.019	0.016	0.009	0.015	0.012	0.011	0.007	0.007	0.015	0.008	0.003	0.003	0.00E+00	−0.006	0.00E+00	0.00E+00
2	0.338	0.177	−0.152	−0.045	0.092	0.007	0.041	0.007	−0.002	−0.006	−0.002	−0.024	−0.024	−0.021	−0.019	−0.016	−0.009	−0.015	−0.012	−0.011	−0.007	−0.007	−0.015	−0.008	−0.003	−0.003	0.00E+00	0.006	−2.22E−16	0.00E+00
3	0.224	0.303	−0.024	−0.076	0.157	0.012	0.070	0.012	−0.003	−0.011	−0.003	−0.041	−0.041	−0.036	−0.033	−0.028	−0.016	−0.025	−0.021	−0.018	−0.012	−0.012	−0.025	−0.014	−0.006	−0.006	0.00E+00	0.011	0.00E+00	0.00E+00
4	0.338	0.177	0.848	−0.045	0.092	0.007	0.041	0.007	−0.002	−0.006	−0.002	−0.024	−0.024	−0.021	−0.019	−0.016	−0.009	−0.015	−0.012	−0.011	−0.007	−0.007	−0.015	−0.008	−0.003	−0.003	0.00E+00	0.006	0.00E+00	0.00E+00
5	0.136	0.161	0.055	0.038	−0.422	−0.006	−0.172	−0.006	0.002	0.005	0.002	0.020	0.020	0.018	0.016	0.014	0.008	0.012	0.010	0.009	0.006	0.006	0.012	0.007	0.003	0.003	4.44E−16	−0.005	0.00E+00	0.00E+00
6	0.302	0.358	0.122	0.084	0.173	−0.013	0.061	−0.013	0.003	0.012	0.003	0.044	0.044	0.040	0.036	0.031	0.018	0.028	0.023	0.020	0.013	0.013	0.027	0.016	0.006	0.006	4.44E−16	−0.012	0.00E+00	0.00E+00
7	0.404	0.326	0.650	0.701	0.109	−0.108	−0.021	−0.106	0.029	0.101	0.029	0.372	0.372	0.333	0.303	0.257	0.147	0.232	0.190	0.168	0.106	0.108	0.229	0.130	0.051	0.051	1.78E−15	−0.096	0.00E+00	0.00E+00
8	0.136	0.161	0.055	0.038	0.578	−0.006	−0.172	−0.006	0.002	0.005	0.002	0.020	0.020	0.018	0.016	0.014	0.008	0.012	0.010	0.009	0.006	0.006	0.012	0.007	0.003	0.003	0.00E+00	−0.005	2.22E−16	0.00E+00
9	−0.136	−0.161	−0.055	−0.038	−0.578	0.006	−0.828	0.006	−0.002	−0.005	−0.002	−0.020	−0.020	−0.018	−0.016	−0.014	−0.008	−0.012	−0.010	−0.009	−0.006	−0.006	−0.012	−0.007	−0.003	−0.003	0.00E+00	0.005	4.44E−16	0.00E+00
10	0.129	0.129	0.128	0.128	0.129	0.130	0.130	−0.736	0.117	0.110	0.117	0.113	0.113	0.110	0.108	0.112	0.110	0.109	0.109	0.109	0.105	0.104	0.098	0.085	0.033	0.033	1.78E−15	−0.063	0.00E+00	0.00E+00
11	0.126	0.128	0.118	0.116	0.135	0.142	0.140	0.140	−0.474	−0.273	−0.474	−0.082	−0.082	−0.103	−0.119	−0.164	−0.241	−0.173	−0.205	−0.222	−0.255	−0.249	−0.141	−0.172	−0.067	−0.067	−1.78E−15	0.127	−9.99E−16	0.00E+00
12	0.072	0.073	0.067	0.067	0.077	0.081	0.080	0.080	−0.075	−0.156	−0.075	−0.047	−0.047	−0.059	−0.068	−0.094	−0.138	−0.099	−0.117	−0.127	−0.145	−0.142	−0.081	−0.098	−0.038	−0.038	−9.99E−16	0.073	−5.55E−16	0.00E+00
13	0.0E+00	0.0E+00	4.4E−16	8.9E−16	0.0E+00	0.0E+00	4.4E−16	0.0E+00	−4.4E−16	0.0E+00	−1.0E+00	4.4E−16	4.4E−16	0.0E+00	4.4E−16	4.4E−16	0.0E+00	4.4E−16	0.0E+00	0.0E+00	−4.4E−16	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.2E−16	4.4E−16	1.1E−16	0.0E+00
14	0.126	0.128	0.118	0.116	0.135	0.142	0.140	0.140	0.526	−0.273	0.526	−0.082	−0.082	−0.103	−0.119	−0.164	−0.241	−0.173	−0.205	−0.222	−0.255	−0.249	−0.141	−0.172	−0.067	−0.067	−1.33E−15	0.127	−1.11E−15	0.00E+00
15	0.159	0.154	0.174	0.177	0.140	0.127	0.132	0.124	−0.034	−0.118	−0.034	−0.437	−0.437	−0.390	−0.355	−0.301	−0.172	−0.272	−0.223	−0.197	−0.124	−0.126	−0.269	−0.153	−0.059	−0.059	2.22E−16	0.113	1.11E−16	0.00E+00
16	8.88E−16	0.00E+00	1.78E−15	0.00E+00	1.78E−15	0.00E+00	0.00E+00	0.00E+00	8.88E−16	1.78E−15	8.88E−16	8.88E−16	−1.00E+00	1.78E−15	8.88E−16	1.78E−15	8.88E−16	0.00E+00	−8.88E−16	1.78E−15	1.78E−15	0.00E+00	8.88E−16	8.88E−16	1.33E−15	4.44E−16	4.44E−16	8.88E−16	0.00E+00	0.00E+00
17	0.028	0.027	0.030	0.030	0.026	0.024	0.025	0.024	0.007	−0.001	0.007	0.076	0.076	−0.463	−0.109	0.043	0.012	−0.072	−0.049	−0.037	−0.006	−0.008	−0.075	−0.029	−0.011	−0.011	6.66E−16	0.021	−1.11E−16	0.00E+00
18	0.099	0.097	0.105	0.106	0.091	0.085	0.087	0.084	0.026	−0.004	0.026	0.270	0.270	−0.101	−0.387	0.153	0.042	−0.253	−0.174	−0.132	−0.023	−0.028	−0.266	−0.102	−0.040	−0.040	−4.44E−16	0.076	−6.66E−16	0.00E+00
19	0.032	0.030	0.039	0.041	0.024	0.018	0.020	0.017	−0.068	−0.112	−0.068	0.217	0.217	0.174	0.141	−0.498	−0.226	0.053	0.000	−0.028	−0.096	−0.091	0.072	−0.021	−0.008	−0.008	−1.11E−15	0.016	−6.66E−16	0.00E+00
20	0.028	0.027	0.030	0.030	0.026	0.024	0.025	0.024	0.007	−0.001	0.007	0.076	0.076	0.537	−0.109	0.043	0.012	−0.072	−0.049	−0.037	−0.006	−0.008	−0.075	−0.029	−0.011	−0.011	−1.33E−15	0.021	−2.22E−16	0.00E+00
21	0.032	0.030	0.039	0.041	0.024	0.018	0.020	0.017	−0.068	−0.112	−0.068	0.217	0.217	0.174	0.141	0.502	−0.226	0.053	0.000	−0.028	−0.096	−0.091	0.072	−0.021	−0.008	−0.008	−1.55E−15	0.016	−6.66E−16	0.00E+00
22	0.004	0.003	0.008	0.008	−0.001	−0.004	−0.003	−0.004	−0.056	−0.083	−0.056	0.106	0.106	0.151	0.185	0.026	−0.051	−0.559	−0.408	−0.327	−0.067	−0.062	0.109	0.005	0.002	0.002	−1.11E−15	−0.004	−4.44E−16	0.00E+00
23	0.004	0.003	0.008	0.008	−0.001	−0.004	−0.003	−0.004	−0.056	−0.083	−0.056	0.106	0.106	0.151	0.185	0.026	−0.051	0.441	−0.408	−0.327	−0.067	−0.062	0.109	0.005	0.002	0.002	−4.44E−16	−0.004	0.00E+00	0.00E+00
24	0.004	0.003	0.008	0.008	−0.001	−0.004	−0.003	−0.004	−0.056	−0.083	−0.056	0.106	0.106	0.151	0.185	0.026	−0.051	0.441	0.592	−0.327	−0.067	−0.062	0.109	0.005	0.002	0.002	0.00E+00	−0.004	−4.44E−16	0.00E+00
25	−0.004	−0.003	−0.008	−0.008	0.001	0.004	0.003	0.004	0.056	0.083	0.056	−0.106	−0.106	−0.151	−0.185	−0.026	0.051	−0.441	−0.592	−0.673	0.067	0.062	−0.109	−0.005	−0.002	−0.002	1.11E−15	0.004	6.66E−16	0.00E+00
26	−0.032	−0.030	−0.039	−0.041	−0.024	−0.018	−0.020	−0.017	0.068	0.112	0.068	−0.217	−0.217	−0.174	−0.141	−0.502	−0.774	−0.053	0.000	0.028	0.096	0.091	−0.072	0.021	0.008	0.008	8.88E−16	−0.016	8.88E−16	0.00E+00
27	0.146	0.147	0.145	0.145	0.147	0.148	0.148	0.146	0.205	0.234	0.205	0.121	0.121	0.102	0.087	0.169	0.215	0.139	0.169	0.185	−0.435	−0.340	−0.026	−0.179	−0.069	−0.069	−2.66E−15	0.132	−1.33E−15	0.00E+00
28	0.088	0.088	0.087	0.087	0.088	0.089	0.089	0.087	0.123	0.141	0.123	0.073	0.073	0.061	0.052	0.102	0.129	0.083	0.101	0.111	−0.127	−0.204	−0.015	−0.107	−0.042	−0.042	−8.88E−16	0.079	−4.44E−16	0.00E+00
29	0.146	0.147	0.145	0.145	0.147	0.148	0.148	0.146	0.205	0.234	0.205	0.121	0.121	0.102	0.087	0.169	0.215	0.139	0.169	0.185	0.565	−0.340	−0.026	−0.179	−0.069	−0.069	0.00E+00	0.132	0.00E+00	0.00E+00
30	0.123	0.121	0.127	0.128	0.117	0.113	0.115	0.111	0.090	0.077	0.090	0.240	0.240	0.284	0.319	0.171	0.105	0.234	0.185	0.158	0.038	0.026	−0.450	−0.137	−0.053	−0.053	−2.22E−16	0.101	−2.22E−16	0.00E+00
31	0.234	0.234	0.232	0.232	0.236	0.237	0.237	0.233	0.328	0.375	0.328	0.194	0.194	0.163	0.140	0.271	0.344	0.222	0.271	0.297	0.438	0.456	−0.041	−0.286	−0.111	−0.111	2.22E−15	0.212	1.33E−15	0.00E+00
32	0.123	0.121	0.127	0.128	0.117	0.113	0.115	0.111	0.090	0.077	0.090	0.240	0.240	0.284	0.319	0.171	0.105	0.234	0.185	0.158	0.038	0.026	0.550	−0.137	−0.053	−0.053	−6.66E−16	0.101	−2.22E−16	0.00E+00
33	0.357	0.356	0.360	0.360	0.353	0.351	0.352	0.344	0.417	0.452	0.417	0.434	0.434	0.448	0.458	0.442	0.449	0.456	0.455	0.454	0.476	0.482	0.509	0.577	−0.164	−0.164	1.11E−15	0.313	6.66E−16	0.00E+00
34	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.44E−16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−2.22E−16	0.00E+00	0.00E+00	2.22E−16	2.22E−16	−2.22E−16	0.00E+00	0.00E+00	0.00E+00	−2.22E−16	0.00E+00	−1.00E+00	−1.11E−16	0.00E+00	0.00E+00	0.00E+00
35	0.357	0.356	0.360	0.360	0.353	0.351	0.352	0.344	0.417	0.452	0.417	0.434	0.434	0.448	0.458	0.442	0.449	0.456	0.455	0.454	0.476	0.482	0.509	0.577	0.836	0.836	1.11E−15	0.313	5.55E−16	0.00E+00
36	−0.643	−0.644	−0.640	−0.640	−0.647	−0.649	−0.648	−0.656	−0.583	−0.548	−0.583	−0.566	−0.566	−0.552	−0.542	−0.558	−0.551	−0.544	−0.545	−0.546	−0.524	−0.518	−0.491	−0.423	−0.164	−0.164	−7.77E−16	−0.687	−4.44E−16	0.00E+00
37	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	3.99E−01	0.399	−3.22E−01	0.00E+00
38	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601	6.01E−01	0.601	3.22E−01	0.00E+00

Table 5. *Cont.*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
39	0.429	0.429	0.429	0.429	0.429	0.429	0.429	0.429	0.429	0.429	0.429	0.429	0.429	0.429	0.429	0.429	0.429	0.429	0.429	0.429	0.429	0.429	0.429	0.429	0.429	0.429	4.29E−01	0.429	7.30E−01	0.00E+00
40	0.129	0.129	0.128	0.128	0.129	0.130	0.130	0.264	0.117	0.110	0.117	0.113	0.113	0.110	0.108	0.112	0.110	0.109	0.109	0.109	0.105	0.104	0.098	0.085	0.033	0.033	−2.22E−16	−0.063	0.00E+00	0.00E+00
41	0.515	0.515	0.512	0.512	0.517	0.520	0.519	0.391	0.466	0.438	0.466	0.453	0.453	0.442	0.433	0.447	0.441	0.435	0.436	0.436	0.420	0.414	0.393	0.338	0.131	0.131	0.00E+00	−0.250	0.00E+00	0.00E+00

Table 6. Optimal market structure and configuration.

n Firm	*r*	Combination
12	1.526	15 Merge 30
11	1.521	3 Merge 11
10	1.497	1 Merge 18
9	1.418	13 Merge 27
8	1.387	8 Merge 15 + 30
7	1.324	14 Merge 22
6	1.294	3 + 11 Merge 23
5	1.185	1 + 18 Merge 2
4	1.043	8 + 15 + 30 Merge 13 + 27

The use of the Residual Supply Index (RSI) in a merger analysis is a key approach to identifying the optimal market structure for a competitive electricity market. By analyzing the combination of generation technology and the installed capacity of power producers post-merger, this approach allows for the creation of competition between different generation technologies within a firm and the spreading of large, pivotal power plants among multiple competitive players. The RSI was first introduced in the California electricity market by [1], and traditionally a threshold of 120% is used to determine a reasonable competitive market. In this study, a six-player configuration with an RSI of 1.294 is identified as the minimum number of players needed to create a competitive market, while a configuration with five players has an RSI of less than 1.2, indicating the potential for market power to be exercised. Figures 4–12 display all of the possible configurations resulting from the merger.

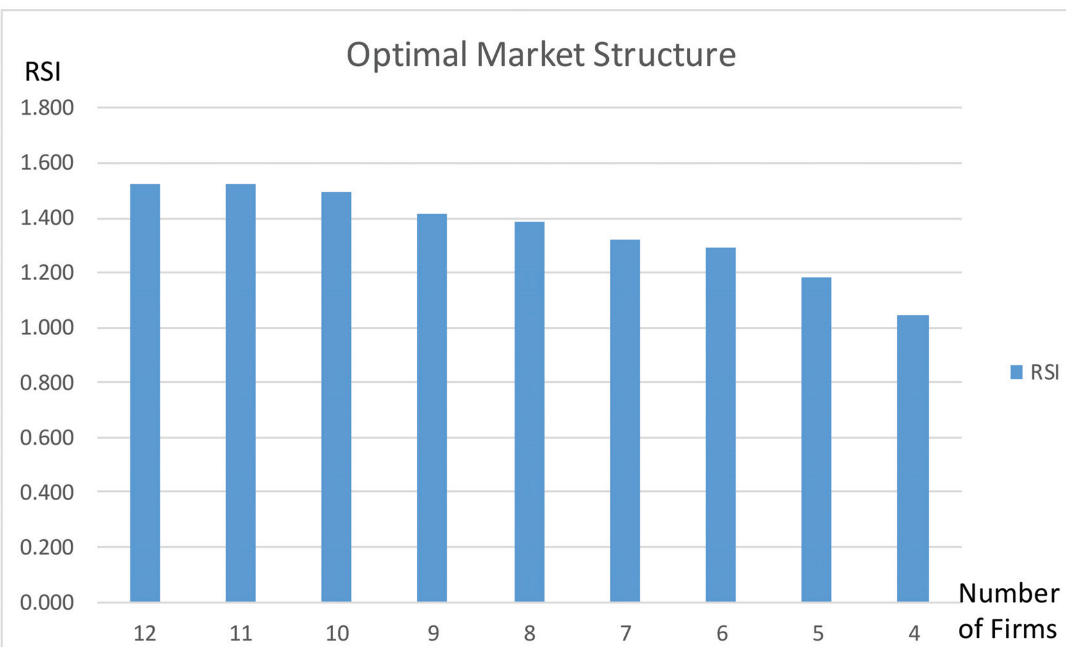


Figure 4. Optimal market structure case 1.

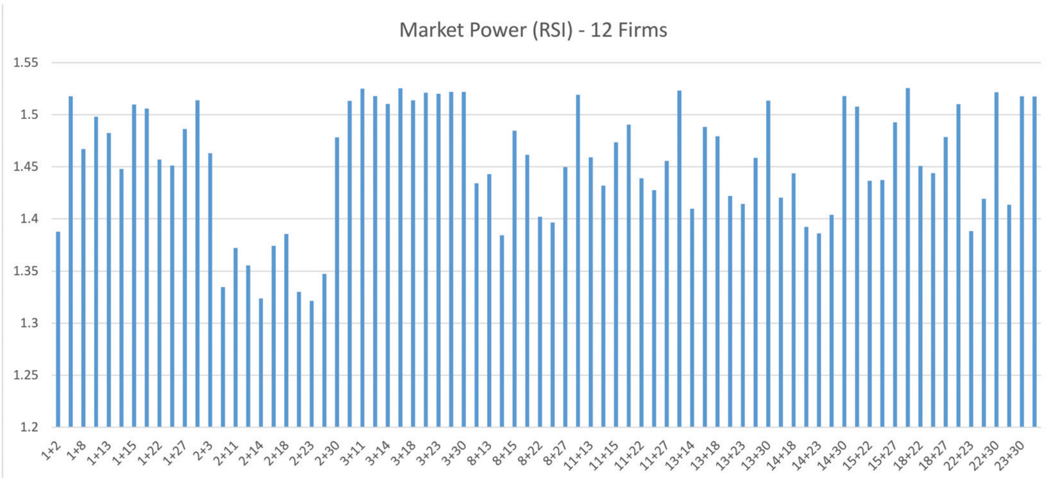


Figure 5. RSI for 12 firms' setting (PC).

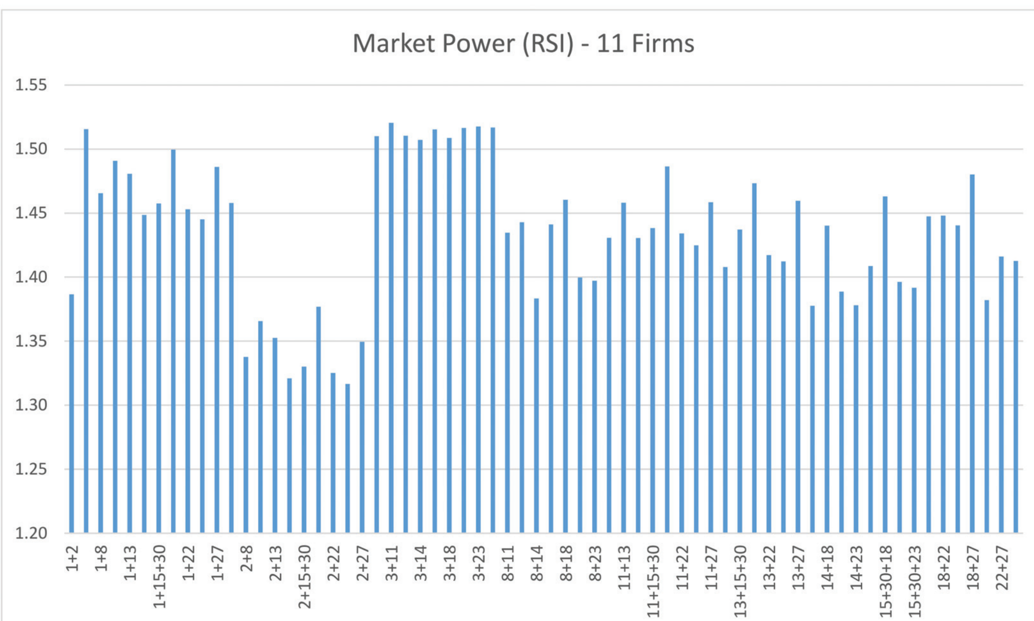


Figure 6. RSI for 11 firms' setting (PC).

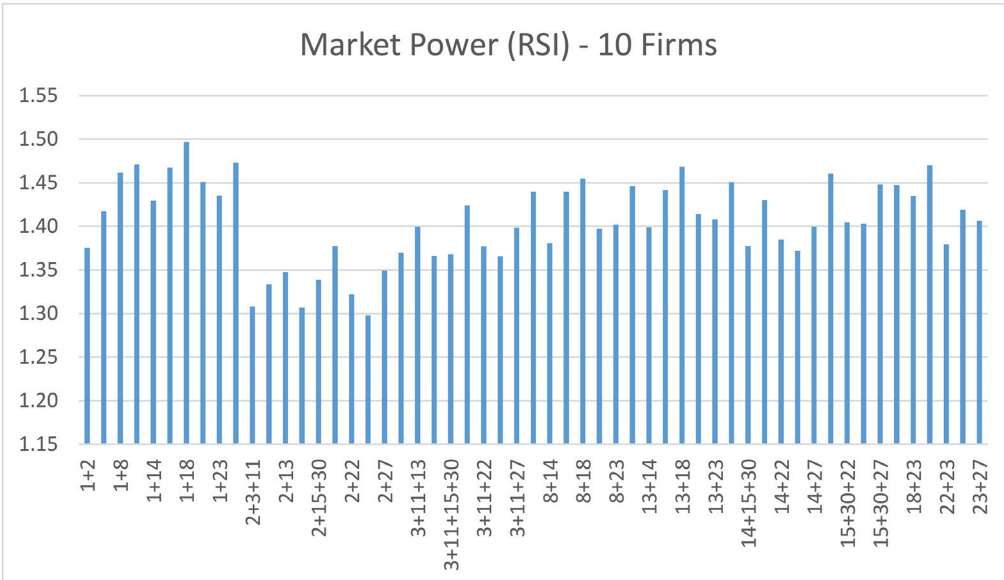


Figure 7. RSI for 10 firms' setting (PC).

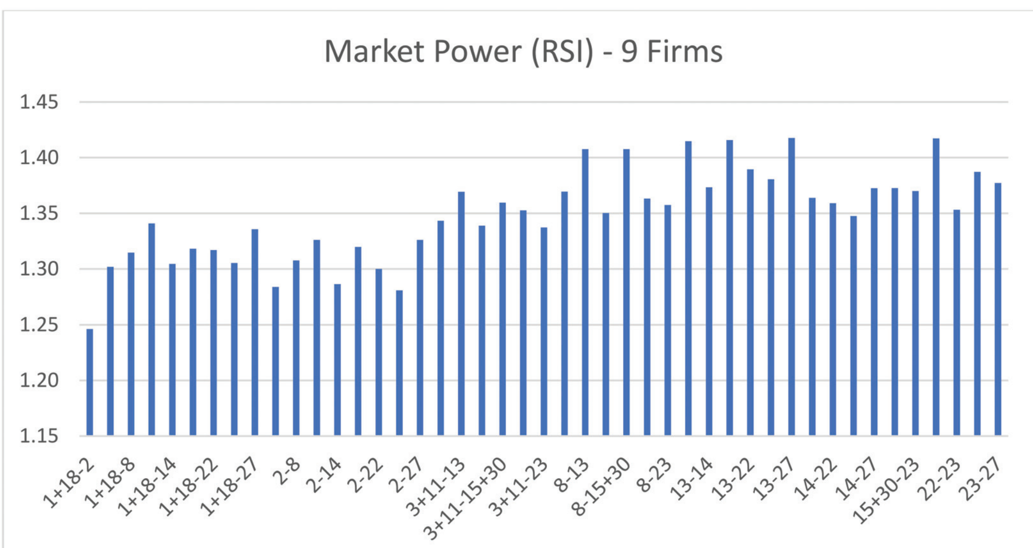


Figure 8. RSI for 9 firms' setting (PC).

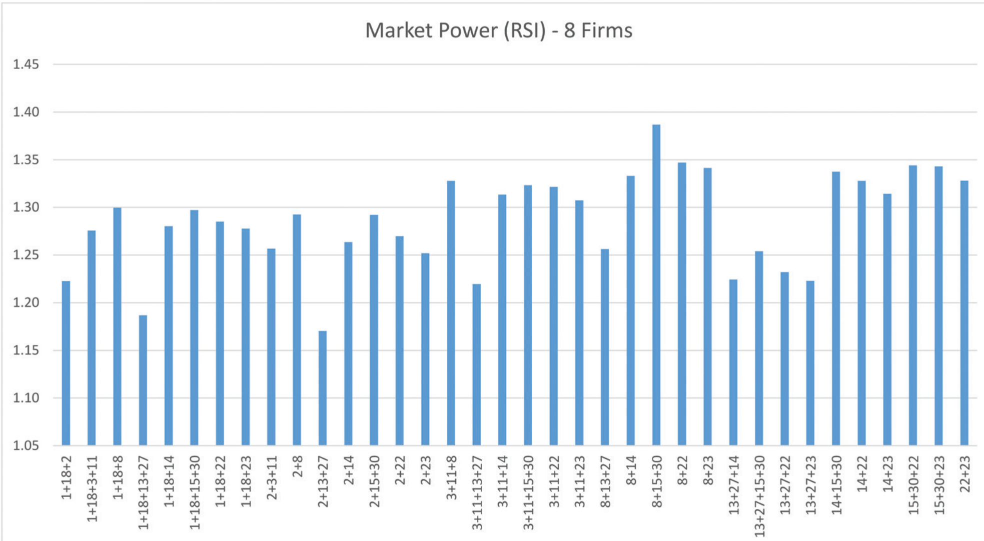


Figure 9. RSI for 8 firms' setting (PC).

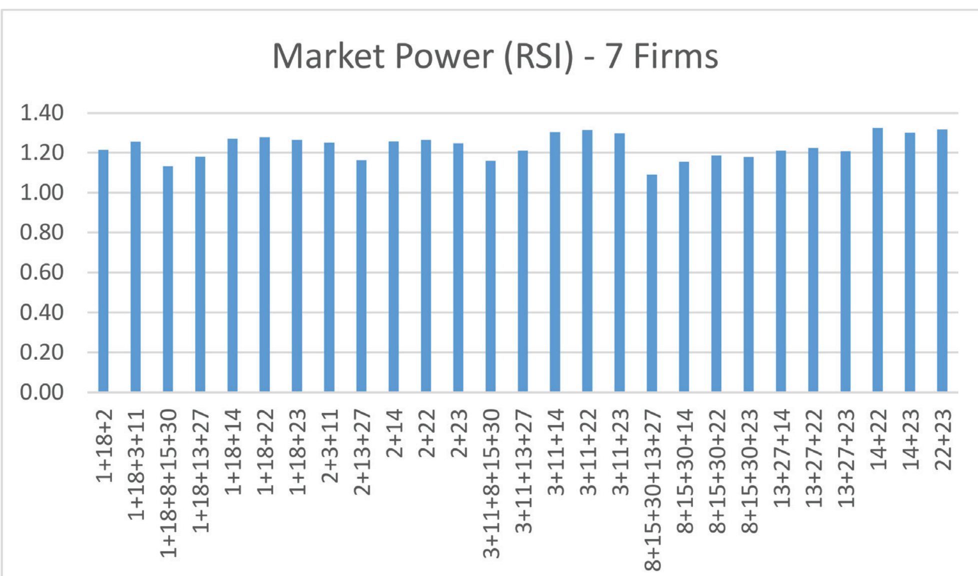


Figure 10. RSI for 7 firms' setting (PC).

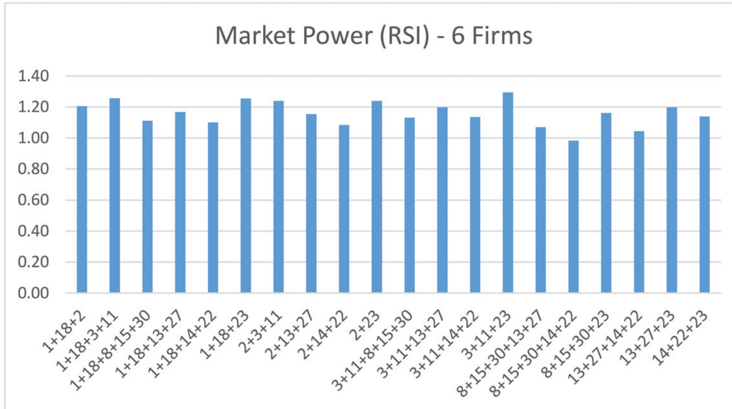


Figure 11. RSI for 6 firms' setting (PC).

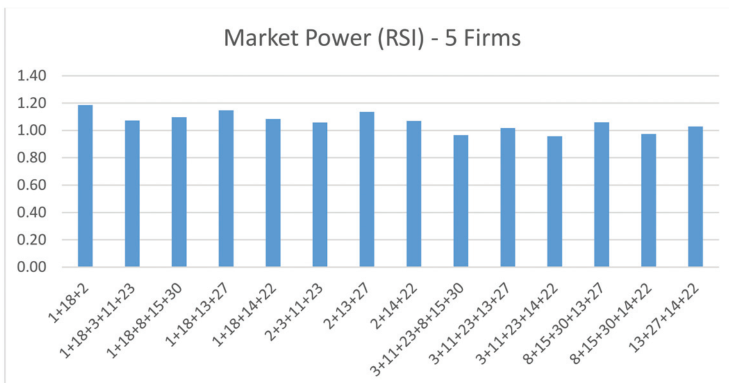


Figure 12. RSI for 5 firms' setting (PC).

4.2.2. Second Case: Cournot Model

Figures 13–21 display all the possible configurations resulting from the merger in the Cournot assumption. In this Cournot case study, the simulation results in a slightly different optimal market structure compared to the base case scenario, as can be seen in Figure 22 and Table 7. The first merger step taken by the model is similar to the base case scenario, where two peaking power plants at nodes 15 and 30 are combined, resulting in a Residual Supply Index (RSI) of 1.573 in a 12-player market structure. However, the next merger steps taken to create the optimal market structure in eleven- to four-player configurations are different from the base case. This means that the minimum number of players needed to create a reasonably competitive electricity market is five players with an RSI of 1.224. Market configurations with player participation below five have the potential for market power exercise. The load flow for the locational marginal pricing (LMP) and Cournot modeling can be seen in Table 8.

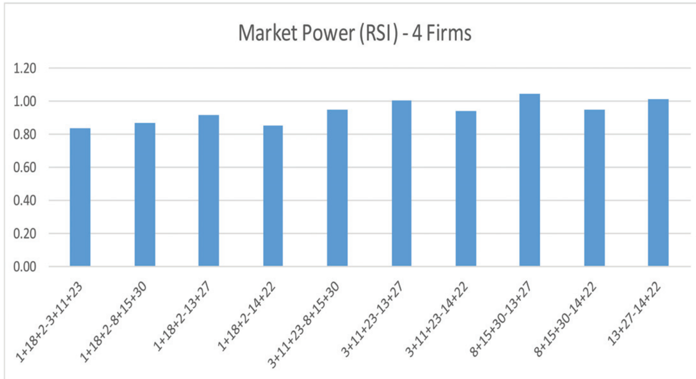


Figure 13. RSI for 4 firms' setting (PC).

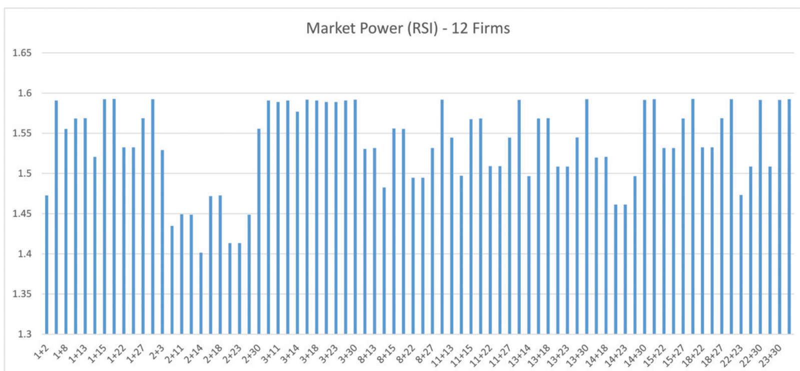


Figure 14. RSI for 12 firms' setting (Cournot).

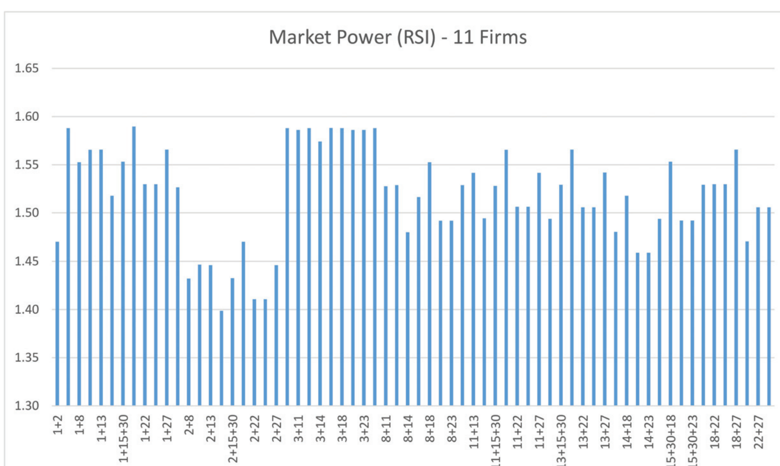


Figure 15. RSI for 11 firms' setting (Cournot).

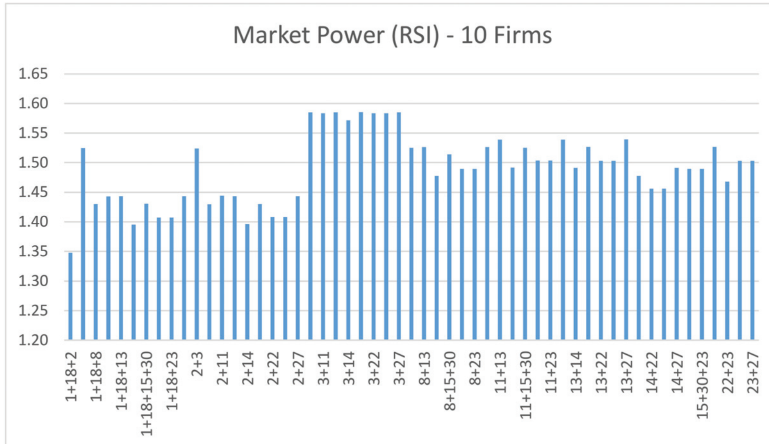


Figure 16. RSI for 10 firms' setting (Cournot).

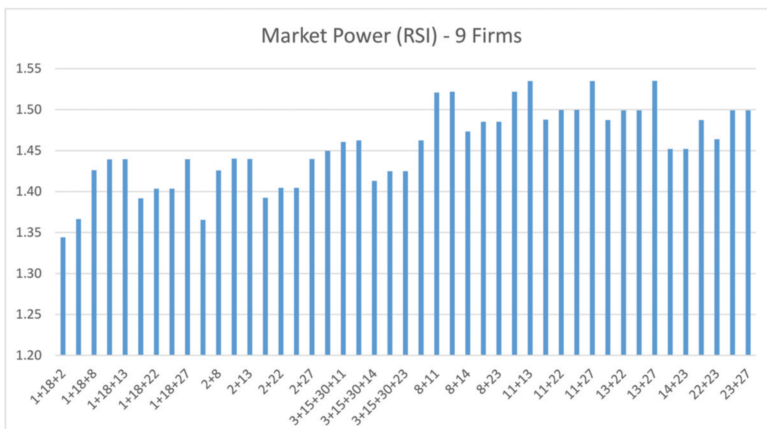


Figure 17. RSI for 9 firms' setting (Cournot).

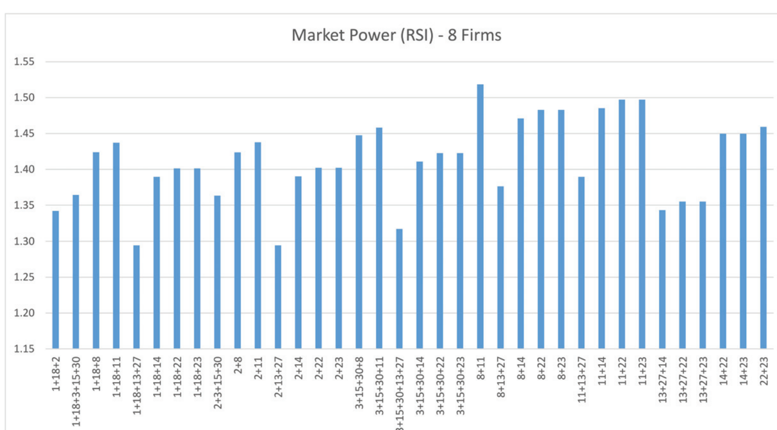


Figure 18. RSI for 8 firms' setting (Cournot).

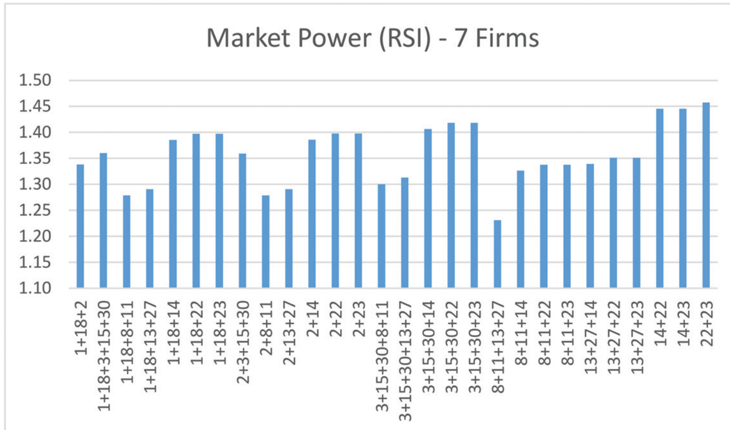


Figure 19. RSI for 7 firms' setting (Cournot).

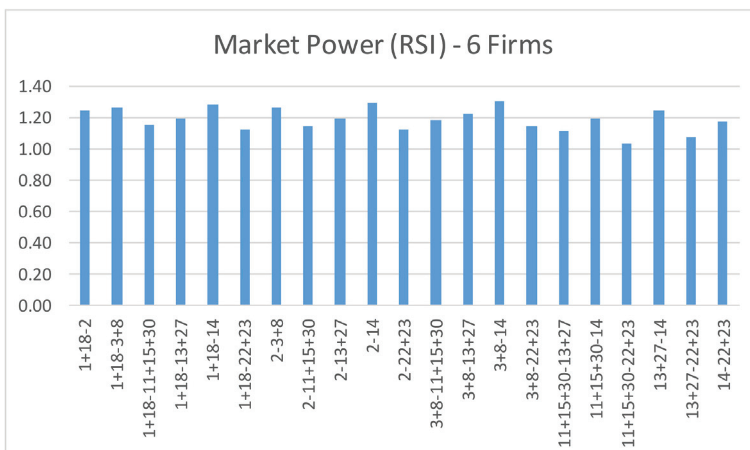


Figure 20. RSI for 6 firms' setting (Cournot).

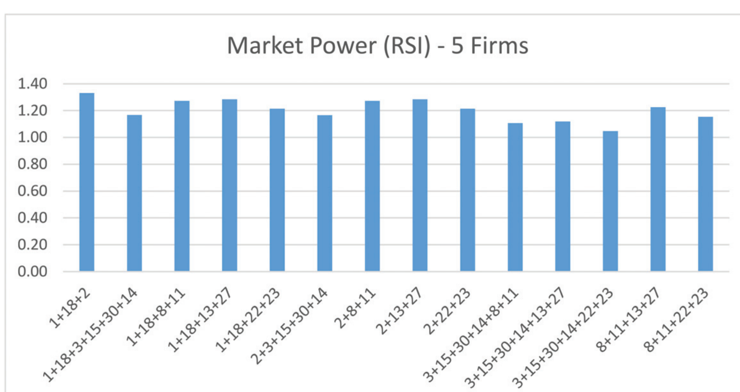


Figure 21. RSI for 5 firms' setting (Cournot).

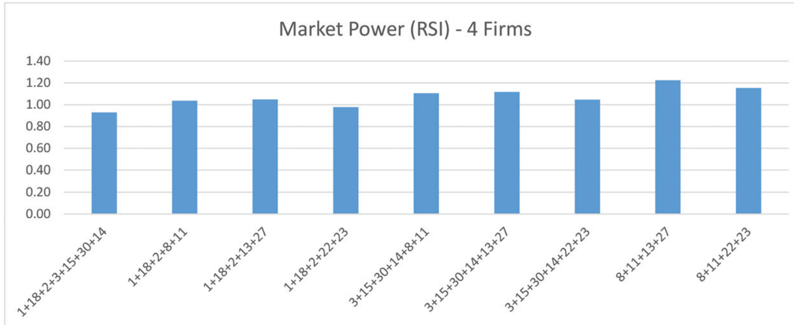


Figure 22. RSI for 4 firms' setting (Cournot).

Table 7. Cournot case study: optimal market structure.

n Firm	*r*	Combination
12	1.573	15 Merge 30
11	1.562	3 Merge 8
10	1.541	1 Merge 18
9	1.477	13 Merge 27
8	1.432	11 Merge 15 + 30
7	1.383	22 Merge 23
6	1.311	3 + 8 Merge 14
5	1.224	1 + 18 Merge 2
4	1.051	13 + 27 Merge 22 + 23

Table 8. DC load flow for PC and Cournot.

From i	to j	$P_{ij}(DC)$ (MW) Case 1: Perfect Competition	$P_{ij}(DC)$ (MW) Case 2: Cournot	T_l (MW)
1	2	27.0	20.0	130
1	3	37.6	23.6	130
2	4	43.0	25.7	65
3	4	44.8	26.9	130
2	5	79.8	66.9	130
2	6	60.6	33.1	90
4	6	90.0	39.6	90
5	7	−5.3	−17.7	140
6	7	55.0	66.4	130
6	8	3.3	0.3	132
6	9	43.1	−8.5	96
6	10	28.9	15.9	96
9	11	−21.9	−105.7	65
9	10	65.0	97.2	65
4	12	−2.2	13.0	65
12	13	−65.0	−32.1	65
12	14	−44.8	−24.1	64
12	15	9.0	0.2	132
12	16	48.5	19.8	64
14	15	64.0	31.4	64
16	17	39.6	11.7	100
15	18	15.8	31.0	100
18	19	80.8	46.1	100
19	20	63.8	25.4	132
10	20	−3.7	35.7	64
10	17	−39.6	−11.7	64

Table 8. *Cont.*

From i	to j	$P_{ij}(DC)$ (MW) Case 1: Perfect Competition	$P_{ij}(DC)$ (MW) Case 2: Cournot	T_l (MW)
10	21	−30.0	−58.2	64
10	22	−22.5	−38.9	64
21	22	−64.0	−87.9	64
15	23	7.2	−20.1	64
22	24	−31.7	−21.1	96
23	24	32.3	5.5	100
24	25	−8.3	−17.3	64
25	26	0.0	0.0	130
25	27	−17.3	−20.4	65
28	27	1.1	26.6	65
27	29	21.8	12.8	64
27	30	4.8	−5.5	64
29	30	−14.0	−19.3	18
8	28	5.4	−0.5	32
6	28	20.3	−1.4	32

Table 8 presents the power transfer for each transmission cable in the LMP and Cournot case study. The table provides a detailed analysis of the power flow for each transmission line, including the congested lines identified in the base case scenario. The load flow for the LMP case study is calculated based on the transmission constraint and the optimal load flow for each transmission line, as determined by the shift factor matrix. On the other hand, the load flow for the Cournot case study is calculated based on the Cournot equilibrium, which takes into account the strategic behavior of the market players. The comparison between the two load flow results can provide insight into how different market structures and behaviors affect the power flow in the system. Additionally, the table also shows how the power transfer changes between the two scenarios, which can be used to identify the potential impact on market power and welfare.

4.2.3. Forward Contract in Cournot Model

Table 8 shows the power transfer for each transmission cable in the LMP and Cournot case study, with the addition of forward contract as a variable. The simulation results indicate that the Cournot model, when incorporating the forward contract as a portion of the installed capacity, is a suitable method for analyzing the market equilibrium. In order to ensure realistic data in the numerical simulation, we have avoided the conjured forward contract and instead calibrated contract coverage in the Cournot formula to determine the optimal contract coverage that can create a competitive market structure. The simulation results show that by using forward contract as an instrument, it is possible to create a competitive electricity market with a lower number of player participants, with the optimal market configuration resulting in an RSI of 1.005 with only four players. Furthermore, by calibrating the contract coverage, as can be seen in Figures 23 and 24 and Table 9, we have determined that a minimum contract coverage of 26% is needed to increase the market power index to a competitive level.

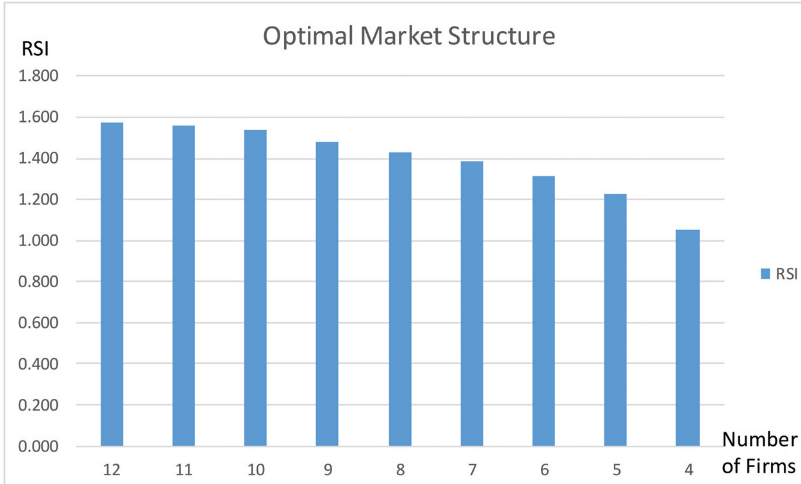


Figure 23. Optimal market structure case 2.

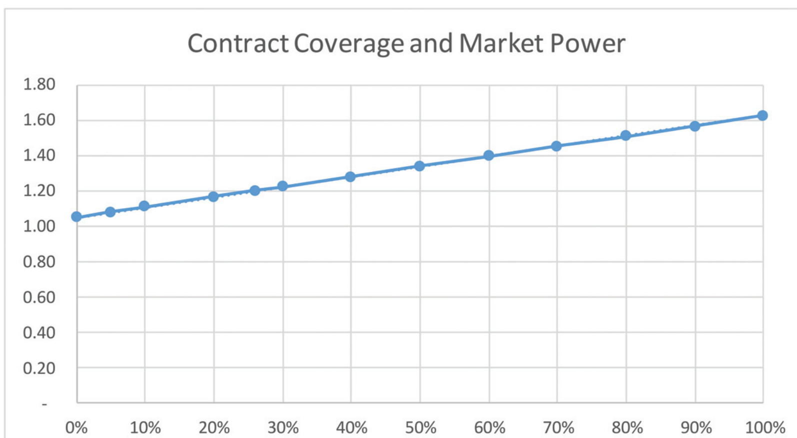


Figure 24. Relationship between contract coverage and market power.

Table 9. Contract coverage and RSI.

Scenario	Contract Coverage	*r*
1	0%	1.05
2	5%	1.08
3	10%	1.11
4	20%	1.17
5	26%	1.20
6	30%	1.22
7	40%	1.28
8	50%	1.34
9	60%	1.40
10	70%	1.45
11	80%	1.51
12	90%	1.57
13	100%	1.62

5. Discussion

This study presents a preventive approach for optimizing the structure of electricity markets [11,13] by considering the use of forward contracts and using the IEEE 30 bus test system as a case study. The simulations demonstrate the ability to determine the optimal mix and structure of successor companies using a bottom-up merger approach. The use of the RSI as a measure of market power mitigation highlights the importance of a minimum number of players to create a reasonably competitive market. This study extends the application of forward contracts in Cournot models, as previously studied in [23,25], by incorporating the RSI as a tool to mitigate market power. It also extends the application of the RSI in the contract-Cournot study of [21] by applying the concept of forward contracts in a more complex market structure, represented by the IEEE 30 bus test system, and taking into account DC load flow.

The level of contract coverage in a competitive market plays a crucial role in maintaining competitiveness and reducing market power. The optimal level of contract coverage is determined by the model behavior and assumptions. According to the authors of [21], under a Cournot model with a constant marginal cost and linear demand schedule, the equilibrium level of contract coverage for each oligopolist is the same fraction of output. The level of forward contracting under a monopoly is 0%, increasing to 50% under a duopoly, and reaching up to 80% when there are five firms. It ultimately converges on full coverage with a sufficient number of companies. When power producers are fully contracted, the best strategy for them is to bid competitively in the spot market, as their bidding would not change the spot price, as per [24]. However, the authors of [25] have shown that the optimal contract coverage under the Cournot model in the German market is 50%, twice as much as in the SFE case.

In this study, we used a threshold of 1.2 for the Residual Supply Index (RSI) based on the experience of the California Independent System Operator (CAISO). Using Cournot modeling and a 120% RSI limit threshold, we found that a minimum of five players with a balanced mix of generation technology are needed to create a competitive market. Additionally, by using forward contracts as a tool to reduce market power, the market regulator could design a four-player configuration with an optimal contract coverage of 26%. It is important to note that the results of this simulation are subject to the assumptions and characteristics of the power system used, and that a dynamic calculation in a real-time power system could yield different results.

6. Conclusions

This study highlights the significance of utilizing an ex-ante analysis approach in the restructuring of electricity markets to ensure the creation of competitive successor companies. The goal of market restructuring should be to avoid the formation of market structures with firms possessing excessive market power. Poor market restructuring can lead to the emergence of a dominant GenCo, which can significantly increase market prices due to strategic behavior constrained by other GenCos. Conversely, successful market restructuring results in the formation of efficient and competitive successor companies. The use of preventive antitrust policies, as outlined in [38], plays a crucial role in preventing the formation of uncompetitive market structures by promoting wholesale configurations that foster competition and positive economic growth, while also preventing the abuse of dominant market power.

The main contribution of this paper is the development of an algorithm that can be used to optimize the structure of electricity markets in large power systems, providing a balanced mix of generation technologies for each GenCo. By using a bottom-up merger approach and incorporating forward contracts, the algorithm is able to determine the optimal mix and structure of successor companies in the IEEE 30 bus test system. The results of the simulations show that the Cournot market setting (with five players) offers a lower number of participants compared to the perfect competition setting (with six players). This is consistent with the preference configuration observed in the UK electricity market. However, it is important to note that the equilibrium is affected by the specific characteristics of the power system and the market power index threshold used.

An antitrust analysis is crucial in understanding the factors that drive prices away from marginal cost, such as scarcity rent and market power exercises. Without the implementation of antitrust laws and policies, market players may have the ability to exercise their market power. By monitoring the strategic behavior of players, electricity market authorities, such as OFGEM in the UK, FTC in the US, and KPPU in Indonesia, can maximize customer welfare by reducing the exercise of market power ex-ante. However, guidelines should be efficient, clear, and easily understood by players to avoid any potential business distortions. Effective laws and policies are a fundamental aspect of the application of economics in the real world. The use of simple yet insightful research tools is essential to achieve a comprehensive understanding of the electricity market.

While this study provides useful insights into mitigating market power in electricity markets through the use of forward contracts, some limitations should be noted. For starters, the proposed algorithm is based on a simplified model that does not take into account all of the complexities and nuances found in real-world electricity markets. Furthermore, the study only focuses on the IEEE 30 bus test case, which may not be representative of other electricity markets. Finally, the study is based on hypothetical forward contract data and does not include real-world data, which may limit the findings' generalizability.

Future research could focus on incorporating real forward contract data into the algorithm to address these limitations. This would entail gathering and analyzing data on forward contracts in the electricity market, and then using this information to validate and improve the proposed algorithm. Such an approach would provide a more accurate reflection of market conditions and could provide valuable insights into the effectiveness of using forward contracts as a tool for market power mitigation. This study could also be expanded to include a broader range of electricity markets and investigate how the proposed algorithm performs under various scenarios and conditions.

Funding: This research received no external funding.

Data Availability Statement: Data available upon request.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Joskow, P.L. Lessons learned from electricity market liberalization. *Energy J.* **2008**, *29*, 9–42. [CrossRef]
2. Wolak, F.A. Regulating competition in wholesale electricity supply. In *Economic Regulation and its Reform: What Have We Learned?* 1st ed.; Rose, N.L., Ed.; University of Chicago Press: Chicago, NY, USA, 2014.
3. Green, R. Increasing Competition in the British Electricity Spot Market. *J. Ind. Econ.* **1996**, *44*, 205. [CrossRef]
4. Borenstein, S.; Bushnell, J.B.; Wolak, F.A. Measuring Market Inefficiencies in California's Restructured Wholesale Electricity Market. *Am. Econ. Rev.* **2002**, *92*, 1376–1405. [CrossRef]
5. Hakam, D.F. Market power modelling in electricity market: A critical review. *Int. J. Energy Econ. Policy* **2018**, *8*, 347–356.
6. Wilson, R. Architecture of Power Markets. *Econometrica* **2002**, *70*, 1299–1340. [CrossRef]
7. Rahimi, A.; Sheffrin, A. Effective market monitoring in deregulated electricity markets. *IEEE Trans. Power Syst.* **2003**, *18*, 486–493. [CrossRef]
8. Sheffrin, A. Predicting Market Power Using the Residual Supply Index. In Proceedings of the Presented to FERC Market Monitoring Workshop, Folsom, CA, USA, 3–4 December 2002.
9. Sheffrin, A. *Critical Actions Necessary for Effective Market Monitoring: Draft Comments of Anjali Sheffrin*; FERC RTO Workshop: San Francisco, CA, USA, 2001.
10. Marshall, L.; Bruce, A.; MacGill, I. Assessing wholesale competition in the Australian National Electricity Market. *Energy Policy* **2020**, *149*, 112066. [CrossRef]
11. Hakam, D.F. Mitigating the risk of market power abuse in electricity sector restructuring: Evidence from Indonesia. *Util. Policy* **2019**, *56*, 181–191. [CrossRef]
12. Hakam, D.F.; Macatangay, R. Optimising Market Structure using Market Power Mitigation and Forward Contract in Electricity Market Restructuring. In Proceedings of the 40th IAEE International Conference, Skyline of Marina Bay, Singapore, 18–21 June 2017; pp. 1–40.

13. Hakam, D.F.; Wiyono, S.K.; Hariyanto, N. Competition in Power Generation: Ex-ante Analysis of Indonesia's Electricity Market. *Energies* **2020**, *13*, 6741. [CrossRef]
14. Hakam, D.F.; Macatangay, R.E. Optimising Indonesia's electricity market structure: Evidence of Sumatra and Java-Bali power system. In Proceedings of the IEEE International Conference on Industrial Technology, Lyon, France, 21 February 2018; pp. 1266–1271.
15. Hakam, D.F. Optimizing the mix and structure of successor companies in electricity market restructuring. In Proceedings of the 39th IAEE International Conference, Bergen, Norway, 19–26 September 2016; pp. 1–20.
16. Stigler, G.J. The economists and the problem of monopoly. *Am. Econ. Rev.* **1982**, *72*, 1–11.
17. Joskow, P. Transaction Cost Economics, Antitrust Rules, and Remedies. *J. Law Econ. Organ.* **2002**, *18*, 95–116. [CrossRef]
18. Green, R. European Union Regulation and Competition Policy among the Energy Utilities. In *Competition Policy in the EU: Fifty Years on from the Treaty of Rome*; Vives, X., Ed.; Oxford Scholarship Online: Oxford, UK, 2009; pp. 284–313.
19. Hüschelrath, K. *Competition Policy Analysis: An Integrated Approach*, 1st ed.; Physica-Verlag A Springer Company: Mannheim, Germany, 2009.
20. Wils, W.P.J. Optimal Antitrust Fines: Theory and Practice. *World Compet.* **2006**, *29*, 183–208. [CrossRef]
21. Newbery, D. *Predicting Market Power in Wholesale Electricity Markets*; Cambridge Working Papers in Economics: Cambridge, UK, 2011.
22. Ausubel, L.M.; Cramton, P. Using forward markets to improve electricity market design. *Util. Policy* **2010**, *18*, 195–200. [CrossRef]
23. Allaz, B.; Vila, J.-L. Cournot Competition, Forward Markets and Efficiency. *J. Econ. Theory* **1993**, *59*, 1–16. [CrossRef]
24. Newbery, D.M. Competition, Contracts, and Entry in the Electricity Spot Market. *RAND J. Econ.* **1998**, *29*, 726. [CrossRef]
25. Willems, B.; Rumiantseva, I.; Weigt, H. Cournot versus Supply Functions: What does the data tell us? *Energy Econ.* **2009**, *31*, 38–47. [CrossRef]
26. Berry, C.A.; Hobbs, B.F.; Meroney, W.A.; O'Neill, R.P.; Stewart, W.R. Understanding how market power can arise in network competition: A game theoretic approach. *Util. Policy* **1999**, *8*, 139–158. [CrossRef]
27. Green, R. Nodal pricing of electricity: How much does it cost to get it wrong? *J. Regul. Econ.* **2007**, *31*, 125–149. [CrossRef]
28. Leuthold, F.U.; Weigt, H.; Von Hirschhausen, C. A Large-Scale Spatial Optimization Model of the European Electricity Market. *Netw. Spat. Econ.* **2010**, *12*, 75–107. [CrossRef]
29. Hakam, D.F. Nodal pricing: The theory and evidence of Indonesia power system. *Int. J. Energy Econ. Policy* **2018**, *8*, 135–147.
30. Hakam, D.F.; Kanugrahan, S.P.; Rahadi, A.A.; Nugraha, R.; Wicaksono, A. Challenges and Opportunities of Clean Cooking Program in Indonesia: The Journey to Net Zero Emission. In Proceedings of the IAEE Conference, Tokyo, Japan, 31 July–4 August 2022; pp. 1–2.
31. Cunningham, L.B.; Baldick, R.; Baughman, M.L. An Empirical Study of Applied Game theory: Transmission Con-strained Cournot Behavior. *IEEE Trans. Power Syst.* **2002**, *17*, 166–172. [CrossRef] [PubMed]
32. Küpper, G.; Delarue, E.; Delvaux, B.; Meeus, L.; Bekaert, D.; Willems, B.; Proost, S.; D'haeseleer, W.; Deketelaere, K.; Belmans, R. Does More International Transmission Capacity Increase Competition in the Belgian Electricity Market? *Electr. J.* **2009**, *22*, 21–36. [CrossRef]
33. Dahl, C.A. Book Review—International Energy Markets: Understanding Pricing, Policies, and Profits. *Energy J.* **2006**, *27*, 179–181. [CrossRef]
34. Schweppe, F.; Caramanis, M.; Tabors, R.; Bohn, R. *Spot Pricing of Electricity*, 1st ed.; Kluwer Academic Publishers: Amsterdam, The Netherlands, 1988.
35. Caramanis, M.; Bohn, R.; Schweppe, F. Optimal Spot Pricing: Practice and Theory. *IEEE Power Eng. Rev.* **1982**, *PER−2*, 42. [CrossRef]
36. Macatangay, R.E. Space–time prices of wholesale electricity in England and Wales. *Util. Policy* **1998**, *7*, 163–188. [CrossRef]
37. Borowski, P.F. Zonal and Nodal Models of Energy Market in European Union. *Energies* **2020**, *13*, 4182. [CrossRef]
38. Stigler, G.J. Mergers and Preventive Antitrust Policy. *Univ. Pa. Law Rev.* **1955**, *104*, 176. [CrossRef]

MDPI
St. Alban-Anlage 66
4052 Basel
Switzerland
Tel. +41 61 683 77 34
Fax +41 61 302 89 18
www.mdpi.com

Energies Editorial Office
E-mail: energies@mdpi.com
www.mdpi.com/journal/energies

MDPI

Academic Open
Access Publishing

www.mdpi.com

ISBN 978-3-0365-8123-1