ISSN 2782-6333

# SUSTAINABLE DEVELOPMENT and ENGINEERING ECONOMICS

02 2022

Published by Peter the Great St. Petersburg Polytechnic University

**Publisher**
Peter the Great St. Petersburg Polytechnic University
**Corresponding address:**
29 Polytechnicheskaya st., Saint-Petersburg, 195251, Russia

**Contacts:**
**Email:** sustainable@spbstu.ru
**Web:** https://sustainable.spbstu.ru/

**Учредитель**
Санкт-Петербургский политехнический университет Петра Великого
**Адрес:**
195251, Россия, Санкт-Петербург, Политехническая 29

**Контакты:**
**Почта:** sustainable@spbstu.ru
**Веб-сайт:** https://sustainable.spbstu.ru/

# Innovative enterprises and the sustainable development of regional infrastructure

The sustainable development of a country is influenced by the innovative activity of its regions, the sustainability of which is provided by innovative enterprises. Consequently, innovative enterprises play an important role in the development of regions and their infrastructure. Due to the desire of the world community to transition to an innovative type of economy, in which the main share of the gross domestic product is generated by the production and sale of high-tech products, the role of innovative enterprises is only increasing every year. This lends significance to the issue of ensuring the sustainable development of regions through the introduction of innovations at enterprises.

The development of regions' innovation infrastructure requires various industries to reorganize their traditional ways of operating For example, the energy supply industry needs to restructure their traditional system through the introduction of intelligent technologies and a gradual transition to clean energy.

The Sustainable Development and Engineering Economics journal's second issue of 2022 examines how innovation activity affects the sustainable development of enterprises and regions.

The issue's first section, "Economics of engineering and innovation decisions as a part of sustainable development", features the article "Formation of innovative industrial cluster strategy by parallel and sequential real options", by D. Rodionov, E. Koshelev, and L. Escobar-Torres. In this study, the authors address the issue of developing a pilot-innovation cluster using a sequential-option strategy. The authors believe that thanks to the development of the innovative cluster of the Nizhny Novgorod region's electric power industry, it will be possible to realize the innovative potential of the region.

The "Enterprises and the sustainable development of regions" section presents the article "Modeling of production processes parameters of industrial enterprises", by N. Sokolitsyna and A. Sokolitsyn, which concerns economic analysis in production management. The authors have developed a comprehensive information model of enterprise management tasks, which enables the production process of the enterprise to be assessed.

To solve the problems of "Sustainable development of regional infrastructure in the field of energy", U. O. Choijiljav and U. Tudevdagva propose using solar and wind energy. In the article "Comparative study of solar and wind power plant tariff and investment costs", the authors consider feed-in tariffs and how they are affected by currency fluctuations. The authors point out that the adoption of the Law on Renewable Energy Sources motivated the development of this sector.

The second article in this section is "Research and evaluation of the structural capital of the innovation and industrial cluster", by A. Babkin, N. Alekseeva, L. Tashenova, and D. Karimov. The authors conducted an analysis of the internal and external environment of the cluster under study. Based on this analysis, the authors propose a methodology for assessing the structural capital of an innovative industrial cluster, which will help to provide recommendations for its development.

In the final section, "Management of knowledge and innovation for sustainable development", A. Shmelyova and S. Suloeva, in the article "Development of a mechanism for adapting the organization's digital innovation potential, taking into account the specifics of digital innovation projects", propose a methodology that enables the identification of key factors and the determination of each factor's degree of influence on the digital potential of an organization, which can help organizations in building a strategy for the development of digital potential to achieve sustainable development goals.

***Irina Rudskaia,*** *Editor-in-Chief, Doctor of Economics, professor*

# TABLE OF CONTENTS

# СОДЕРЖАНИЕ

SECTION 1

# ECONOMICS OF ENGINEERING AND INNOVATION DECISIONS AS A PART OF SUSTANABLE DEVELOPMENT

РАЗДЕЛ 1

# ЭКОНОМИКА ИНЖЕНЕРНЫХ И ИННОВАЦИОННЫХ РЕШЕНИЙ КАК ЧАСТЬ УСТОЙЧИВОГО РАЗВИТИЯ

**Research article**

**DOI:** https://doi.org/10.48554/SDEE.2022.2.1

# FORMATION OF INNOVATIVE-INDUSTRIAL CLUSTER STRATEGY BY PARALLEL AND SEQUENTIAL REAL OPTIONS

Dmitriy Rodionov[1], Egor Koshelev[2*], Leandro Escobar-Torres[3]

[1]Peter the Great St. Petersburg Polytechnic University, Russian Federation, drodionov@spbstu.ru
[2*]Lobachevsky State University of Nizhny Novgorod, Russian Federation, ekoshelev@yandex.ru
[3]Comillas Pontifical University, Madrid, Spain, lescobar@comillas.edu
[*]Corresponding author: ekoshelev@yandex.ru

**Abstract**

The subject of this study is the strategy of the innovative-industrial cluster. The purpose of this work is to form a cluster strategy using parallel and sequential real options. The method proposed for this involves applying a parallel real option when justifying the prospect of acquisition, and a sequential real option to assess the prospect of individual development. A parallel option involves assessing risky forms of financing as part of the cluster strategy presented by the core company. In this case, the operation "management buyout" (MBO) is considered, for example, from the managers of the parent organization. A sequential option implies the stage of cluster strategy implementation. In this case, we consider two options that make up the sequence of possible adjustments to the strategy of the core company. This is an option to develop experience in the cluster and an option to switch the cluster strategy. As an example of the implementation of the presented method, the process of forming a strategy for the development of a pilot electric power cluster, was considered. Here, a sequential option allows us to obtain a slightly higher net present value than the net present value of a parallel option. Therefore, the managers must themselves decide whether to negotiate on the acquisition or to independently develop further based on the stage of implementation of the cluster strategy. The second choice will allow the preservation and development of the pilot innovative-industrial cluster of the electric power industry in the region in accordance with the priorities of the region in which it is located. This will make it possible to further realise the innovative potential in the region.

**Keywords:** innovative-industrial cluster, compound real option, innovations, cluster strategy

**Citation:** Rodionov, D., Koshelev, E., Escobar-Torres, L., 2022. Formation of innovative-industrial cluster strategy by parallel and sequential real options. Sustainable Development and Engineering Economics 2, 1. https://doi.org/10.48554/SDEE.2022.2.1

**Научная статья**
**УДК 336.645.1**
**DOI:** https://doi.org/10.48554/SDEE.2022.2.1

# ФОРМИРОВАНИЕ СТРАТЕГИИ ИННОВАЦИОННО-ИНДУСТРИАЛЬНОГО КЛАСТЕРА МЕТОДОМ ПАРАЛЛЕЛЬНЫХ И ПОСЛЕДОВАТЕЛЬНЫХ РЕАЛЬНЫХ ОПЦИОНОВ

Дмитрий Родионов[1], Егор Кошелев[2*], Леандро Эскобар-Торрес[3]

[1]Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Российская Федерация, drodionov@spbstu.ru
[2*]Нижегородский государственный университет им. Н.И. Лобачевского, Российская Федерация, ekoshelev@yandex.ru
[3]Папский университет Комильяс, Мадрид, Испания, lescobar@comillas.edu
[*]Автор, ответственный за переписку: ekoshelev@yandex.ru

**Аннотация**

Предметом исследования является стратегия инновационно-индустриального кластера. Цель работы - формирование стратегии кластера методом параллельных и последовательных реальных опционов. Предложенный для этого метод предполагает при обосновании перспективности поглощения применять параллельный реальный опцион, а для оценки перспективности индивидуального развития – последовательный реальный опцион. Параллельный опцион подразумевает оценку рискованных форм финансирования в рамках стратегии кластера, представленного компанией – ядром. В данном случае рассматривается операция “management buyout” (MBO), например, от менеджеров головной организации. Последовательный опцион подразумевает стадийность осуществления стратегии кластера. В данном случае рассматриваются два опциона, составляющие последовательность возможной корректировки стратегии компании – ядра. Это опцион на развитие опыта в кластере и опцион на переключение стратегии кластера. В качестве примера реализации представленного метода рассмотрен процесс формирования стратегии развития пилотного кластера электроэнергетики в Нижегородской области, который представлен компанией – ядром ПАО «ТНС энерго НН». Для него последовательный опцион позволяет получить чистый приведенный доход незначительно больше чистого приведенного дохода параллельного опциона. Поэтому менеджеры должны сами принять решение: договариваться с ПАО ГК «ТНС энерго» о выкупе ПАО «ТНС энерго НН» или развиваться дальше самим на основе стадийности осуществления стратегии кластера. Второй вариант позволит сохранить и развивать пилотный инновационно-индустриальный кластер электроэнергетики в Нижегородской области в соответствии с приоритетами региона, в котором он находится. Это позволит в дальнейшем реализовать имеющийся в регионе инновационный потенциал.

**Ключевые слова:** инновационно-индустриальный кластер, составной реальный опцион, инновации, стратегия кластера

**Цитирование:** Родионов, Д., Кошелев, Е., Эскобар-Торрес, Л., 2022. Формирование стратегии инновационно-индустриального кластера методом параллельных и последовательных реальных опционов. Sustainable Development and Engineering Economics 2, 1. https://doi.org/10.48554/SDEE.2022.2.1

## 1. Introduction

Bringing the socioeconomic values of innovative-industrial clusters in line with the value system of a large region is an integral part of the development and subsequent correction of the cluster development strategy. Often, the core company of a pilot cluster has to make a choice between the strategy of its acquisition and the strategy of individual development in accordance with the priorities of the region in which it is located. Such priorities include, primarily, social traditions, as well as innovative potential, expressed by the availability of production, financial, labour, and other resources for the successful development of the region (Yashin et al., 2019).

Nowadays, clustering is one of the most effective ways to overcome systemic challenges and crisis phenomena in the economy. For example, Polyanin et al. (2020) created a methodology for assessing the economic security of a cluster, which is characterized by a comprehensive approach that takes into account all possible risks and threats in the functioning of individual components of the cluster structure.

Kudryavtseva et al. (2020) developed a methodology for assessing and monitoring cluster structures. The method proposed by the authors allows us to assess the level of development of the cluster structure by analysing the cluster transformation in the information and communication sectors of the regional economy, the prerequisites for the formation of the cluster, as well as the current level of development of the digital cluster in the region. To assess the prerequisites for the formation of a digital economy cluster, an integral indicator is calculated, and a multiparameter approach is used to assess the effectiveness of the cluster. The proposed methodology allows researchers to compare clusters from different regions and monitor their development.

Moeis et al. (2020) studied the dynamics and sustainability of the Tanjung Priok port cluster. System dynamics are used to study the problem, and the stability of the port cluster is assessed by modelling the dynamics of the system over a 20-year period. This study further examines the impact of an alternative port cluster development programme (namely, free trade policy) and shore power system (SPS) programme policies on the sustainability of the port cluster. The model points out that when free trade policies and the SPS programme are implemented in tandem to maximise the economy and reduce environmental damage, they provide additional benefits.

Significant attention is drawn to the issues of digitalization of industrial enterprises and clusters in the formation of the "Industry 4.0". For instance, Tashenova et al. (2020) developed a method for assessing the digital potential of the main innovatively active industrial clusters. The method is developed on the basis of existing methods and approaches to assessing the innovative potential of industrial clusters and the digital potential of industrial enterprises, and allows calculation of the final integral assessment, which includes calculations for each of the seven subpotentials of the parameters that experts have identified as important.

Considering the formation of the cluster strategy, it is necessary to note that strategic decisions should be based on a correct understanding of the results of the systematic analysis conducted by managers to form sustainable competitive advantages. For example, Bogdanova and Karlik (2020) consider the following aspects: sectoral and regional conditions within the strategic directions of activities and interests of organizations, the prevailing forms and types of strategic interactions, the level of innovative potential of the industry and the region, and specific influencing factors of macro- and micro-levels. However, what is really important is not only the socioeconomic significance (efficiency and rationality) of the decision itself but also the speed, and even more so the timeliness of its implementation, predetermined by the dynamics of industry factors.

A cluster is a group of geographically adjacent interrelated companies (suppliers, manufacturers, intermediaries) and related organizations (educational institutions, government bodies, infrastructure companies) operating in a certain area and complementing each other (Porter, 2008).

The allocation of pilot clusters that bring the greatest benefit to the population of the region, taking into account its historical traditions as well as the types of production in the region, is a strategically important task for the executive authorities. To develop an innovative strategy for state-defined pilot clusters, it is important to apply technologies that allow flexible management decisions to be made. Taking into account the wide range of opportunities and threats to clusters, such a technology can be compound parallel and sequential real options. This technology has not been previously used by anyone to develop a strategy for an innovative-industrial cluster.

Speaking about the innovative-industrial cluster, it is necessary to start by singling out the situation in which the pilot cluster is formed around a single company, the core of the cluster. Such a development of events is possible only if there is, first, a sufficiently significant production capacity of such a company. In the opposite situation, for example, when we consider a tourist cluster, the presence of a single company, the core, will kill the nascent cluster, since there will be no internal competition in the region that could contribute to the harmonious development of the territory.

In this manner, the development of a pilot innovative-industrial cluster in a region is largely due to the activities of the core company of the cluster. To justify the strategic choice between acquisition and individual development of the core company of the pilot cluster, it is necessary to conduct an appropriate monetary assessment of such management decisions. However, in practice, such an assessment cannot always give an unambiguous answer about the choice of strategy. In this case, it is advisable to focus on the socioeconomic needs of the region in which the pilot innovative-industrial cluster is located. This will facilitate further realisation of the innovative potential available in the region.

To solve this problem, it is possible to use the method of compound real options, where a parallel real option can be used to justify the acquisition strategy, and a sequential real option is used to assess the individual development strategy (Mun, 2002; Kodukula and Papudesu, 2006).

## 2. Literature Review

Recent advances in real options cover a wide range of solvable business, governmental, and banking issues.

For example, Locatelli, Mancini, and Lotti (2020) presented a method based on a systematic simulation of several scenarios generated according to the exercise thresholds of relevant investment parameters. An exercise threshold gives the investors the exercise right of making some decision, for instance, building a power plant. An exercise threshold is, therefore, a rule to decide whether to exercise or not a certain option on the basis of the values of one or more state variables.

The work of Lai and Locatelli (2021) is aimed at implementing and testing an algorithm based on real options analysis to quantify the "option to prototype" in the energy sector. First, the interrelated research areas of prototyping, energy systems, and real options analysis are considered. A new algorithm is then introduced and applied to an innovative integrated generation energy storage site system, i.e. wind-driven thermal pumping, to demonstrate the efficiency of prototype selection and the main parameters affecting this decision. The results show that the key parameters are the cost of the prototype and the size of the market (the number of identical systems to build).

Tan and Trimidad (2018) applied the real options theory to banking operations among the actively traded Philippine Universal Banks. Scientists study the option premiums of loan portfolios, which reflect managerial flexibility with investment strategy. The real options model, which takes into account both lending and idling strategies, shows that smaller credit institutions value loans higher than their larger competitors. Based on the model, the need to maintain smaller deviations in the profitability of the loan portfolio limits the flexibility of managers' decisions. Option premiums in the Philippines demonstrate sensitivity to information asymmetry.

Tan (2018) found that variables that expand real options models provide interfaces through which entrepreneurs can view promising ventures or resources. Factors affecting the real value of options stem from the external environment of the enterprise and are forms of various business conditions between entrepreneurs, the venture, and the external environment. Interface identification increases the final value of a real option and provides entrepreneurs with information with which to structure businesses that derive value from arbitrage and innovation opportunities.

The already classic compound real options for options are divided into sequential and parallel. The sequential connection option exists when the project has several phases, and the last phases depend on the success of the previous phases (Mun, 2002).

The compound option may be sequential or parallel, also known as simultaneous. If it is necessary to exercise it to create another option, it is considered sequential. For example, before starting to create a factory, one must complete the design phase. In a parallel option, however, both options are available at the same time. The term of an independent option is greater than or equal to the lifetime of the underlying option. A television broadcaster can simultaneously build an infrastructure for digital transmission and apply for the required broadcast spectrum but cannot complete infrastructure testing without a spectrum license. The acquisition of spectrum, i.e. the option itself, gives the broadcaster the opportunity to complete the infrastructure and launch a digital broadcasting service (Kodukula and Papudesu, 2006).

First we consider in more detail a number of scientific achievements in the field of sequential real options. Hauschild and Reimsbach (2015) proposed a binomial approach to modelling sequential investments in R&D. More specifically, they presented a comprehensive approach to real options, simplifying the existing valuation methodology. The authors demonstrated the applicability of their approach to a real-world example of evaluating new drug use.

Martins and Silva (2005) developed a real option model with uncertain and consistent investments and time to build. The model includes options for entering and exiting activities and solves the problem of maximizing the value of the company, taking into account the possibility of investment.

Leiblein and Ziedonis (2006) considered the application of real options theory to sequential investment decision-making. They presented a conceptual model that explains technological implementation as a sequence of built-in options. After implementing each generation of technology, a company can either postpone investment and wait for the arrival of the next generation, or invest now and gain experience that provides the preferred approval for the adoption of subsequent generations.

Baranov and Muzyko (2015) concluded that the value of a compound real option increases the total cost of an innovative project due to the factor of phased investment and the possibility of termination of financing.

Claire and Guise (2019) evaluated different types of compound options and ultimately applied this estimate to real options to assess a biotechnology firm's successive investment in R&D. Scientists have found that for a compound option with multiple execution periods, transaction costs may need to be paid on each execution. The total transaction costs cannot be insignificant, and the estimated value of the option may be higher than the actual value of the option.

Tavakkolnia (2016) developed an intuitive and practical method for evaluating multi-stage strategic or investment projects. Within it, specific volatility is assigned to each stage of the project and is assessed in a fuzzy framework using data from previous similar projects and expert knowledge. These fuzzy volatilities are then incorporated into a multi-stage model of the binomial tree valuation. Finally, the presented model is implemented using an R&D project as an example. The advantage of the model is that it can be easily extended through the use of different types of options built into multi-stage projects.

Konstandatos (2015) evaluated a multi-stage mining solution in which mining operators have the option to delay the start of a project, as well as options to phase out production and expand production to a new rock formation if conditions improve.

Cassimon, Engelen, and Yordanov (2011) obtained an extended model through a case study evaluating real options of a multi-stage software application project by a major mobile operator and showed how project managers can estimate volatility depending on the phase.

Xu, Zhou, and Phan (2010) studied how firms in emerging markets solve their information problems during acquisitions. One strategy is to complete the acquisition sequentially rather than as a one-time trade. Unlike companies in developed countries, which have relatively easy access to information, emerging market firms face different access to information on target firms due to institutional weaknesses and constraints in these markets. Sequential acquisitions are conceptualized as a strategy based on real options whereby a sequential acquirer resolves the uncertainty of valuation through information gathering and post-purchase learning. The value of a successive acquisition strategy increases for information-disadvantaged firms.

Parallel real options are most often used to assess risky forms of project financing. A typical example is the LBO (leveraged buyout) scheme. If the LBO project is carried out by the top managers of the company, then it is called MBO (management buyout).

For example, the work of Renneboog and Vansteenkiste (2017) developed a theoretical justification for potential sources of value creation from private ones: a distinction is made between reducing the costs of agencies associated with shareholders, transfers of stakeholder wealth, tax incentives, savings of operating costs, takeover defence strategies, and corporate undervaluation. The paper then examines and summarises how these theories have been empirically tested in four different lines of literature in LBO research. These lines of literature are classified by phase in an LBO transaction: intent (buyout), impact (LBO on various stakeholders), process (restructuring after buyout), and duration (retention of private status).

Demiroglu and James (2010) investigated whether the reputation of the acquisition of private equity groups (PEG) was linked to the financing structure of the LBO. They found that reputable PEGs are more active in the LBO market when credit risk spreads are low and lending standards in credit markets are weak. The authors also found that reputable PEGs pay narrower banking and institutional spreads on loans, have longer loan repayment terms, and rely more on institutional loans. In addition, although the scientists found that a PEG’s reputation is positively related to buyout leverage (i.e., LBO debt divided by profits before the LBO before interest, taxes, amortisation, and depreciation (EBITDA) of the target), and leverage is significantly positively related to buyout pricing, the authors found no direct relationship between PEG reputation and buyout estimates. The data suggests that a PEG's reputation is tied to the LBO's funding structure, not only because reputable PEGs are more likely to take advantage of market terms in credit markets, but also because a PEG's reputation reduces the agency costs of LBO debt.

Private equity investors have traditionally used innovative financial techniques to structure their leveraged buyout (LBO) transactions. In recent years, they have often resorted to securitization to raise funds from the operating assets of their acquisitions. A distinctive feature of these transactions is that they aim to strengthen the securitizing solvency of the LBO through a set of structural improvements, including operational debt obligations. The results of a study by Bouvier and Nisar (2015) showed that under the operating system adopted by Hertz LBO, securitization improved the ability to service the debt of the transaction.

A debt buyout entails the purchase of a corporation or division, financing the purchase primarily through debt. Management buyout (MBO) is most often understood as a leveraged buyout in which the managers of a corporation or division take ownership of an enterprise. Buyouts by management can change the ownership structure and operational and financial image of the firm and therefore cover all relevant aspects of the company's restructuring activities. Tax incentives are a common source of value creation through both buyouts and acquisitions using borrowed funds, and through buyout by management. Additional sources of value creation resulting from the purchase of management services include reorganized management incentives and increased budgetary discipline, which contribute to improved performance (Wehrly and Shen, 2016).

## 3. Materials and Methods

We will consider both options for the possible formation of the cluster strategy represented by the core company. Initial and projected data on its cash flows are provided on the Conomy website by the company "M3" (https://old.conomy.ru).

1. Evaluation of risky forms of financing within the framework of the cluster strategy (parallel real option). In this case, the MBO operation is considered, for example, by the managers of the parent organisation. By making such a transaction, managers will receive a real call option on the company's shares, which are themselves an option. Thus, we are dealing with an option for an option. In this case, the basis and derivative options exist at the same time, so the option is parallel.

The value of the basis option, i.e. the shares of the acquired company, the core of the cluster (Fig. 1), will have the value

$$C_0 = \frac{(S_{1,\mathrm{opt}} - K_1)p_{\mathrm{opt}} + S_{1,\mathrm{pes}} \cdot p_{\mathrm{pes}}}{1 + \mathrm{WACC}} = \frac{(S_{1,\mathrm{opt}} - K_1)p_{\mathrm{opt}} + 0 \cdot p_{\mathrm{pes}}}{1 + \mathrm{WACC}} \tag{1}$$

where $S_{1,opt}$ and $S_{1,pes}$ are the optimistic and pessimistic values of the future monetary earnings of the acquired firm, adjusted for the beginning of the next year (rub.);

$K_1$ are investments in the implementation of the company's strategy in the next year (rub.);

$p_{opt}$ and $p_{pes}$ are the probabilities of optimistic and pessimistic scenarios; and

WACC is the weighted average cost of capital of the firm (%).

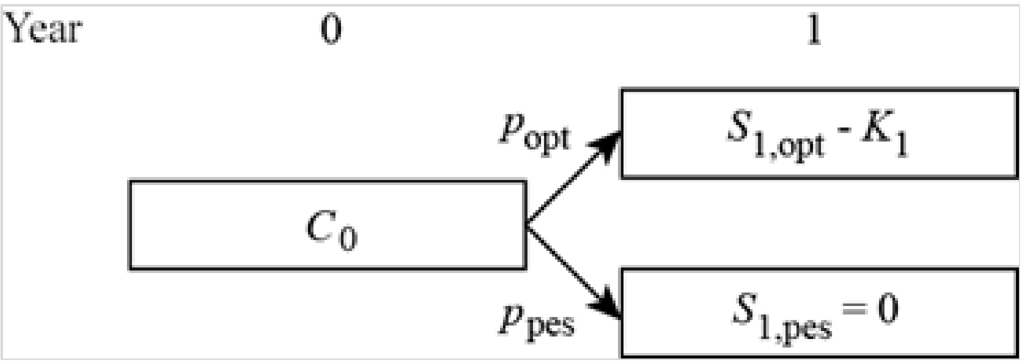



**Figure 1.** 100% Option Value Tree

To check whether there will be 0 in the 2nd component of the numerator of the formula (1), the own debt of the acquired company, the core of the cluster, $D_1 = D_0$ (1 + WACC) is compared with the value of $S_{1,pes}$. If $S_{1,pes} < D_1$, executing the call option becomes unprofitable, so there will be 0 in the numerator.

Next, the managers of the parent organization take a long-term loan $D_0$ to carry out the MBO transaction, which partially covers the value of the underlying option $C_0$. The rest of the value of $C_0$ is financed by the own and other capital of the acquiring company, i.e. $CS_0 = C_0 - D_0$.

Then, using the projected MBO credit rate, the value $S_{1,opt}$ - $K_1$ required to estimate the value of the derivative option $C_0$, i.e. the option managers get on the shares of the acquired firm, is estimated. The investment $K_1$ in this case is a loan for the MBO operation with interest after a year.

After that, the value of the derivative of the $C_0$ option is calculated according to the formula (1) with the only difference that here the WACC rate for the parent organization is used, since the profitability of this operation is estimated for it (Fig. 2).

 Sustain. Dev. Eng. Econ. 2022, 2, 1. https://doi.org/10.48554/SDEE.2022.2.1

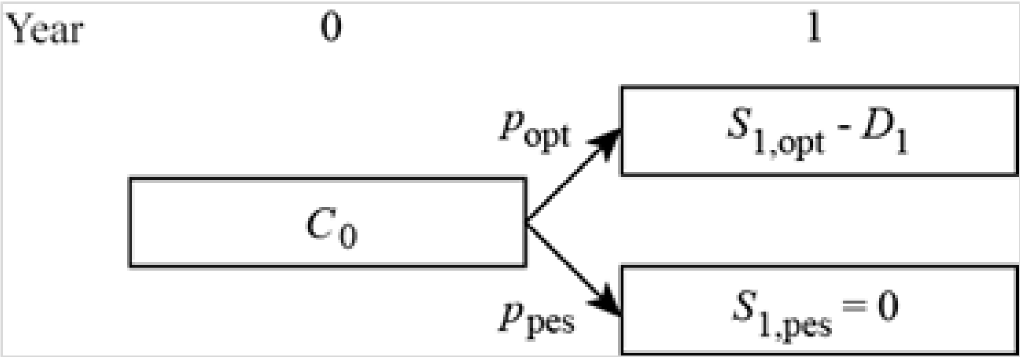



**Figure 2.** Parallel Option Value Tree

Finally, based on the value of the derivative option $C_0$, the net present value for managers from the MBO transaction is estimated as NPV = $C_0$ - $CS_0$.

2. Evaluation of options for the staged implementation of the cluster strategy (sequential real option). In this case, two options are considered that make up the sequence of the possible formation of the strategy of the core company of the cluster. These are the cluster experience development option and the cluster strategy switch option. That is, as soon as the possibilities for cluster experience development are thoroughly exhausted, it is assumed that the cluster will switch to a new, more progressive technology that will increase the value of the core company's business.

The value of the underlying (Fig. 3) and derivative (Fig. 4) options, as well as the net present value of the staged implementation of the firm's core strategy, can be estimated using the following formulas:

$$C_1 = \frac{(S_{2,\text{opt}} - K_2)p_{\text{opt}} + 0 \cdot p_{\text{pes}}}{1 + \text{WACC}},\ C_0 = \frac{(S_{1,\text{opt}} - K_1)p_{\text{opt}} + 0 \cdot p_{\text{pes}}}{1 + \text{WACC}},\ \text{NPV} = C_0 - K_0 \quad (2)$$

where $K_0$ and $K_1$ are the present values (PV) of costs at the beginning of each stage of the implementation of the cluster strategy (rub.).

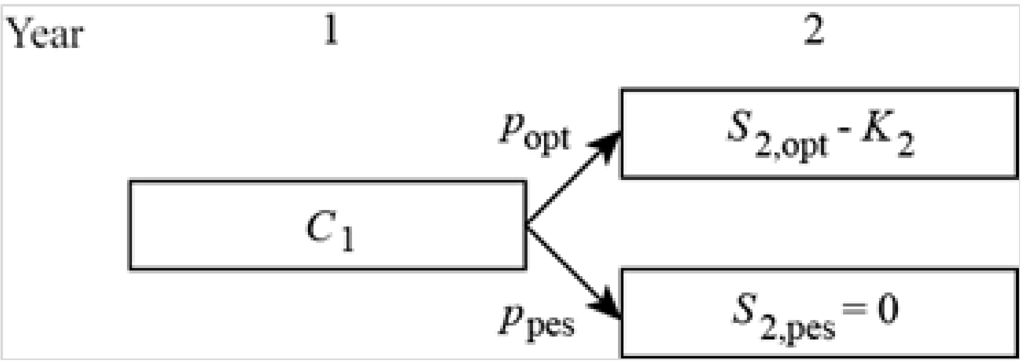



**Figure 3.** Cluster Strategy Switch Option Value Tree

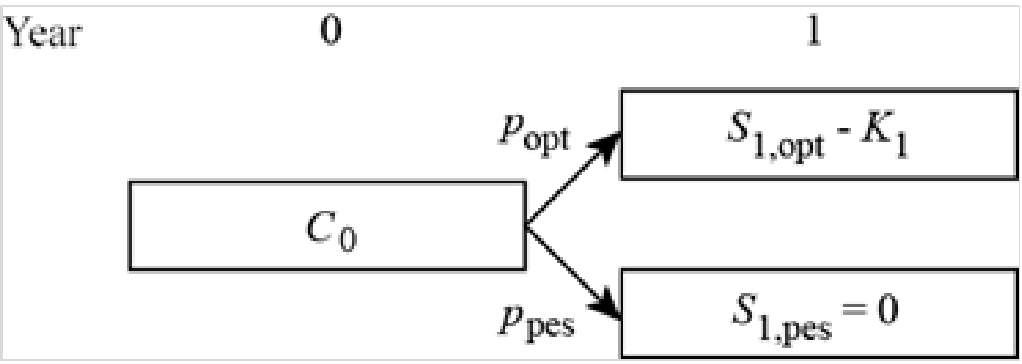



**Figure 4.** Cluster Experience Development Option Value Tree

## 4. Results

As an example of the implementation of the proposed method, we will consider the process of forming a development strategy for a pilot electric power industry cluster in the Nizhny Novgorod region. It was found that it is more profitable for the Nizhny Novgorod innovation and industrial cluster to develop in the "Electric Power Industry" direction (Yashin et al., 2019). For this, the Nizhny Novgorod region has the necessary innovative potential, i.e. enough production, financial, labour, and other resources for the successful evolution of the cluster.

This pilot cluster is represented by the core company of the TNS energo NN PJSC cluster. The TNS energo Nizhny Novgorod PJSC is the largest energy supply company in the Nizhny Novgorod region, with the status of a guaranteeing supplier. It was founded in 2005 as Nizhny Novgorod Sales Company OJSC. Ten years later, it received its modern name. It occupies a share of about 60% of the regional electricity sales market. It belongs to the GC TNS energo PJSC (https://old.conomy.ru). Initial and forecast data on its cash flows are provided in previous research (Yashin et al., 2021).

Further, we will compare two options for the formation of a development strategy for a pilot cluster of the electric power industry, using the corresponding compound real options for this purpose. In the first case, it is assumed that TNS energo NN PJSC will be acquired by the parent organisation GC TNS energo PJSC. In the second case, independent individual development of PJSC TNS energo NN is expected.

The second case will allow the preservation and development of a pilot innovation and industrial cluster of the electric power industry in the Nizhny Novgorod region in accordance with the priorities of the region in which it is located. Such priorities include social traditions, as well as innovative potential, expressed by the availability of production, financial, labour, and other resources for the successful development of the region.

The parent organization GC TNS energo PJSC does not need a pilot electric power cluster in the Nizhny Novgorod region. It only wants to assess the possibility of increasing the market value of its business through MBO operation with the shares of TNS energo NN PJSC.

On the contrary, the pilot electric power industry cluster represented by its core company TNS energo NN PJSC wants to assess which of the two options under consideration will give the highest cost of its strategy, that is, the effect of its implementation by the core company of the cluster.

GC TNS energo PJSC is the parent company of the eponymous largest Russian energy supply holding, which includes 10 companies: TNS energo Veliky Novgorod LLC, TNS energo Voronezh PJSC, TNS energo Karelia JSC, Kubanenergosbyt JSC, TNS energo Mari El PJSC, TNS energo NN PJSC, TNS energo Penza LLC, TNS energo Rostov-on-Don PJSC, TNS energo Tula JSC, and TNS energo Yaroslavl PJSC. Registered in 2013 in Moscow as GC TNS energo JSC, in 2014, it received its public status (https://old.conomy.ru).

1. Evaluation of risky forms of financing within the framework of the cluster strategy (parallel real option). The MBO operation is expected from the managers of the parent organization, i.e. GC TNS energo PJSC.

Loans and borrowings of TNS energo NN PJSC for 2020:

$$D_1 = D_0(1+\text{WACC}) = 4\ 558\ 531 \cdot 1{,}1256 = 5\ 131\ 082 > 2\ 358\ 870 = S_{1,\text{pes}}$$

Therefore, in a pessimistic scenario, all the assets of the core company of the cluster will be allocated for paying off its debts, and the managers of the parent company (GC) will not receive anything.

The value of the basis option, i.e. the shares of the acquired core company of the cluster according to the formula (1) will equal

$$C_0 = \frac{(8770\ 806 - 5\ 131\ 082) \cdot 0,5 + 0 \cdot 0,5}{1,1256} = 1\ 616\ 793 \text{ (thousand rubles).}$$

Managers of the GC in 2019 can take a long-term loan for MBO in the amount of

$$D_0 = 1\ 547\ 149 \text{ (thousand rubles).}$$

Own and other capital of the GC:

$$\mathrm{CS}_0 = C_0 - D_0 = 1\ 616\ 793 - 1\ 547\ 149 = 69\ 644 \text{ (thousand rubles).}$$

The projected loan rate is 13%. Then,

$$S_{1,\mathrm{opt}} - K_1 = 3\ 639\ 724 - 1\ 547\ 149 \cdot 1,13 = 1\ 891\ 446 \text{ (thousand rubles).}$$

The value of the derivative option, i.e. the managers' option on the shares of the acquired firm, taking into account for the GC according to the formula (1) will be

$$C_0 = \frac{1\ 891\ 446 \cdot 0,5 + 0 \cdot 0,5}{1,1152} = 848\ 030 \text{ (thousand rubles).}$$

The net present value for GC managers from an MBO transaction is:

$$\mathrm{NPV} = C_0 - \mathrm{CS}_0 = 848\ 030 - 69\ 644 = 778\ 386 > 0 \text{ (thousand rubles),}$$

i.e. the MBO operation is beneficial for the managers of the GC.

2. Evaluation of options for the staged implementation of the cluster strategy (sequential real option). To do this, two options are used that make up the sequence of possible formation of the strategy of the core company of the cluster. At the same time, each stage of the formation of the cluster strategy lasts for one year.

Cluster experience development option. Short-term investments in 2019 will amount to 489,948 thousand rubles, and in the optimistic scenario, they will increase the cash flow (CF) by 13.5% by reducing losses of the network companies (https://old.conomy.ru):

$$S_{1,\mathrm{opt}} = 1\ 225\ 461 + (8\ 770\ 806 - 1\ 225\ 461)1,135 - 551\ 486 = 9\ 237\ 942 \text{ (thousand rubles),}$$

$$\Delta S_{1,\mathrm{opt}} = 9\ 237\ 942 - 8\ 770\ 806 = 467\ 136 \text{ (thousand rubles).}$$

Cluster strategy switch option. A year after the successful reduction of losses of the network companies, i.e. in 2020, it is implied that TNS energo NN PJSC will switch to the new technology of TNS energo Rostov-on-Don PJSC. Initial and forecast data on the cash flows of TNS energo Rostov-on-Don PJSC are provided in previous research (Yashin et al., 2021).

Taking into account the effect of the previous stage, i.e. the execution of the cluster experience development option, in an optimistic scenario, the present value (PV) of costs at the beginning of the stage of switching to a new technology in 2020 will be

$$\Delta K - \Delta S_{1,\mathrm{opt}} = 3\ 876\ 628 - 467\ 136 = 3\ 409\ 492 \text{ (thousand rubles).}$$

As a result, we can collect data on the two stages of forming the cluster strategy in Table. 1.

**Table 1.** Data on the Stages of Implementation of the Cluster Strategy

| Stage | Term (years) | PV of costs at the beginning of the stage (thousand rubles) | Probability of success |
|---|---|---|---|
| Reducing losses of network companies | 1 | 489 948 | 0.5 |
| Switching to a new technology | 1 | 3 409 492 | 0.5 |

Then, the value of the underlying and derivative options, as well as the net present value of the staged implementation of the firm's core strategy, will be evaluated using the formulas (2):

$$C_1 = \frac{14984\ 536 \cdot 0,5 + 0 \cdot 0,5}{1,1256} = 6\ 656\ 244 \text{ (thousand rubles)},$$

$$C_0 = \frac{(6\ 656\ 244 - 3\ 409\ 492) \cdot 0,5 + 0 \cdot 0,5}{1,1256} = 1\ 442\ 232 \text{ (thousand rubles)},$$

$$\text{NPV} = 1\ 442\ 232 - 489\ 948 = 952\ 284 > 0 \text{ (thousand rubles)},$$

That is, staging the implementation of the cluster strategy is beneficial.

The final conclusion for the pilot cluster of the electric power industry will be that in the process of forming the cluster strategy, the sequential option allows us to obtain slightly higher NPV than the NPV of the parallel option. Therefore, the managers of TNS energo NN PJSC must make their own decisions: to negotiate with GC TNS energo PJSC on the acquisition of TNS energo NN PJSC or to develop further on the basis of the staged implementation of the cluster strategy. The second option will allow the preservation and development of a pilot innovation and industrial cluster of the electric power industry in the Nizhny Novgorod region in accordance with the priorities of the region in which it is located. Such priorities include social traditions, as well as innovative potential, expressed by the availability of production, financial, labour, and other resources for the successful development of the region.

## 5. Discussion

The allocation of pilot clusters that have the greatest benefit for the population of the region, taking into account its historical traditions as well as the types of production in the region, is a strategically important task for the executive authorities.

Comparing the results obtained with the experience of other scientists, Polyanin et al. (2020) created a methodology for assessing the economic security of the cluster, which is characterized by a comprehensive approach that takes into account all possible risks and threats in the functioning of individual components of the cluster structure.

Kudryavtseva et al. (2020) developed a methodology for assessing and monitoring cluster structures. To assess the prerequisites for the formation of a digital economy cluster, an integral indicator is calculated, and a multiparameter approach is used to assess the effectiveness of the cluster. The proposed methodology allows researchers to compare clusters from different regions and monitor their development.

Moeis et al. (2020) studied the dynamics and stability of the Tanjung Priok port cluster. System dynamics are used to study the problem, and the stability of the port cluster is estimated by modelling the dynamics of the system over a 20-year period of time.

Tashenova et al. (2020) developed a method for assessing the digital potential of the main innovatively active industrial clusters. The method is developed on the basis of existing methods and approaches to assessing the innovative potential of industrial clusters and the digital potential of industrial enterprises, and it allows calculation of the final integral assessment, which includes calculation for each of the seven subpotentials of the parameters that experts have identified as important.

However, in order to develop an innovative strategy for the pilot clusters defined by the state, it is important to apply technologies that allow flexible management decisions to be made. Taking into account the wide range of opportunities and threats to clusters, such a technology can be compound parallel and sequential real options. They make it possible to turn the future risks of the innovative-industrial cluster strategy into advantages due to the preliminary calculation of the effect of changing the strategy to account for future adverse situations as well as tactical opportunities for the development of the cluster.

The results obtained can be useful to public authorities in the processes of planning the development of innovative-industrial clusters and the harmonious development of the country's territories.

## 6. Conclusion

In the end, we will formulate the most important theoretical and practical conclusions.

1. To justify the choice between the acquisition strategy and the individual development of a pilot innovative-industrial cluster, it is necessary to conduct an appropriate monetary assessment of such management decisions. However, in practice, such an assessment cannot always give an unambiguous answer about the choice of strategy. In this case, it is advisable to focus on the socioeconomic needs of the region in which the cluster is located. This will allow further realization of the innovative potential available in the region.

2. To solve the indicated problem, it is possible to use the method of compound real options, where a parallel real option is applied when justifying the acquisition strategy, and a sequential real option is applied to assess the strategy of individual development.

3. As an example of the implementation of the presented method, the process of forming a strategy for the development of an electric power industry pilot cluster in the Nizhny Novgorod region, which is represented by the core company TNS energo NN PJSC, is considered. Here, the sequential option allows us to obtain slightly higher NPV than the value of the NPV of the parallel option. Therefore, the managers of TNS energo NN PJSC must make their own decisions: whether to negotiate with GC TNS energo PJSC on the acquisition of TNS energo NN PJSC or to develop further on the basis of the staged implementation of the cluster strategy. The second option will allow the preservation and development of a pilot innovation and industrial electric power industry cluster in the Nizhny Novgorod region in accordance with the priorities of the region in which it is located.

**Acknowledgements**

The study was carried out with the financial support of the Russian Foundation for Basic Research within the scientific project No. 19-010-00932 "Creation of a model for the evolution of the innovation system of industrial regions in modern conditions of socioeconomic development".

## References

Baranov, A., Muzyko, E., 2015. Valuation of compound real options for investments in innovative projects in pharmaceutical industry. Procedia Economics and Finance, 27,116–125. https://doi.org/10.1016/S2212-5671(15)00980-6

Bogdanova, T., Karlik, M., 2020. Problems of competitive strategy choice according to industry and regional factors. International Journal of Technology, 11(8), 1478–1488. https://doi.org/10.14716/ijtech.v11i8.4531

Bouvier, L., Nisar, T.M., 2015. Design and impacts of securitized leveraged buyouts. Cogent Economics & Finance, 3(1), David McMillan (Reviewing Editor). https://doi.org/10.1080/23322039.2015.1009307

Cassimon, D., Engelen, P.J., Yordanov, V., 2011. Compound real option valuation with phase-specific volatility: A multi-phase mobile payments case study. Technovation 31, 240–255.

Claire, J., Guise, F., 2019. Compound options: Numerical valuation methods and a real option application. BSc Thesis in Applied Mathematics, Delft University of Technology, Delft, Netherlands.

Demiroglu, C., James, C.M., 2010. The role of private equity group reputation in LBO financing. Journal of Financial Economics 96(2),

306–330. https://doi.org/10.1016/j.jfineco.2010.02.001
Hauschild, B., Reimsbach, D., 2015. Modeling sequential R&D investments: A binomial compound option approach. Business Research 8, 39–59. https://doi.org/10.1007/s40685-014-0017-5
Kodukula, P., Papudesu, C., 2006. Project Valuation Using Real Options: A Practitioner's Guide. J. Ross Publishing, Inc., Fort Lauderdale.
Konstandatos, O., 2015. Third order compound option valuation of flexible commodity based mining enterprises. Archives of Business Research 3(1), 19–35. https://doi.org/10.14738/abr.31.801
Kudryavtseva, T., Kulagina, N., Lysenko, A., Berawi, M.A., Skhvediani, A., 2020. Developing methods to assess and monitor cluster structures: The case of digital clusters. International Journal of Technology 11(4), 667–676. https://doi.org/10.14716/ijtech.v11i4.4191
Lai, C.S., Locatelli, G., 2021. Valuing the option to prototype: A case study with generation integrated energy storage. Energy, 217. https://doi.org/10.1016/j.energy.2020.119290
Leiblein, M.J., Ziedonis, A., 2006. Deferral and growth options under sequential innovation. Advances in Strategic Management 24. https://doi.org/10.1016/S0742-3322(07)24008-2
Locatelli, G., Mancini, M., Lotti, G., 2020. A simple-to-implement real options method for the energy sector. Energy 197. https://doi.org/10.1016/j.energy.2020.117226
Martins, G.B., Silva, M.E., 2005. A real option model with uncertain, sequential investment and with time to build. Revista Brasileira de Financas 3(2), 141–172.
Moeis, A.O., Desriani, F., Destyanto, A.R., Zagloel, T.Y., Hidayatno, A., Sutrisno, A., 2020. Sustainability assessment of the Tanjung Priok Port cluster. International Journal of Technology 11(2), 353–363. https://doi.org/10.14716/ijtech.v11i2.3894
Mun, J., 2002. Real Options Analysis: Tools and Techniques for Valuing Strategic Investments and Decisions. John Wiley & Sons, New Jersey.
Polyanin, A., Pronyaeva, L., Pavlova, A., Fedotenkova, O., Rodionov, D., 2020. Integrated approach for assessing the economic security of a Cluster. International Journal of Technology 11(6), 1148–1160. https://doi.org/10.14716/ijtech.v11i6.4420
Porter, M.E., 2008. On Competition, Updated and Expanded Ed. Harvard Business School Publishing, Boston.
Renneboog, L., Vansteenkiste, C., 2017. Leveraged buyouts: A survey of the literature. European Corporate Governance Institute (ECGI) - Finance Working Paper 492. http://dx.doi.org/10.2139/ssrn.2896653
Tan, J.J., 2018. Interfaces for enterprise valuation from a real options lens. Strategic Change 27(1), 69–80. https://doi.org/10.1002/jsc.2181
Tan, J.J., Trinidad, F.L., 2018. A real options model for loan portfolios of actively traded Philippine universal banks. J Glob Entrepr Res. 8(4). https://doi.org/10.1186/s40497-018-0091-9
Tashenova, L., Babkin, A., Mamrayeva, D., Babkin, I., 2020. Method for evaluating the digital potential of a backbone innovative active industrial cluster. International Journal of Technology 11(8), 1499–1508. https://doi.org/10.14716/ijtech.v11i8.4537
Tavakkolnia, A., 2016. A binomial tree valuation approach for compound real options with fuzzy phase-specific volatility. In 12th International Conference on Industrial Engineering (ICIE), Tehran, Iran, 73–78. https://doi.org/10.1109/INDUSENG.2016.7519351
Wehrly, E., Shen, T., 2016. Management Buyouts, in: Augier M., Teece D. (eds), The Palgrave Encyclopaedia of Strategic Management, Palgrave Macmillan, London. https://doi.org/10.1057/978-1-349-94848-2_672-1
Xu, D., Zhou, C., Phan, P., 2010. A real options perspective on Sequential Acquisitions in China. J Int Bus Stud. 41, 166–174. https://doi.org/10.1057/jibs.2009.16
Yashin, S.N., Koshelev, E.V., D.A. Sukhanov, D.A., 2021. Razrabotka Strategii Razvitiya Innovatsionno-industrial`nogo Klastera Metodom Sostavnykh Real`nykh Optsionov [Articulating the development strategy for the innovation and industrial cluster by the compound option method]. Finance & Credit 27(7), 1647–1671. https://doi.org/10.24891/fc.27.7.1647
Yashin, S.N., Koshelev, E.V., Kostrigin, R.V., 2019. Sostavleniye Lineynogo Funktsionala Tsennosti Innovatsionno-Industrial'nogo Klastera Dlya Regiona [Compilation of Linear Functional of the Value of the Innovation and Industrial Cluster for the Region]. Management of Economic Systems: Scientific Electronic Journal 130(12). Available at: http://uecs.ru/innovacii-investicii/item/5774-2019-12-21-11-28-53.

## Список источников

Baranov, A., Muzyko, E., 2015. Valuation of compound real options for investments in innovative projects in pharmaceutical industry. Procedia Economics and Finance, 27,116–125. https://doi.org/10.1016/S2212-5671(15)00980-6
Bogdanova, T., Karlik, M., 2020. Problems of competitive strategy choice according to industry and regional factors. International Journal of Technology, 11(8), 1478–1488. https://doi.org/10.14716/ijtech.v11i8.4531
Bouvier, L., Nisar, T.M., 2015. Design and impacts of securitized leveraged buyouts. Cogent Economics & Finance, 3(1), David McMillan (Reviewing Editor). https://doi.org/10.1080/23322039.2015.1009307
Cassimon, D., Engelen, P.J., Yordanov, V., 2011. Compound real option valuation with phase-specific volatility: A multi-phase mobile payments case study. Technovation 31, 240–255.
Claire, J., Guise, F., 2019. Compound options: Numerical valuation methods and a real option application. BSc Thesis in Applied Mathematics, Delft University of Technology, Delft, Netherlands.
Demiroglu, C., James, C.M., 2010. The role of private equity group reputation in LBO financing. Journal of Financial Economics 96(2), 306–330. https://doi.org/10.1016/j.jfineco.2010.02.001
Hauschild, B., Reimsbach, D., 2015. Modeling sequential R&D investments: A binomial compound option approach. Business Research 8, 39–59. https://doi.org/10.1007/s40685-014-0017-5
Kodukula, P., Papudesu, C., 2006. Project Valuation Using Real Options: A Practitioner's Guide. J. Ross Publishing, Inc., Fort Lauderdale.
Konstandatos, O., 2015. Third order compound option valuation of flexible commodity based mining enterprises. Archives of Business Re-

search 3(1), 19–35. https://doi.org/10.14738/abr.31.801
Kudryavtseva, T., Kulagina, N., Lysenko, A., Berawi, M.A., Skhvediani, A., 2020. Developing methods to assess and monitor cluster structures: The case of digital clusters. International Journal of Technology 11(4), 667–676. https://doi.org/10.14716/ijtech.v11i4.4191
Lai, C.S., Locatelli, G., 2021. Valuing the option to prototype: A case study with generation integrated energy storage. Energy, 217. https://doi.org/10.1016/j.energy.2020.119290
Leiblein, M.J., Ziedonis, A., 2006. Deferral and growth options under sequential innovation. Advances in Strategic Management 24. https://doi.org/10.1016/S0742-3322(07)24008-2
Locatelli, G., Mancini, M., Lotti, G., 2020. A simple-to-implement real options method for the energy sector. Energy 197. https://doi.org/10.1016/j.energy.2020.117226
Martins, G.B., Silva, M.E., 2005. A real option model with uncertain, sequential investment and with time to build. Revista Brasileira de Financas 3(2), 141–172.
Moeis, A.O., Desriani, F., Destyanto, A.R., Zagloel, T.Y., Hidayatno, A., Sutrisno, A., 2020. Sustainability assessment of the Tanjung Priok Port cluster. International Journal of Technology 11(2), 353–363. https://doi.org/10.14716/ijtech.v11i2.3894
Mun, J., 2002. Real Options Analysis: Tools and Techniques for Valuing Strategic Investments and Decisions. John Wiley & Sons, New Jersey.
Polyanin, A., Pronyaeva, L., Pavlova, A., Fedotenkova, O., Rodionov, D., 2020. Integrated approach for assessing the economic security of a Cluster. International Journal of Technology 11(6), 1148–1160. https://doi.org/10.14716/ijtech.v11i6.4420
Porter, M.E., 2008. On Competition, Updated and Expanded Ed. Harvard Business School Publishing, Boston.
Renneboog, L., Vansteenkiste, C., 2017. Leveraged buyouts: A survey of the literature. European Corporate Governance Institute (ECGI) - Finance Working Paper 492. http://dx.doi.org/10.2139/ssrn.2896653
Tan, J.J., 2018. Interfaces for enterprise valuation from a real options lens. Strategic Change 27(1), 69–80. https://doi.org/10.1002/jsc.2181
Tan, J.J., Trinidad, F.L., 2018. A real options model for loan portfolios of actively traded Philippine universal banks. J Glob Entrepr Res. 8(4). https://doi.org/10.1186/s40497-018-0091-9
Tashenova, L., Babkin, A., Mamrayeva, D., Babkin, I., 2020. Method for evaluating the digital potential of a backbone innovative active industrial cluster. International Journal of Technology 11(8), 1499–1508. https://doi.org/10.14716/ijtech.v11i8.4537
Tavakkolnia, A., 2016. A binomial tree valuation approach for compound real options with fuzzy phase-specific volatility. In 12th International Conference on Industrial Engineering (ICIE), Tehran, Iran, 73–78. https://doi.org/10.1109/INDUSENG.2016.7519351
Wehrly, E., Shen, T., 2016. Management Buyouts, in: Augier M., Teece D. (eds), The Palgrave Encyclopaedia of Strategic Management, Palgrave Macmillan, London. https://doi.org/10.1057/978-1-349-94848-2_672-1
Xu, D., Zhou, C., Phan, P., 2010. A real options perspective on Sequential Acquisitions in China. J Int Bus Stud. 41, 166–174. https://doi.org/10.1057/jibs.2009.16
Яшин С.Н., Кошелев Е.В., Суханов Д.А., 2021. Разработка стратегии развития инновационно-индустриального кластера методом составных реальных опционов. Финансы и кредит 27(7), 1647–1671. https://doi.org/10.24891/fc.27.7.1647
Яшин С. Н., Кошелев Е. В., Костригин Р.В., 2019. Составление линейного функционала ценности инновационно-индустриального кластера для региона. Управление экономическими системами: электронный научный журнал 12, 90-90. Режим доступа: http://uecs.ru/innovacii-investicii/item/5774-2019-12-21-11-28-53.

The article was submitted 1.03.2022, approved after reviewing 29.04.2022, accepted for publication 1.05.2022.

Статья поступила в редакцию 1.03.2022, одобрена после рецензирования 29.04.2022, принята к публикации 1.05.2022.

About authors:
1. Dmitriy G. Rodionov, Doctor of Economic Sciences, Director of the Graduate School of Engineering and Economics, Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russian Federation, drodionov@spbstu.ru, https://orcid.org/0000-0002-1254-0464.
2. Egor V. Koshelev, Candidate of Economic Sciences, Associate Professor of the Department of Management and Public Administration, Lobachevsky State University of Nizhny Novgorod, Nizhny Novgorod, Russian Federation, ekoshelev@yandex.ru, https://orcid.org/0000-0001-5290-7913.
3. Leandro S. Escobar-Torres, PhD (abd) in Economics, MSc in Finance, Associate Professor of the Department of Quantitative Methods, ICADE, Comillas Pontifical University, Madrid, Spain, lescobar@comillas.edu, https://orcid.org/0000-0001-5603-5737.

Информация об авторах:
1. Дмитрий Григорьевич Родионов, доктор экономических наук, директор Высшей инженерно-экономической школы, Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Российская Федерация, drodionov@spbstu.ru, https://orcid.org/0000-0002-1254-0464.
2. Егор Викторович Кошелев, кандидат экономических наук, доцент кафедры менеджмента и государственного управления, Нижегородский государственный университет им. Н.И. Лобачевского, Нижний Новгород, Российская Федерация, ekoshelev@yandex.ru, https://orcid.org/0000-0001-5290-7913.
3. Леандро Эскобар-Торрес, PhD (экономика), магистр (финансы), доцент департамента количественных методов, Папский университет Комильяс, Мадрид, Испания, lescobar@comillas.edu, https://orcid.org/0000-0001-5603-5737.

SECTION 2

# ENTERPRISES AND SUSTAINABLE DEVELOPMENT OF REGIONS

РАЗДЕЛ 2

# ПРЕДПРИЯТИЯ И УСТОЙЧИВОЕ РАЗВИТИЕ РЕГИОНОВ

**Research article**
**DOI:** https://doi.org/10.48554/SDEE.2022.2.2

# MODELING OF PRODUCTION PROCESSES PARAMETERS OF INDUSTRIAL ENTERPRISES

Natalya Sokolitsyna[1*], Alexander Sokolitsyn[1]

[1]Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia, natasokoli@yandex.ru, alex.sokol1951@yandex.ru
[*]Corresponding author: natasokoli@yandex.ru

## Abstract

Corporative industrial firms' enterprises for organizationally-technical and economic measures on product competitiveness improvement realization require creating low-cost and resource-saving mechanisms. An important role in this mechanism is to allow for wide searching and systematic internal reserves to economize production, assessing and choosing variants of improving constructions, technologies, and ways to organize production. Identifying economically stimulating operators allows for firms to participate in measures and elaborations realization. Because of the role of economic analysis in production management growth, practical interest in these analysis methods is relevant at all management levels, from brigades to enterprise directors. A comprehensive information model of enterprise management tasks was formed. Statistical modelling of the production process parameters of industrial enterprises based on a single balance sheet model is characterized by system integration based on a single information base and software. The developed model makes it possible to assess the state of the production process of the enterprise and to increase the efficiency of using the results of economic analysis in the preparation and implementation of several levels of production plans, and, as a result, to increase the level of assessment of the realism of the implementation of the established production plans.

**Keywords:** modelling, production process, parameters, economic analysis

**Citation:** Sokolitsyna, N., Sokolitsyn, A., 2022. Modeling of production processes parameters of industrial enterprises. Sustainable Development and Engineering Economics 2, 2. https://doi.org/10.48554/SDEE.2022.2.2

**Научная статья**
*УДК 338.3*
**DOI:** https://doi.org/10.48554/SDEE.2022.2.2

# МОДЕЛИРОВАНИЕ ПАРАМЕТРОВ ПРОИЗВОДСТВЕННЫХ ПРОЦЕССОВ ПРОМЫШЛЕННЫХ ПРЕДПРИЯТИЙ

Наталья Соколицына[1*], Александр Соколицын[1]

[1]Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия, natasokoli@yandex.ru, alex.sokol1951@yandex.ru

[*]Автор, ответственный за переписку: natasokoli@yandex.ru

**Аннотация**

Реализация организационно-технических и экономических мероприятий предприятий по повышению конкурентоспособности выпускаемой продукции требует создания противозатратного и ресурсосберегающего механизмов. Важная роль в этом механизме отводится широкому и систематическому поиску внутренних резервов экономии в производстве, оценке и выбору вариантов совершенствования конструкций, технологий и способов организации производства, экономическому стимулированию исполнителей, участвующих в реализации мероприятий и разработок. В связи с этим возрастает роль экономического анализа в управлении производством, повышается практический интерес к внедрению его методов на всех уровнях управления, начиная от участков и бригад до директоров предприятий. Сформирована комплексная информационная модель задач управления предприятием. Статистическое моделирование параметров производственных процессов промышленных предприятий на базе единой балансовой модели отличается системной интеграцией на базе единой информационной базы и программного обеспечения. Разработанная модель позволяет оценить состояние производственного процесса предприятия и повысить эффективность использования результатов экономического анализа при составлении и реализации нескольких уровней производственных планов и, как следствие, повысить уровень оценки реалистичности выполнения установленных производственных планов.

**Ключевые слова:** моделирование, производственный процесс, параметры, экономический анализ

**Цитирование:** Соколицына, Н., Соколицын, А., 2022. Моделирование параметров производственных процессов промышленных предприятий. Sustainable Development and Engineering Economics 2, 2. https://doi.org/10.48554/SDEE.2022.2.2

## 1. Introduction

Economic analysis, as one of the basic management functions, realises the same tasks as the whole management system and is in close link with other functions: planning, accounts, and regulation. Considering these links allows us to determine the role of analysis in the management process.

Economic analysis is the most important element of industrial firms' research object development plan elaboration process. Forming current and perspective plans requires detailed analysis of production-household activity in some plan time, finding unused internal production reserves, and taking into account technical progress factors impacting the plan period.

Planning is closely connected with economic analysis of expected and fact-solving plan tasks, including defining work results in the considered plan time, finding several factors' impact on production processes, and getting information for objective achieved results assessment. In this regard, quality planning is the basis for economic analysis.

In the middle position in management systems, between planning and accounts on one side, and regulation compliance on the other side, analysis always impacts management decision-making and is its logic base. Analysis quality and complexity highly impact the optimality of decisions made at several production management levels.

The role of economic analysis in management, including an awareness of the links with other functions, determines its importance in all production elements' practical activities. Analysis is not just an element of planning and prognosing the scientific base, but also serves as an instrument for objective activity assessment and is perhaps the most important means of household mechanism realization, production effectiveness, and improvement of reserves mobilization.

The modern practice of researching complex economic systems, as in industrial firms, requires creating a complex economic analysis (CEA) system, taking into account the complexity of the analysed objects and solved tasks. Because this practice requires elaborating on such economic analysis methods, which allow determining and appreciating several production process elements' complex interconnections and interdeterminance, finding their development among existing rules is critical (Figure 1).

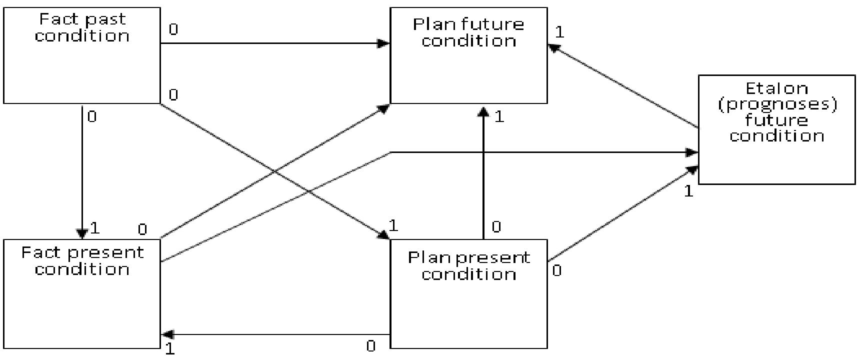



**Figure 1.** Several production process condition comparison types in CEA: 0 – comparison base; 1 – comparison (analysis) object

The advantage of the CEA system methodology is that it provides sufficiently wide analysis functions and strengthens its management aspect. Several kinds of analysis, forming CEA systems, allow researching all sides of enterprises (unions) and their units of activity integrated in each calendar time, which substantially increases management systems' effectiveness.

The authors of works on CEA solve its structuration question differently, describing several CEA kinds. On usage aims and spheres, in the CEA system there are the following analysis kinds: perspective, retrospective, operative, comparing, and functionally-cost. All mentioned analysis kinds differ on compared production process condition types (Figure 1). Each CEA kind considers one or some production process condition pairs when either comparison base, or object is only one type (Table 1) (Sheremet et al., 2004).

Thus, in the plan elaboration CEA process, the analysis object always plans the future production process condition, and comparison bases are fact present, plan, and etalon (prognoses) process conditions. In perspective analysis, comparison objects are prognoses or etalons—best analogic productions in the country and abroad—and the comparison base can be fact or plan present condition. Retrospective analysis compares several plan and fact present conditions with base past and fact conditions. Operative analysis compares only two production process condition types: analysis object is fact present condition, and comparison base is plan present production process condition. Inside each kind, CEA tasks are classified on production process compared condition types. Perspective and retrospective analyses are also divided on analysed time (future or past) deepness, and plan elaborations analysis and operative analysis of their solving.

CEA tasks are divided on the kind of figures analysed (money or natural volumes of resources and products) because it determines the specifics of the information search used and elaboration methods (Sokolitsyn, 2001), and CEA results usage in several plans' preparation. Principal CEA kinds and task classifications of the mentioned features are shown in Table 1. CEA methods are classified on researched objects and process descriptions with regard to economic-mathematical model kinds. There are linear, nonlinear, continuous, integer, static, dynamic, determined, and stochastic models, and two basic classes of economic analysis methods: direct and reciprocal factors (Bakanov & Sheremet, 1998).

**Table 1.** Principal CEA kinds and tasks classification

<table>
<tr><th rowspan="2">Analysis kind</th><th colspan="5">Compared production process conditions</th><th colspan="3">Figures analysis tasks</th></tr>
<tr><th>Fact past</th><th>Fact present</th><th>Plan present</th><th>Plan future</th><th>Etalon</th><th colspan="2">Money</th><th>Natural</th></tr>
<tr><td rowspan="2">Elaborations and plans system analysis</td><td rowspan="2">-</td><td rowspan="2">0</td><td rowspan="2">0</td><td rowspan="2">1</td><td rowspan="2">0</td><td colspan="2">Financial plan, enterprise and its units figures analysis</td><td>Resources, its usage, productivity analysis</td></tr>
<tr><td colspan="3">Analysis of technically-economic plansof functioning<br>Production improvement and development plan analysis<br>Functionally cost analysis</td></tr>
<tr><td rowspan="2">Perspective</td><td rowspan="2">-</td><td rowspan="2">0</td><td rowspan="2">0</td><td rowspan="2">-</td><td rowspan="2">1</td><td rowspan="5">Enterprise units activity comparison analysis (assessment)</td><td colspan="2">Long-term aim programs analysis</td></tr>
<tr><td>Production volumes and effectiveness growth prognoses and aims analysis on perspective</td><td>Science-technicalprognoses and aims of diminishing average resources of product analysis on single production stage</td></tr>
<tr><td rowspan="2">Retrospective</td><td rowspan="2">0</td><td rowspan="2">1</td><td rowspan="2">1</td><td rowspan="2">1</td><td rowspan="2">1</td><td colspan="2">Analysing dynamics and tendencies of changing figures<br>Statistical figures trust analysis</td></tr>
<tr><td>Analysing changing production volumes and effectiveness</td><td>Analysing changing average resources of product, resource usage on production stages</td></tr>
<tr><td>Operative</td><td>-</td><td>1</td><td>0</td><td>-</td><td>-</td><td>Deviations from operative plans analysis on enterprise units activity assessment figures</td><td>Deviations from operative production plans analysis on product, material stocks, material purchases, loading equipment and work force</td></tr>
</table>

Technology allows for the receipt of a product from a determined resources combination, which is data on resource costs for a production product unit. Then, the enterprise production process can be shown as a dozen interconnected technologies. Enterprise productions process resource products and create elaborate models for the resource products dozen.

When considering the technology dozen, there are multiple hypotheses, eventually leading to linear production models. The first hypothesis is that this dozen is finite. The second is that each average resource on the product unit for each technology is independent of the technology usage intensity (technology homogeneity). A third hypothesis is that the average resource on some technologies doesn't change with their uniting into one complex technology in one production unit (technologies additivity).

In the real economy, the majority of dependencies are more complex and non-linear; therefore, the linearity hypothesis simplifies reality. However, the suggested simplification is necessary because of two conditions. First, the production process characteristic links linearity, allowing for the simplification of the production process' mathematical description and usually adequately expresses this real process character. Secondly, deviations from linearity are compatible with the inevitable noise of modelling – casual changes in production process, account, and calculation errors.

All three mentioned hypotheses mean that each of the production process parts can be shown as an initial technologies linear combination, where the linear form coefficients are average resource products, and its variables are technology usage intensities.

## 2. Literature review

Many scientific works consider economic analysis to be the most important part of system industrial enterprise development management. Only a system approach allows for elaborating CEA methodology (Bakanov & Sheremet, 1998; Gluhov et al., 1998; Gradov et al., 2008; Kobzev & Kolesnichenko-Yanusheva, 2002; Sokolitsyn et al., 2013; Sokolitsyn, 2008; Sokolitsyn, 2001; Sokolitsyn et al., 2009; Sokolitsyn, 2012(a); Sokolitsyn, 2012(b); Sokolitsyn & Ivanov, 2012). Question is raised in A. D. Sheremet's works, having elaborated on the need for CEA theory elaboration based on inquiring about economic analysis as a production management method (Sheremet et al., 2004).

Economic analysis increases the role of statistical modelling of industrial enterprise production process parameters and provides a mechanism for entering all enterprise management levels (Gluhov et al., 2007; Demidenko & Malevskaya-Malevich, 2016; Mednikov, 2012; Nikolova et al., 2017; Nikolova et al., 2014; Semenov et al., 2016; Silkina, 2017; Rodionov et al., 2019; Demidenko, 2019; Sokolitsyna, 2019; Silkina & Danilov, 2020).

In modern organizationally economic conditions, much attention is paid to real production process data transformation for process-mining analysis. Dišek et al. (2017) considered real data transformation formatted from several information systems, achieving production process-mining analysis in a big automobile company. The research detailed the analysis production process, identifying "bottlenecks". Khalili and Chua (2014) suggested resource optimization for planned production by forming integrated pre-configured and grouped components. To predict complex configurations related to production resources and cost optimization, the study of Khalili and Chua adopts two new ideas, pre-configuring and component grouping, which are integrated into the mixed integer linear programming (MILP) model. These concepts form the basis for optimization of the MILP model development, leading to appropriate model adaptation and optimal production plan creation.

Ben-Gal and Singer (2004) present a new statistical process control methodology based on context modelling of discrete processes. The method uses a series of context tree models to estimate the condition distribution of process results based on data from previous observations. The Kullback–Leiber divergence statistic is used to find sufficient changes in the tree models during the process, allowing for flexible production system simulation.

Issues with analysing functioning, predicting several technologies, and mathematical programming for object development get enough attention in several aspects of their production-household activity (Yabuta et al., 2017; Brezhnev & Chernetskiy, 2016), which allows for an increase in their competitiveness and effectiveness.

Therefore, mathematical programming methods are widely used for describing and analysing production and technologic processes of household subjects related to several industries and property forms because these programming methods have enough universal character.

## 3. Materials and methods

The enterprise resource product transformation production process is modelled using the mentioned technologies dozen per defined time – usually a year. As with other such models, stocks of all identified resource products are defined based on a considered timeline, and resource product circulation (consumption) per this time. Any technological process usage intensity is measured as the product volume per considered time.

The technologies dozen is also used to model the enterprise production process part, in which the same resource products are manufactured on several technologies, or resource products can be changed by entering new technologies and organizational measures, changing the average resources of the products. The results of elaboration and organizational measures, named in general organizationally technical measures on economizing resources, are shown as changed or added technologies as new receipts of obtaining resource products.

The analysis of enterprise production programme variants requires an entire enterprise production process model. As with previous tasks, the desired outcome is maximal production process differentiation, allowing for increased precision in finding bottlenecks.

The descriptive statistics for the initial characteristics of the production process are used to form a complex information model of current conditions, developing and functioning the enterprise. This model helps to determine and compactly write figures, methods, and algorithms to solve complex economic analysis tasks related to enterprise work.

Uniting the enterprise's controlled and planned characteristics, figure descriptions, and measurements requires that an enterprise information model utilizes a mathematically-statistical description that can be used in its work planning. Therefore, an enterprise's mathematically statistical description must be determined by the essence of its planning tasks.

The basic tasks of planning, using economic analyses with mathematically statistical methods, form the classic balance input-output model.

## 4. Results

We must first establish initial production process characteristic marks. Their definitions are based on a "resource product" term – each material or labour resource or product of any production process unit.

We define $I = \{ i \mid i = \overline{1,n}\}$ as the enterprise resource products dozen for enterprise work economic analysis; depending on the particular economic analysis task, this dozen can include only input and output resources and products for single workplaces, primary units, works, or whole enterprises. $I_{op}$ represents equipment type sizes, professions, and worker levels sub-dozen; T is the basic technological equipment work-time regime fund in the analysed period (below named *period T*); $V = \{v_1, v_2, \ldots, v_n\}$ is enterprise resource product circulation vector-column in period T; and $Y = \{y_1, y_2, \ldots, y_n\}$ is the resource product inputs from the environment and production stocks vector-column in period T for equipment and workers (their unit's or group's effective time funds, depending on classification). The vector $W = \{w_1, w_2, \ldots, w_n\}$ is the enterprise resource products and production stocks manufacturing vector-column in period T for equipment and workers (their underload); $d_{i\ell}$ is the i product direct cost coefficient per l resource product unit in the production process for equipment and workers (the exploitation hours number); and $D = \{d_{i\ell|i}, \ell \in I\}$ is the enterprise resource products direct costs coefficients square matrix.

The coefficient $d_{i\ell}$ describes the cost relationship in production technological processes with set resource product elaboration and assembly initial and middle conditions description differentiation levels. The model used the following typical hypotheses for defining the economically mathematical modelling of production technological processes:

1) The modelled technological processes dozen is finite.
2) Average resources (direct cost coefficients) per product unit for each product are independent of process usage intensity.
3) The average resources of some processes don't change once united into one complex technological process in one production unit.

In the case of resource product identification on some classification levels, each particular resource product in the enterprise classification group has its own particular number. Such a method allows the formation of a production process model at the same time for several equipment, labour resources, and materials classification levels.

In this model, equipment and labour resources are obtained from the environment, i.e. required no resources excluding financial resources. This, therefore, implies that

Figures $v_i$, $i \in I$ of vector-column V are determined in the following way:

$$v_i = \sum_{\ell \in I} d_{i\ell}\left(v_\ell - y_\ell\right) + w_i, i = I,$$

If

$$v_\ell \geq y_\ell, \ell \in I, v_i \geq w_i, i \in I. \tag{1}$$

In matrix form, equation (1) is written as follows:

$$\mathrm{V} = \mathrm{D}\left(\mathrm{V} - \mathrm{Y}\right) + \mathrm{W}, \quad \mathrm{V} - \mathrm{W} = \mathrm{D}\left(\mathrm{V} - \mathrm{Y}\right), \tag{2}$$

when are *V, V - Y, V - W*, correspondingly, resource product circulation, production, and consumption vector columns.

We can solve equation (2) relative to V to obtain the following equation:

$$\mathrm{V} = \left(\mathrm{E} - \mathrm{D}\right) - 1\left(\mathrm{W} - \mathrm{DY}\right) \tag{3}$$

(E is a single square matrix with scale n x n).

The reciprocal matrix $(E - D)^{-1}$ is determined by dividing (4), if described by matrix D for which the production process has no turns, i.e. no middle process product is a resource for itself:

$$\left(E - D\right) - 1 = E + D^1 + D^2 + \ldots + D^k + \ldots, \tag{4}$$

if corresponding $k \leq n$ then $D^k = 0$ .

Let's consider this matrix through F:

$$F = \left(E - D\right)^{-1} = \left\{f_{ij} \mid j \in I\right\}$$

where $f_{ij}$ for $i \neq j$ is the *i* resource product total costs coefficient per *j* resource-product unit.

$$FD = F - E = DF \tag{5}$$

According to (3) and (5),

$$V = FW = \left(F - E\right)Y \tag{6}$$

or

$$V - Y = F\left(W - Y\right).$$

Marking matrix (5) as F*, we obtain

$$\mathrm{V} - \mathrm{W} = \mathrm{F}^*\left(\mathrm{W} - \mathrm{Y}\right). \tag{7}$$

Matrix equations (5)–(7) are the basis of forming the FIG enterprise balance.

We can define $I_0 \subset I$ as the resources sub-dozen obtained only from the environment. We can also set $I_{op} \subset I$. It must confirm that $v_i = y_i$, $i \in I_0$. Then, from (6), we obtain the FIG enterprises balance equation:

$$F_{(i)}\left(W - Y\right) = 0, i \in I_0, \tag{8}$$

where $F_{(i)}$ is the *i* row of the F matrix.

All other resource products must confirm that:

$$v_i - y_i \geq 0,$$

i.e.

$$F_{(\mathrm{i})}\left(\mathrm{W} - \mathrm{Y}\right)0,\ \mathrm{iI} \setminus I_0. \tag{9}$$

In addition, there are limitations on resource product consumption from the environment:

$$Y \leq Y_0, \tag{10}$$

where $Y_0$ is the corresponding limitation vector-column in the plan period *T*;

and limitations on manufacturing products are given by:

$$W \geq W_0, \tag{11}$$

where $W_0$ is the minimal tasks vector-column on manufacturing products.

All non-negative W and Y values, confirming (8)–(11), form a firm enterprise possible plan in period *T*.

Fact (present) production process conditions correspond to one of system (8)–(11) possible answers:

$$\begin{cases} v_i = w_i + \sum_{j \in I \setminus I_0} f_{ij}^* (w_j - y_j), \quad \mathrm{i} \in I \setminus I_0; \\ y_i = v_i = w_i + \sum_{j \in I \setminus I_0} f_{ij}^* (w_j - y_j), \quad \mathrm{i} \in I \setminus I_{\mathrm{op}}; \\ w_i = y_i - \sum_{j \in I \setminus I_0} f_{ij}^* (w_j - y_j), \quad \mathrm{i} \in I_{\mathrm{op}}; \end{cases}$$

because $f_{ij}^* = 0$ for $i \in I, j \in I_0$ according to the initial resources dozen $I_0$ definition (including the equipment and workers sub-dozen $I_{op}$).

Let's consider $t_{i\ell}$ as the time of closing (manufacturing forwarding) *i* resource product units in the production process of making $\ell$ resource product units. For equipment and workers $t_{il} = 0, i \in I_{op}, \ell \in I$. For $i = \ell$, we can set $t_{i\ell}$ equal to the time of closing I resource product in its own circulating stock, if this stock isn't included in any production process of making another $\ell$ resource product (in this case, time of closing in this circulating stock is included in the time of closing in the production process). This gives the stock-level characteristic:

$$h_{i\ell} = \begin{cases} \dfrac{1}{T} d_{i\ell} t_{i\ell}, i \neq l, i \in I \setminus I_{op}, l \in I, \\ \dfrac{t_{i\ell}}{T}, i = l, \end{cases}$$

where $h_{i\ell}$ is the level of direct closing (stock) of *i* resource product in the production process of making $\ell$ resource product units, particularly circulating stock if *i* =. For equipment and workers, definitely, $h_i = 0$, if $i \in I_{op}, \ell \in I$ or $\in I, \ell \in I_{op}$.

We can consider $H = \{h_{ij} | i_{ij} \in I\}$ as the square matrix of levels of direct closing (stocks) resource products in the production process. Let's define $g_{ks}$ as the level of direct closing *k* resource product in the production process of making *s* resource product as follows:

$$g_{ks} = \sum_{i \in I} \sum_{\ell \in I} f_{ki} h_{i\ell} f_{\ell s}, \ \ \mathrm{k} \in \mathrm{I}, \ \ \mathrm{s} \in I \setminus I_{\mathrm{op}}; \ \ \mathrm{g}_{\mathrm{ks}} = 0, \ \ \mathrm{s} \in I_{\mathrm{op}} \tag{12}$$

We can define a set G of all possible $g_{ks}$ characteristics if $k, s \in I$ form a matrix of levels of total closing resource products in the production process:

$$G = \{g_{ks} \mid k, s \in I\} = FHF.$$

The $g_{ks}$ characteristics are used to calculate the time lag between manufacturing *k* and *s* resource products:

$$\tau_{ks} = \frac{g_{ks}}{f_{ks}} T, \quad \mathrm{k} \in \mathrm{I}, \ \ \mathrm{s} \in I \setminus I_{\mathrm{op}}$$

Therefore, there are financially industrial groups' enterprise production processes initial mathematically statistical characteristic and natural figures systems.

With coordinated operative accounts and accounting, a united balance model includes initial and final stocks, circulation of materials, and middle, non-finished, and mature products in a set operative period in natural and money volumes. The model allows us to obtain the needed data for both basic production operative management and material values accounting (forming circulating and saldo sheets).

These normative changes allow us to locate when corresponding fact production stocks exceed or underperform and eliminate their causes. Finding and analysing these and all other set figure deviations from the norm require special methods.

The described mathematical statistical approach usage allows for the modelling of enterprise processes for effective production development plan elaboration with methods of mathematical programming in the following ways:

- Defining production programme alternatives and identifying production development opportunities and threats;

- Defining constructor-technologic solution alternatives and buying resources for production development.

These approaches are realised with all-side economic analysis of enterprise development plans.

The task of effective planning can be formulated as follows:

$$ZW \rightarrow max;$$

$$F_{(i)}(W - Y) = 0,\ i \in I_0, \tag{18}$$

$$F_{(i)}(W - Y) \geq 0,\ i \in I/\ I_0, \tag{19}$$

$$0 \leq Y \leq Y^0, \tag{20}$$

$$W \geq W^0. \tag{21}$$

The objective function includes money figures: $Z=\{z_i\ |i \in I\}$ is the price vector of resource products together with materials and middle product prices, when $z_i = \alpha_i$;and $ZW$ is total revenue.

Effective planning is realised on these sums basis with methods of linear programming on the basis of the unknown vectors W and Y. Defining an effective plan to double estimations (20) allows the identification of resource deficits and damaging production development with diminishing product outputs. Defining production development opportunities and threats correlates with the task of defining an effective production programme, W. Thus, complex modelling of enterprise production activity is realised for economic analysis and effective planning.

With a coordinated operative account, a united balance model of statistical modelling for enterprise production process parameters includes initial and final stocks, flows of materials, and middle, unfinished, and mature products in a defined operative period in natural and money volumes. It allows us to obtain the needed data for both basic operative production management and material values accounts.

This elaborated economically mathematical model of defining enterprise production process parameters can be used for a wide range of market economy household subjects' management tasks in several branches and property forms.

The elaborated production process model realization provides the following complex solutions to economic analysis tasks:

- Initial production process parameters account
- Initial natural figures calculation
- Complex natural and money figure calculations.

Cost reduction on entering the elaborated model requires standardized software usage. Calculations consist of standard matrix calculations; the production process model is realised in one of the mechanic assembling production of an energetic machine-making enterprise, having leading positions in St. Petersburg and North-West Russia in this branch.

## 4. Discussion

Factors restricting such multidimensional economic analysis include used production methods and costs operative account system opportunities, and also needed production process plan conditions recalculation (or early calculation usage) opportunities for analysed time intervals. This requires marking three basic economic analysis conditions in the suggested methods:

- United centralized details for the production operative account system, controlled in the balance work objects enterprise model in elaboration and assembly.
- Entering the normative production costs in the account method, including systematic accounts,

summing, and showing each defined period for planning, all caused by norms variation, resource costs, and fact costs deviations.

- Organizationally-technic opportunities to calculate and correct operative plan tasks for production units with needed frequency.

This elaborated economically mathematical model for defining enterprise production process parameters is sufficiently universal. First, it can be used for each enterprise management unit in each production process part with each decomposition or aggregation level. Second, it can be used in several kinds of economic analysis tasks. Thus, this production process description is made for operative, retrospective, and perspective economic analysis with several methods, but in structure and content, it must be unified, fit to a united conceptual balance model with a statistic defining enterprise production process parameters.

## 5. Conclusion

Providing a complex, full-blown, and true enterprise production process description is a difficult problem with some methodological and organizational aspects. Economic analysis task solutions on a united complex enterprise production process description base take into account several enterprise production household activity factors that require appropriate mathematical and informational resources. If a factor economic analysis mathematical apparatus is elaborated enough and universal for all analysed factor models figures, then the factor model creations with statistical modelling enterprise production process parameters on existing enterprise statistical data is no longer an unelaborated task in both method and organisationally informational aspects. This task is most effectively solved in creating special complex economic analysis subsystems, whose core is a united model of defining complex balance enterprise production process statistic parameters. Usable analysis methodologies are needed for some economic analysis tasks, particularly factor figure models defined from these balance model enterprise production process statistic parameters.

Existing enterprise management systems are maximally prepared too wide, entering only retrospective economic analysis tasks using cumulated account-statistic production data.

Obviously, particular enterprise management systems can include several solutions to these questions. Therefore, elaborating on economic analysis models and software, oriented not on a particular enterprise management system but on the whole industrial enterprise, requires a clear united standard (typical) base that considers an elaborated complex enterprises balance, production process parameters statistics, a defined model base universal for some enterprises, and also tasks and methods of constructing optimal development for a particular enterprise.

## References


Bakanov, M.I., Sheremet, A.D., 1998. Economic Analysis Theory. Textbook. 4th ed. M.: Finance and Statistics, 416.

Ben-Gal, I., Singer, G., 2004. Statistical processes control via context modelling of finite-state processes: An application to production monitoring. IIE TRANSACTIONS. Publisher: Taylor & Francis, Ltd, 36 (5), 401-415. https://doi.org/10.1080/07408170490426125. ISSN: 0740-817X.

Brezhnev, E., Chernetskiy, B., 2016. Risk matrix-based method for critical infrastructure safety assessment taking into account interdependencies. Proceedings of the MATEC Web of 20th International Conference on Circuits, Systems, Communications and Computers, CSCC 2016; Corfu Island, Greece. Publisher: EDP Sciences. https://doi.org/10.1051/matecconf/20167602050. ISSN: 2261236X. Article number: 02050.

Demidenko, D.S., 2019. Innovation processes effectiveness economic analysis specialties in enterprise. Foresight «Russia»: technologies, economy and people future. St. Petersburg International Economic Congress (SPEC-2019) reports collection. SPb.: "S. Y. Vitte new industrial development institute" non-commercial scientific-research partnership, associated, 608-616.

Demidenko, D.S., Malevskaya-Malevich, E.D., 2016. Resource management in enterprise's production process (Conference Paper). Proceedings of the 28th International Business Information Management Association Conference – Vision 2020: Innovation Management, Development Sustainability, and Competitive Economic Growth (IBIMA), 3789-3793. ISBN: 978-098604198-3.

Dišek, M., Šperka, R., Kolesár, J., 2017. Conversion of real data from production process of automotive company for process mining analysis. Smart Innovation, Systems and Technologies, Proceedings of the 11th KES International Conference on Agent and Multi-Agent Systems—Technologies and Applications (KES-AMSTA 2017). Publisher: Springer International Publishing AG, 223-233. https://doi.org/10.1007/978-3-319-59394-4_22. ISSN: 21903018.

Gluhov, V.V., Kobyshev, A.N., Kozlov, A.V., 1998. Situation Analysis. Business situations and business games for management: Supplementary file. Eds. By prof. V.V. Gluhov. SPb: SPbSTU, 301.

Gluhov, V.V., Mednikov, M.D., Korobko, S.B., 2007. Mathematical methods and models for management: High school supplementary file. Edition 2nd corresponding edting. Publisher: Lane, St. Petersburg, 528.

Gradov, A.P., Ilyin, I.V., Suloeva, S.B., 2008. Industrial enterprise strategy: Structure, functions, processes, environment. SPb.: Polytechn. Un-ty Press, 551.

Khalili, A., Chua, D.K., 2014. Integrated prefabrication configuration and component grouping for resource optimization of precast production. Publisher: American Society of Civil Engineers. Journal of Construction Engineering and Management 140, article number: 04013052. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000798. ISSN: 07339364.

Kobzev, V.V., Kolesnichenko-Yanusheva, N.S., 2002. Enterprise economy: Supp. file. Eds. By V.V. Kobzev. SPb.: SPbSTU Press, 129.

Mednikov, M.D., 2012. Crisis Firm Management. Publisher: Polytechnic University Press, St. Petersburg, 198.

Nikolova, L.V., Rodionov, D.G., Afanasyeva, N.V., 2017. Impact of globalization on innovation project risks estimation. European Research Studies, 20(2). Publisher: International Strategic Management Association, 396-410. ISSN: 11082976,

Nikolova, L.V., Rodionov, D.G., Mokeeva, T.V., 2014. The formalization of the conflicts management models of the strategic alliances under the conditions of the globalizations. Asian Social Science 10. Publisher: Canadian Center of Science and Education, 296-302. ISSN: 19112017, https://doi.org/10.5539/ass.v10n19p296.

Rodionov, D.G., Mottaeva, A.B., Koshman, A.V., 2019. Oil–gas complex household subjects sustainable development and innovational activity. Kant 1 (30), 325-330.

Semenov, V.P., Sokolitsyn, A.S., Sokolitsyna, N.A., 2016. Forming production program with homogenous product in market environment uncertainty (Conference Paper). Proceedings of 5th IEEE Forum on Strategic Partnership of Universities and Enterprises of Hi-Tech Branches, Science. Education, 76-78. ISBN: 978-150905424-4. https://doi.org/10.1109/IVForum.2016.7835860

Sheremet, A.D., Sayfulin, L.S., Negashev, E.V., 2004. Financial Analysis Methodic. M.: INFRA, 236.

Silkina, G.Y., 2017. Decision-Making Methods. Publisher: Polytechnic University Press, St. Petersburg, 184.

Silkina, G.Y., Danilov, A.A., 2020. Principles of functioning industrial enterprise in sustainable development conditions. St. Petersburg polytechnic university science-technic times. Economics 13, 5, 82-94.

Sokolitsyn, A.S., Ivanov, M.V., Bogomolov, Yu.A., 2009. Industrial enterprises activity diversification management – most important socially-economic systems development mechanism: supp. file. SPb.: Polytechn. Un-ty Press, 138.

Sokolitsyn, A.S., 2001. Industrial firms' management: Methodology, models, and economic analysis. SPb.: SPbSTU Press, 279.

Sokolitsyn, A.S., 2008. Industrial firms interfirm management. SPb.: Polytechn. Un-ty Press, 151.

Sokolitsyn, A.S., 2012(a). Integrated industrial structures enterprises economic interests coordination methodological principles. SPbSTU science-technical times, series «Economical sciences. Book 1». SPb.: Polytechn. un-ty press, 2-1 (144), 23-26.

Sokolitsyn, A.S., 2012(b). Modeling industrial enterprise production process parameters. SPbSTU science-technical times, series «Economical sciences. Book 1». SPb.: Polytechn. Un-ty Press, 2-1 (144), 104-108.

Sokolitsyn, A.S., Ivanov, M.V., Sokolitsyna, N.A., Shevtsov, E.G., 2013. Entrepreneurship organization. Industrial enterprises development management mechanisms improvement: supp. file. SPb.: Polytechn. Un-ty press, 400.

Sokolitsyn, A.S., Ivanov, M.V., 2012. Defining industrial enterprise activity development optimal strategy. Collection: Science-methodical problems, methodic and practice of specialists' preparation for management and information technologies. Science Edition. SPb.: Polytechn. un-ty press, 151-154.

Sokolitsyna, N.A., 2019. Industrial enterprise activity complex socially-statistical analysis model. Economics and Entrepreneurship, 12(113), 804-808.

Yabuta, K., Hirao, M., Sugiyama, H., 2017. Process model for enhancing yield in sterile drug product manufacturing. Journal of Pharmaceutical Innovation (Open access). Publisher: Springer Science + Business Media New York, 1-12. https://doi.org/10.1007/s12247-017-9278-9. ISSN: 18725120.

## Список источников

Bakanov, M.I., Sheremet, A.D., 1998. Economic Analysis Theory. Textbook. 4th ed. M.: Finance and Statistics, 416.

Ben-Gal, I., Singer, G., 2004. Statistical processes control via context modelling of finite-state processes: An application to production monitoring. IIE TRANSACTIONS. Publisher: Taylor & Francis, Ltd, 36 (5), 401-415. https://doi.org/10.1080/07408170490426125. ISSN: 0740-817X.

Brezhnev, E., Chernetskiy, B., 2016. Risk matrix-based method for critical infrastructure safety assessment taking into account interdependencies. Proceedings of the MATEC Web of 20th International Conference on Circuits, Systems, Communications and Computers, CSCC 2016; Corfu Island, Greece. Publisher: EDP Sciences. https://doi.org/10.1051/matecconf/20167602050. ISSN: 2261236X. Article number: 02050.

Demidenko, D.S., 2019. Innovation processes effectiveness economic analysis specialties in enterprise. Foresight «Russia»: technologies, economy and people future. St. Petersburg International Economic Congress (SPEC-2019) reports collection. SPb.: "S. Y. Vitte new industrial development institute" non-commercial scientific-research partnership, associated, 608-616.

Demidenko, D.S., Malevskaya-Malevich, E.D., 2016. Resource management in enterprise's production process (Conference Paper). Proceedings of the 28th International Business Information Management Association Conference – Vision 2020: Innovation Management, Development Sustainability, and Competitive Economic Growth (IBIMA), 3789-3793. ISBN: 978-098604198-3.

Dišek, M., Šperka, R., Kolesár, J., 2017. Conversion of real data from production process of automotive company for process mining analysis. Smart Innovation, Systems and Technologies, Proceedings of the 11th KES International Conference on Agent and Multi-Agent Systems—Technologies and Applications (KES-AMSTA 2017). Publisher: Springer International Publishing AG, 223-233. https://doi.org/10.1007/978-3-319-59394-4_22. ISSN: 21903018.

Gluhov, V.V., Kobyshev, A.N., Kozlov, A.V., 1998. Situation Analysis. Business situations and business games for management: Supplementary file. Eds. By prof. V.V. Gluhov. SPb: SPbSTU, 301.

Gluhov, V.V., Mednikov, M.D., Korobko, S.B., 2007. Mathematical methods and models for management: High school supplementary file. Edition 2nd corresponding edting. Publisher: Lane, St. Petersburg, 528.

Gradov, A.P., Ilyin, I.V., Suloeva, S.B., 2008. Industrial enterprise strategy: Structure, functions, processes, environment. SPb.: Polytechn. Un-ty Press, 551.

Khalili, A., Chua, D.K., 2014. Integrated prefabrication configuration and component grouping for resource optimization of precast production. Publisher: American Society of Civil Engineers. Journal of Construction Engineering and Management 140, article number: 04013052. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000798. ISSN: 07339364.

Kobzev, V.V., Kolesnichenko-Yanusheva, N.S., 2002. Enterprise economy: Supp. file. Eds. By V.V. Kobzev. SPb.: SPbSTU Press, 129.

Mednikov, M.D., 2012. Crisis Firm Management. Publisher: Polytechnic University Press, St. Petersburg, 198.

Nikolova, L.V., Rodionov, D.G., Afanasyeva, N.V., 2017. Impact of globalization on innovation project risks estimation. European Research Studies, 20(2). Publisher: International Strategic Management Association, 396-410. ISSN: 11082976,

Nikolova, L.V., Rodionov, D.G., Mokeeva, T.V., 2014. The formalization of the conflicts management models of the strategic alliances under the conditions of the globalizations. Asian Social Science 10. Publisher: Canadian Center of Science and Education, 296-302. ISSN: 19112017, https://doi.org/10.5539/ass.v10n19p296.

Rodionov, D.G., Mottaeva, A.B., Koshman, A.V., 2019. Oil–gas complex household subjects sustainable development and innovational activity. Kant 1 (30), 325-330.

Semenov, V.P., Sokolitsyn, A.S., Sokolitsyna, N.A., 2016. Forming production program with homogenous product in market environment uncertainty (Conference Paper). Proceedings of 5th IEEE Forum on Strategic Partnership of Universities and Enterprises of Hi-Tech Branches, Science. Education, 76-78. ISBN: 978-150905424-4. https://doi.org/10.1109/IVForum.2016.7835860

Sheremet, A.D., Sayfulin, L.S., Negashev, E.V., 2004. Financial Analysis Methodic. M.: INFRA, 236.

Silkina, G.Y., 2017. Decision-Making Methods. Publisher: Polytechnic University Press, St. Petersburg, 184.

Silkina, G.Y., Danilov, A.A., 2020. Principles of functioning industrial enterprise in sustainable development conditions. St. Petersburg polytechnic university science-technic times. Economics 13, 5, 82-94.

Sokolitsyn, A.S., Ivanov, M.V., Bogomolov, Yu.A., 2009. Industrial enterprises activity diversification management – most important socially-economic systems development mechanism: supp. file. SPb.: Polytechn. Un-ty Press, 138.

Sokolitsyn, A.S., 2001. Industrial firms’ management: Methodology, models, and economic analysis. SPb.: SPbSTU Press, 279.

Sokolitsyn, A.S., 2008. Industrial firms interfirm management. SPb.: Polytechn. Un-ty Press, 151.

Sokolitsyn, A.S., 2012(a). Integrated industrial structures enterprises economic interests coordination methodological principles. SPbSTU science-technical times, series «Economical sciences. Book 1». SPb.: Polytechn. un-ty press, 2-1 (144), 23-26.

Sokolitsyn, A.S., 2012(b). Modeling industrial enterprise production process parameters. SPbSTU science-technical times, series «Economical sciences. Book 1». SPb.: Polytechn. Un-ty Press, 2-1 (144), 104-108.

Sokolitsyn, A.S., Ivanov, M.V., Sokolitsyna, N.A., Shevtsov, E.G., 2013. Entrepreneurship organization. Industrial enterprises development management mechanisms improvement: supp. file. SPb.: Polytechn. Un-ty press, 400.

Sokolitsyn, A.S., Ivanov, M.V., 2012. Defining industrial enterprise activity development optimal strategy. Collection: Science-methodical problems, methodic and practice of specialists’ preparation for management and information technologies. Science Edition. SPb.: Polytechn. un-ty press, 151-154.

Sokolitsyna, N.A., 2019. Industrial enterprise activity complex socially-statistical analysis model. Economics and Entrepreneurship, 12(113), 804-808.

Yabuta, K., Hirao, M., Sugiyama, H., 2017. Process model for enhancing yield in sterile drug product manufacturing. Journal of Pharmaceutical Innovation (Open access). Publisher: Springer Science + Business Media New York, 1-12. https://doi.org/10.1007/s12247-017-9278-9. ISSN: 18725120.

The article was submitted 12.03.2022, approved after reviewing 21.04.2022, accepted for publication 02.05.2022.

Статья поступила в редакцию 12.03.2022, одобрена после рецензирования 21.04.2022, принята к публикации 02.05.2022.

About authors:

1. Natalya Alexandrovna Sokolitsyna, Candidate of Economic Sciences, Associate Professor, Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia, https://orcid.org/0000-0003-3322-5911, natasokoli@yandex.ru

2. Alexander Sergeevich Sokolitsyn, Doctor of Economic Sciences, Professor, Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia, https://orcid.org/0000-0002-8640-1678, alex.sokol1951@yandex.ru

Информация об авторах:

1. Наталья Александровна Соколицына, кандидат экономических наук, доцент, Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия, https://orcid.org/0000-0003-3322-5911, natasokoli@yandex.ru

2. Александр Сергеевич Соколицын, доктор экономических наук, профессор, Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия, https://orcid.org/0000-0002-8640-1678, alex.sokol1951@yandex.ru

SECTION 3

# SUSTAINABLE DEVELOPMENT OF REGIONAL INFRASTRUCTURE

РАЗДЕЛ 3

# УСТОЙЧИВОЕ РАЗВИТИЕ РЕГИОНАЛЬНОЙ ИНФРАСТРУКТУРЫ

**Research article**
**DOI:** https://doi.org/10.48554/SDEE.2022.2.3

# COMPARATIVE STUDY OF SOLAR AND WIND POWER PLANT TARIFF AND INVESTMENT COSTS

Ulam-Orgil Choijiljav[1], Uranchimeg Tudevdagva[2*]

[1]Mongolian University of Science and Technology, Mongolia, ulamorgil@must.edu.mn
[2*]Chemnitz University of Technology, Germany, uranchimeg.tudevdagva@informatik.tu-chemnitz.de
[*]Corresponding author: uranchimeg.tudevdagva@informatik.tu-chemnitz.de

**Abstract**

One of the main directions of sustainable energy is the development of renewable energy. Mongolia is rich in renewable energy resources and has a very favourable geographical location. Therefore, with the construction of solar and wind power plants, these power plants will be able to supply power to half-day and evening peak loads in any season of the year, and to reduce the amount of imported energy from Russia during peak hours. The Renewable Energy Law was enacted in 2007 and revised in 2015 and 2019, and it has successfully met its goal of developing the sector and attracting foreign investors. The law sets a cap on electricity sales in US dollars, which has had a significant impact on system-wide efficiency. Compared to 2007, the average USD exchange rate increased by 143.41%. The price of 1 kWh of electricity increased from 210.68 MNT to 512.82 MNT for solar power plants; for wind power plants, it increased from 111.19 MNT to 270.66 MNT. In other words, the price of renewable energy in our country fluctuates according to the dollar exchange rate, and the US dollar exchange rate has increased by an average of 7% per year over the past 15 years. Therefore, this paper examines how the US dollar tariff in the Renewable Energy Law affects feed-in tariffs.

**Keywords:** feed-in tariff, investment cost, solar and wind power plant, renewable energy, electricity market, sustainable energy, energy economics

**Citation:** Choijiljav, U.O., Tudevdagva, U., 2022. Comparative study of solar and wind power plant tariff and investment costs. Sustainable Development and Engineering Economics 2, 3. https://doi.org/10.48554/SDEE.2022.2.3

**Научная статья**

**УДК 338.4**

**DOI:** https://doi.org/10.48554/SDEE.2022.2.3

# СРАВНИТЕЛЬНОЕ ИССЛЕДОВАНИЕ ТАРИФОВ И ИНВЕСТИЦИОННЫХ ЗАТРАТ НА СОЛНЕЧНЫЕ И ВЕТРОВЫЕ ЭЛЕКТРОСТАНЦИИ

Улам-Оргил Чойжилжав[1], Уранчимэг Тудэвдагва[2*]

[1]Монгольский Государственный Университет Науки и Технологий, Монголия, ulamorgil@must.edu.mn

[2*]Технический Университет Кемница, Германия, uranchimeg.tudevdagva@informatik.tu-chemnitz.de

[*]Автор, ответственный за переписку: uranchimeg.tudevdagva@informatik.tu-chemnitz.de

## Аннотация

Одним из основных направлений устойчивой энергетики является развитие возобновляемых источников энергии. Монголия богата возобновляемыми источниками энергии и имеет очень выгодное географическое положение. Поэтому благодаря строительству солнечных и ветряных электростанций, дневные и вечерние пиковые нагрузки будут покрыты в любое время года, а также будет сокращено количество импортируемой энергии из России в часы пик. Закон о возобновляемых источниках энергии был принят в 2007 году и пересмотрен в 2015 и 2019 годах, он успешно достиг своей цели по развитию сектора и привлечению иностранных инвесторов. Закон устанавливает ограничение на продажу электроэнергии в долларах США, что оказало значительное влияние на эффективность всей системы. По сравнению с 2007 годом средний обменный курс доллара США вырос на 143,41%. Цена 1 кВт*ч электроэнергии увеличилась с 210,68 тугриков до 512,82 тугриков для солнечных электростанций; для ветряных электростанций она увеличилась с 111,19 тугриков до 270,66 тугриков. Другими словами, цена на возобновляемые источники энергии в нашей стране колеблется в зависимости от курса доллара, а курс доллара США за последние 15 лет рос в среднем на 7% в год. Поэтому в данном исследовании авторами рассматривается, как тариф в долларах США в Законе о возобновляемых источниках энергии влияет на льготные тарифы на энергию, произведенную с помощью возобновляемых источников.

**Ключевые слова:** зеленый тариф, инвестиционные затраты, солнечные и ветровые электростанции, возобновляемые источники энергии, рынок электроэнергии, устойчивая энергетика, энергетическая экономика

**Цитирование:** Чойжилжав, У.О., Тудэвдагва, У., 2022. Сравнительное исследование тарифов и инвестиционных затрат на солнечные и ветровые электростанции. Sustainable Development and Engineering Economics 2, 3. https://doi.org/10.48554/SDEE.2022.2.3

## 1. Introduction

With the world pursuing a sustainable energy policy, fossil fuels will not be renewable, and fuel reserves will inevitably be depleted. Because oil and coal are not only fuels but also raw materials for many important products, it is important for humans to use them as sparingly as possible. In addition, the global and Mongolian energy sectors continue to focus on renewable energy development policies, as the use of coal and oil as fuel for energy production has serious negative consequences for the environment (Buyankhishig and Ulam-Orgil, 2018).

"Vision – 2050," approved on May 23, 2020, in the framework of Mongolia's long-term development policy, established the economic priorities for the years 2021 to 2030 to include the following:

- Increase the installed capacity of renewable energy to 30%.
- Use of modern and advanced renewable energy technologies in local heating supply.
- Implement the Asian Integrated Energy Network initiative in cooperation with Northeast Asian countries.
- The use of solar, wind, water, biomass, geothermal, fuel cells, and other new sources in line with resource capacity balances is important for the development of renewable energy (Mongolian Government, 2020).

In 2007, the first Renewable Energy Law was passed in Mongolia. Since then, the law has been revised in 2015 and 2019. The revised law stipulates that the renewable energy producer connected to the transmission network has the right and obligation to connect to the transmission point closest to the generator and supply electricity and comply with the requirements of the network dispatcher. The transmission network, on the other hand, is obliged to purchase and transmit electricity supplied by the producer at the tariffs set by this law (Renewable Energy Law, 2019). One of the special provisions of this law is that the price of electricity generated and supplied from renewable energy sources is higher than the selling price of traditional sources, which is a manifestation of the government's major policy in support of renewable energy. In addition, the Investment Law, the Customs Tariff and Customs Tax Law, and the Value Added Tax Law were amended to exempt renewable energy research and production equipment, accessories, and spare parts from customs and value-added taxes. This favourable policy and legal environment pursued by the government has had a significant impact on the successful implementation of renewable energy projects in Mongolia. The study looked at renewable energy tariffs in other countries and how feed-in tariffs are set in those countries (Javadi et al., 2018; Bakhtyar, 2014; Komiyama, et al., 2014; Guild, 2019; Eberhard and Kaberger, 2016; Goodarzi et al., 2018; Yang and Nie, 2016; Masuta et al., 2015; Nair and Sankar, 2014).

Many government policies and regulations are being implemented to increase the development and use of renewable energy sources around the world. For example, after the Fukushima Daiichi nuclear power plant disaster in Japan on March 11, 2011, the Japanese government began a phased energy policy reform. Therefore, the full retail liberalization of the electricity retail market began in April 2016, and the introduction of a market-dependent feed-in tariff system would be a good option for the development of Japan's renewable energy sources (Fuyi, 2017).

The government of Japan introduced the Renewable Energy Feed in Tariff System on July 1, 2012, which is a widely used incentive system to stimulate the development of energy sources. In 2013, electricity from renewable sources accounted for only 2.2% of total electricity generated in Japan, but after the introduction of the feed-in tariff system, this percentage rose to 4.7% in 2015 and increased 2.1 times in just two years (Fuyi, 2017).

Indonesia is an equatorial country and has sun all year round. From 2016 to 2018, the Indonesian government implemented four regulations to increase the value of investment in energy, especially in the renewable energy sector. Feed-in tariff regulation for solar power plants and local tariff regulation have been developed. However, it has been concluded that these regulations still do not provide good incentives for energy developers (Guild, 2019).

Thus, the new feed-in tariffs for the development of renewable energy sources are working well in some countries, but not in others.

The price of 1 kWh of renewable energy is relatively higher than the price of 1 kWh of electricity produced and imported by thermal power plants, and it depends on the exchange rate, so there is a certain price difference (Batzaya et al., 2021; Bani Adam and Miyauchi, 2019; Zhou et al., 2020).

Many countries around the world have introduced a ***feed-in tariff*** (green tariff) system as part of their policy to reduce traditional energy production, which depends on natural resources, and to develop renewable energy (Goodarzi et al., 2018; Von der Fehr et al., 2016; Chawla et al., 2020; Steffen, 2020).

In Mongolia, the feed-in tariff system was introduced in 2015. In addition, the purchase of electricity generated by solar and wind power plants in a single customer model at a fixed price in US dollars negatively affects the efficiency of a single buyer's system in times of large exchange rate fluctuations. This report examines the impact of changes in the US dollar on the selling price and feed-in tariffs for electricity generated by solar and wind power plants, and calculates the feed-in tariffs for new power plants when they are commissioned (OECD, 2019; Frankfurt School of Finance & Management, 2020; Altantsetseg and Ulam-Orgil, 2021; Orolzodmaa, 2021).

## 2. Methodology of Feed-in Tariff

Many countries around the world have introduced a *feed-in tariff* system as part of a policy to develop renewable energy and to reduce traditional energy production dependent on natural resources . The feed-in tariff system is one of the most widely used incentive policies for the introduction of renewable energy. In 1987, the US Public Utilities Policy Act was considered the world's first feed-in tariff system (Batzaya et al., 2021; Bani Adam and Miyauchi, 2019; Zhou et al., 2020). In Germany, the share of renewable energy production has increased from 3.6% in 1990 to 30% in 2015 as a result of the feed-in tariff system (Erneuerbare Energien Gesetz-EEG) under the Renewable Energy Sources Act (IRENA, 2020).

Although the design and calculation methodology of the feed-in tariff system varies from country to country, the key point of the system is to determine the tariff level.

Determining tariff levels is the most important part of the policy. Tariff rates are usually based on the cost of generating electricity from renewable energy sources. Some studies classify the feed-in tariff system into two main groups. One is a market-independent system, and the other is a market-dependent system. In a market-dependent system, payment depends on the price of electricity, while in a standalone market system, payment does not depend on the price of electricity (Fuyi, 2017).

The feed-in tariff policy of the Indonesian Ministry of Energy and Mineral Resources was established to allow users to install solar panels in their systems. This regulation is aimed not only at the use of electricity but also at the supply of electricity using solar panels. There are a number of limitations to the feed-in tariff regulation. The first restriction provides compensation for 65% of the price of energy supplied to the grid (Guild, 2019).

Our country uses a feed-in tariff of a market-dependent system. In doing so, the 2015 reform of the Law on Renewable Energy introduced a special tariff category called "Renewable Energy Feed-in Tariff" instead of incorporating tariffs to support renewable energy production into any type of energy tariff. The law states that feed-in tariffs are tariffs included in energy prices to support renewable energy (Renewable Energy Law, 2019). It also stipulates that the Energy Regulatory Commission will review and approve the price of electricity to be supplied to the system from renewable energy sources and consumer purchase feed-in tariffs.

Feed-in tariffs are defined by the following formula.

$$FiT = \frac{E_{RE}^{\sup}(P_{RE} - P_{SYS}^{avg})}{E_{SYS}^{dis}} \quad (1)$$

where:

$E_{SYS}^{dis}$ – The amount of energy distributed by the system (kWh)

$E_{RE}^{sup}$ – The amount of energy supplied to the system from a renewable energy source (kWh)

$P_{RE}$ – Renewable power plant electricity prices (MNT/kWh)

$P_{SYS}^{avg}$ – The average selling price of the system electricity (MNT/kWh)

From the above formula, it can be seen that the feed-in tariff directly depends on the price and energy supply to the system from renewable energy sources. The Renewable Energy Law sets the price of electricity for renewable energy plants in USD/kWh, and the next chapter discusses how the increase in the exchange rate to MNT/kWh affects the selling price of electricity. The increase in the exchange rate will also affect the level of these feed-in tariffs.

## 3. Results

### 3.1. Mongolia's renewable energy sector and investment cost

As of 2020, the installed capacity of Mongolia's power system has reached 1500 MW.

**Table 1.** Source Structure and Capacity

| | Station Type | Installed capacity (MW) | Percentage (%) |
|---|---|---|---|
| 1 | Thermal power plants | 1217 | 81.13 |
| 2 | Wind power plants | 154.6 | 10.31 |
| 3 | Solar power plants | 90 | 6 |
| 4 | Hydro power plants | 23 | 1.53 |
| 5 | Diesel stations | 15.5 | 1.03 |
| 6 | TOTAL | 1500.1 | 100 |

In terms of total installed capacity, 81.13% are thermal power plants, 17.84% are renewable energy plants and 1.03% are diesel power plants. As of today, three 154.6 MW wind farms and six 90 MW solar power plants are successfully connected to the Central Region integrated system in Mongolia.

As of 2019, Mongolia's total electricity consumption was 8719.1 million kWh, of which 7.49%, or 653.7 million kWh, was supplied by solar, wind, and hydropower plants (Statistical Yearbook of the Energy Regulatory Commission, 2019).

### A. Solar power plant investment cost study

Since the adoption of the Renewable Energy Law, 39 companies have received licences to build renewable energy sources with an installed capacity of more than 1500 MW. Today, there are six solar power plants with a total capacity of 90 MW and three wind farms with a total capacity of 154.6 MW.

Table 2 compares the investment costs and other indicators of the planned construction of new solar power plants in Mongolia.

**Table 2.** Comparison of Investment Costs of Solar Power Plants

| | Key indicators of the project | Nalaikh | Airag | Bayandelger | Choir |
|---|---|---|---|---|---|
| 1 | Capacity | 10 MW | 20 MW | 30 MW | 50 MW |
| 2 | Investment ($) | 15 901 054 | 35 078 008 | 46 500 000 | 80 000 000 |
| 3 | Area | 25 hectares | 40 hectares | 100 hectares | 100 hectares |
| 4 | Investment per kW ($) | 1590.1 | 1753.9 | 1550 | 1600 |
| 5 | Area per MW | 2.5 hectares | 2 hectares | 3.33 hectares | 2.5 hectares |

The table shows that the average investment required per kWh of new solar power plants planned to be built in our country is 1623.25 USD, while the average area per MW is 2.58 hectares. Also, in recent years, new solar power plants have been required to have a battery storage capacity of 20% of their capacity, so the investment cost of a solar power plant is expected to increase sharply to about 2500 USD per 1 kW.

The investment required for 1 kW of solar power plants in the world has been steadily declining since 2010, averaging about 1,000 USD, which is about 60% less than in Mongolia.

**B. Wind power plant investment cost study**

The first 49.6 MW Salkhit wind power plant was commissioned in Mongolia in 2013, followed by the 50 MW Tsetsii wind power plant in 2017 and the 55 MW Sainshand wind power plant in 2018. The total capacity of wind farms is 154.6 MW. Table 3 compares data from Salkhit, Tsetsii, and Sainshand wind power plants.

**Table 3.** Comparison of Wind Power Plant Investment Costs

| | Key indicators of the project | Salkhit | Tsetsii | Sainshand |
|---|---|---|---|---|
| 1 | Capacity | 49.6 MW | 50 MW | 55 MW |
| 2 | Capacity of one wind turbine | 1.6 MW | 2 MW | 2.2 MW |
| 3 | Number of wind turbines | 31 | 25 | 25 |
| 4 | Investment ($) | 120 000 000 | 128 000 000 | 120 000 000 |
| 5 | Investment per kW ($) | 2419.35 | 2560.00 | 2181.81 |

The table shows that the average investment required for 1 kW of wind power plants built in Mongolia is 2387 USD.

Investment in 1 kW of wind farms around the world has been steadily declining since 2006, with an average investment of about 1400 USD per 1 kW, which is about 70% lower than in Mongolia. In our country (Mongolia), investment costs are high due to high construction and installation costs due to poor infrastructure.

**3.2. Price of renewable power plants and feed-in tariffs**

**A. Solar and wind power plant prices**

The Law on Renewable Energy stipulates that the price of 1 kWh of electricity will range from 0.15 USD to 0.18 USD for solar power generation and from 0.08 USD to 0.095 USD for wind power generation (Renewable Energy Law, 2019). However, tariffs have negatively affected the overall efficiency of the energy system, and the initial investment costs have been reduced due to the recent decline in the price of solar panels and wind turbines. As a result, the levelized costs of solar and wind power plants are also declining, which creates conditions for lowering the legal minimum tariffs.

Therefore, 13 years after the law was enacted, an amendment to the law in 2019 stipulates that the price of 1 kWh of electricity will be up to 0.12 USD for solar power and up to 0.085 USD for wind power. In the 15 years since the Renewable Energy Law was first enacted, Mongolia's socio-economic situation, the structure of the energy sector, and the development of renewable energy techniques and technologies have changed, one of which is the appreciation of the US dollar. Table 4 shows the average exchange rate of the US dollar for 2007-2021 and the rate of change and growth rate of 1 kWh of electricity price for solar and wind power plants.

**Table 4.** Changes in the Dollar Exchange Rate and Renewable Energy Prices

| Year | Average annual USD exchange rate (₮) | Price of 1 kWh of electricity from solar power plants (₮) | | Price of 1 kWh of electricity from wind power plants (₮) | | Growth percentage |
|---|---|---|---|---|---|---|
| | | 0.15$ per kWh | 0.18$ per kWh | 0.08$ per kWh | 0.095$ per kWh | - |
| 2007 | 1170.44 | 175.57 | 210.68 | 93.64 | 111.19 | |
| 2008 | 1166.1 | 174.92 | 209.90 | 93.29 | 110.78 | -0.37% |
| 2009 | 1437.9 | 215.69 | 258.82 | 115.03 | 136.6 | 23.31% |
| 2010 | 1356.44 | 203.47 | 244.16 | 108.52 | 128.86 | -5.67% |
| 2011 | 1265.53 | 189.83 | 227.80 | 101.24 | 120.23 | -6.70% |
| 2012 | 1359.4 | 203.91 | 244.69 | 108.75 | 129.14 | 7.42% |
| 2013 | 1525.72 | 228.86 | 274.63 | 122.06 | 144.94 | 12.23% |
| 2014 | 1818.28 | 272.74 | 327.29 | 145.46 | 172.74 | 19.18% |
| 2015 | 1970.66 | 295.60 | 354.72 | 157.65 | 187.21 | 8.38% |
| 2016 | 2145.53 | 321.83 | 386.20 | 171.64 | 203.83 | 8.87% |
| 2017 | 2440.63 | 366.09 | 439.31 | 195.25 | 231.86 | 13.75% |
| 2018 | 2472.67 | 370.90 | 445.08 | 197.81 | 234.9 | 1.31% |
| 2019 | 2663.94 | 399.59 | 479.51 | 213.12 | 253.07 | 7.74% |
| 2020 | 2744.38 | 411.66 | 493.99 | 219.55 | 260.72 | 3.02% |
| 2021 | 2849 | 427.35 | 512.82 | 227.92 | 270.66 | 3.81% |

Compared to 2007, the average USD exchange rate increased by 143.41%. The price of 1 kWh of electricity increased from 427.35 MNT to 512.82 MNT for solar power plants; for wind power plants, it increased from 227.92 MNT to 270.66 MNT. In other words, the price of renewable energy in our country fluctuates according to the dollar exchange rate, and the US dollar exchange rate has increased by an average of 6.88% per year over the past 15 years. Renewable energy prices have risen 2.43 times since 2007 due to the appreciation of the exchange rate. As a result of this increase, the price of electricity for solar and wind power plants has risen sharply.

Table 5 compares the cost of 1 kWh of electricity generated by solar and wind power plants in Mongolia and around the world.

**Table 5.** Comparison of 1 kWh Electricity Prices

| Types | Mongolia ($) | World average ($) | Comparison |
|---|---|---|---|
| Solar power plants | 0.12 | 0.08 | 50% |
| Wind power plants | 0.085 | 0.06 | 41.6% |

The price of electricity generated by our solar power plant is $0.12, which is 50% higher than the world average, while the price of electricity generated by the wind power plant is $0.085, which is 41.6% higher than the world average.

**B. Renewable energy feed-in tariffs**

The price of 1 kWh of renewable energy is relatively higher than the price of 1 kWh of electricity produced and imported by thermal power plants, and it depends on the exchange rate, so there is a certain price difference (Batzaya et al., 2021; Bani Adam and Miyauchi, 2019; Zhou et al., 2020).

Many countries around the world have introduced a ***feed-in tariff*** (green tariff) system as part of their policy to reduce traditional energy production, which depends on natural resources, and to develop renewable energy (IRENA, 2020; Goodarzi et al., 2018; Von der Fehr et al., 2016; Chawla et al., 2020).

Renewable energy production support tariffs are not included in any energy tariffs, but a special tariff category called "Renewable Energy Promotion Tariffs" is included in an amendment of the Renewable Energy Law in 2015. The law states that feed-in tariffs are tariffs that are included in energy prices to support renewable energy (Renewable Energy Law, 2019). In addition, the Energy Regulatory Commission will review and approve the price estimates for electricity supplied to the energy system from renewable energy sources and the feed-in tariffs.

In our country (Mongolia), the feed-in tariff was 4 MNT per 1 kWh of electricity in 2015, but since then, the production of renewable energy has increased. In 2017, the feed-in tariff increased 2.97 times to 11.88 MNT/kWh, and in 2019, the feed-in tariff increased 5.94 times to 23.79 MNT/kWh. Figure 1 shows the growth of Mongolia's renewable energy feed in tariff.

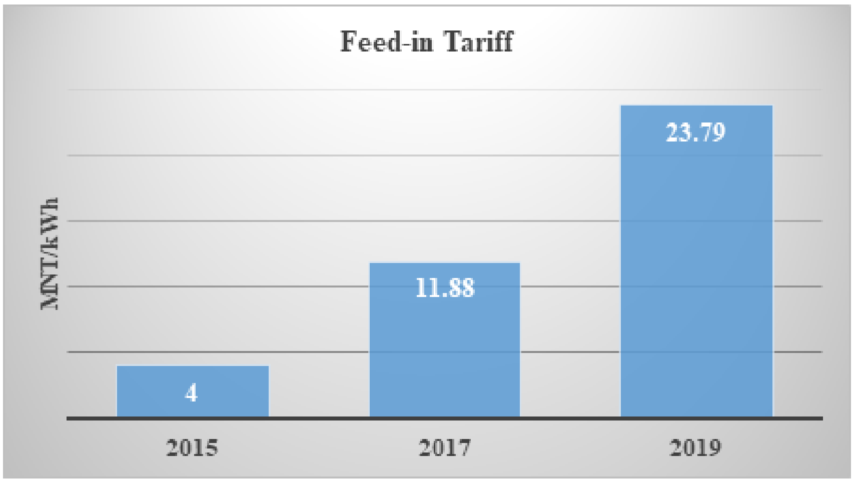



**Figure 1.** Feed in tariff of renewable energy in Mongolia (MNT/kWh)

In the rest of the world, feed-in tariffs tend to be relatively stable and declining as renewable energy production increases. In the case of Mongolia, the increase in feed in tariffs is very high due to the fact that solar and wind power generation is growing every year, and the exchange rate is rising every year.

This increase in energy feed-in tariffs is the basis for increasing the selling price of electricity throughout the system.

In 2015, electricity from renewable energy sources accounted for only 6.65% of the country's total electricity generation. After the introduction of the feed-in tariff system, this percentage reached 11.54% in 2017 and 16.63% in 2019. Feed-in tariffs allow for a sustainable supply of renewable energy, cover operating costs, and provide a certain level of profitability for investors and producers. Therefore, this article calculates the feed-in tariffs for solar and wind power plants that are planned to be built in recent years when they are connected to the energy system.

Figure 2 shows the rates of renewable energy feed in tariffs in some countries of the world in 2015, 2017 and 2019.


**Figure 2.** Renewable energy feed in tariffs in some countries of the world (USD/kWh)

Table 6 shows the preliminary feed-in tariff estimates for the 30 MW Gobi Solar Power Plant, which is scheduled to be commissioned in 2020, and the 102 MW Khanbogd Wind Power Plant, which is scheduled to be commissioned in 2023, in the Central Region Integrated System.

**Table 6.** Calculation of Feed-in Tariff

| Specifications | The amount of electricity produced (thousand kWh) | Feed-in tariff (MNT/кWh) |
|---|---|---|
| 30MW Gobi Solar Power Plant | 42048 | 1.75 |
| 102MW Khanbogd Wind Power Plant | 330602.4 | 7.79 |
| Weighted average tariff | | 7.11 |

The feed-in tariff for the 30 MW Gobi Solar Power Plant is estimated at 1.75 MNT/kWh, while the feed-in tariff for the Khanbogd Wind Power Plant is estimated at 7.79 MNT/kWh. The weighted average feed-in tariff for these two sources is 7.11 MNT/kWh. In other words, it is estimated that the feed-in tariff for these stations will increase to 30.9 MNT/kWh when they are commissioned.

## 4. Discussion

The price in US dollars in the Renewable Energy Law has fulfilled its obligation to attract investment. Compared to 2007, when the law was passed, the average exchange rate of the US dollar increased by 143.41%. The price of 1 kWh of electricity for solar power plants increased from 210.68 MNT to 512.82 MNT, and for wind power plants from 111.19 MNT to 270.66 MNT; in both cases, the price increased 2.43 times. In other words, the price of renewable energy in our country fluctuates with the exchange rate of the US dollar, and the exchange rate of the US dollar has increased by an average of 6.88% per year over the past 15 years. Therefore, it is recommended that this proposal be taken into account when amending the Renewable Energy Law, as the sale of electricity in MNT has the positive effect of minimizing the impact of dollar fluctuations on consumer purchase prices.

If a 30 MW solar power plant and a 102 MW wind power plant are added to the system, the feed-in tariff is estimated to increase to approximately 31 MNT/kWh. Although consumer tariffs will increase by this amount, feed-in tariffs will play an important role in supporting and developing renewable energy.

## 5. Conclusion

Currently, renewable energy accounts for about 18% of Mongolia's total installed capacity and generates 653.7 million kWh of energy annually from renewable sources. As mentioned above, this indicator is expected to grow rapidly in the future.

Mongolia's investment cost per kWh is about 60% higher than the world average for solar power plants and about 70% higher than the world average for wind power plants. This is because Mongolia is not a technology producer, and the infrastructure is underdeveloped.

In the future, it will be necessary to create competition in the renewable energy sector and focus on reducing investment costs due to lower world prices for equipment and technology, as well as lower energy prices for solar and wind power plants. Therefore, if the company offering the lowest price has the principle of building solar and wind power plants, it will be possible to reduce the price of electricity supplied to the energy system from renewable energy sources.

## References


Altantsetseg, D., Ulam-Orgil, C., 2021. Impact of renewable energy feed in tariffs. In: Proceedings of Conference of Renewable Energy and Advanced Technology, Ulaanbaatar Mongolia.

Bakhtyar, B., Saadatian, O., Alghoul, M.A., Ibrahim, Y., Sopian, K., 2014. Solar electricity market in Malaysia: A review of feed-in tariff policy. Environmental Progress & Sustainable Energy, 34(2), 600–606. https://aiche.onlinelibrary.wiley.com/doi/10.1002/ep.12023

Bani Adam, K., Miyauchi, H., 2019. Optimal Planning of Solar PV Using Simple Model for New Feed-in Tariff in Indonesia," In: 2019 International Seminar on Intelligent Technology and Its Applications (ISITIA), pp. 171–176. https://doi.org/10.1109/ISITIA.2019.8937209.

Batzaya, B., Altantsetseg, D., Ulam-Orgil C., 2021. The Green Energy's Impact on the Energy Economy. In: Proceeding of Conference of Renewable Energy and Advanced Technology, Ulaanbaatar Mongolia, pp. 71–71. https://www.dbpia.co.kr/Journal/articleDetail?nodeId=NODE11027108

Buyankhishig, A., Ulam-Orgil, C., 2018. Comparative Study of Solar and Wind Power Plant Costs and Investment Costs, in: Proceedings of the 9th National Renewable Energy Forum - 2018, Renewable Energy and Advanced Technology Conference. Ulaanbaatar, Mongolia, pp. 53–57.

Chawla, K., Aggarwal, M., Dutt, A., 2020. Analyzing the falling solar and wind tariffs: Evidence from India. ADBI Working Paper Series, online available: https://www.adb.org/sites/default/files/publication/566266/adbi-wp1078.pdf

Eberhard, A., Kaberger, T., 2016. Renewable energy auctions in South Africa outshine feed in tariffs. Energy Science & Engineering, 4(3), 190–193. https://onlinelibrary.wiley.com/doi/epdf/10.1002/ese3.118

Frankfurt School of Finance & Management, 2020. Global Trends in Renewable Energy Investment 2020. Online available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/32700/GTR20.pdf?sequence=1

Fuyi, C., 2017. The Basic Structure of the Feed-in Tariff System in Japan. In: Proceedings of 2017 IEEE International Conference on Smart Grid and Smart Cities, Singapore, pp. 1–5. https://ieeexplore.ieee.org/document/8038539

Goodarzi, S., Aflaki, S., Masini, A., 2018. Optimal feed in tariff policies: The impact of market structure and technology characteristics. Production and Operation Management, 28(5). https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2664967

Goodarzi, S., Aflaki, S., Masini, A., 2018. Optimal feed-in tariff policies: The impact of market structure and technology characteristics. Production and Operations Management, 28(5), 1108–1128. https://onlinelibrary.wiley.com/doi/abs/10.1111/poms.12971

Guild, J., 2019. Feed-in-tariffs and the politics of renewable energy in Indonesia and the Philippines. Asia Pac Policy Stud. 6, 417–431. https://onlinelibrary.wiley.com/doi/epdf/10.1002/app5.288

IRENA, 2020. Renewable energy report. https://irena.org/publications/2020/Mar/Renewable-Capacity-Statistics-2020

Javadi, M.S., Nezhad A.E., Shafie-khah M., Siano P., Catalão J.P.S., 2018. Assessing the benefits of capacity payment, feed-in-tariff and time-of-use programme on long-term renewable energy sources integration. https://ietresearch.onlinelibrary.wiley.com/doi/epdf/10.1049/iet-stg.2018.0298

Komiyama, R., Shibata, S., Fujii, Y., 2014. Assessment of optimal power generation mix considering extensive variable renewable energy and nationwide power interchange through tie lines. Electrical Engineering in

Japan, 188(3), 11–21. https://onlinelibrary.wiley.com/doi/pdf/10.1002/eej.22576
Masuta, T., Oozeki, T., Fonseca, J.G.D. Junior, Murata, A., 2015. Evaluation of power surpluses and shortfalls due to error in forecasting of photovoltaic generation output. Electrical Engineering in Japan, 192(3), 34–45. https://onlinelibrary.wiley.com/doi/pdf/10.1002/eej.22736
Mongolian Government, 2020. Vision – 2050. http://parliament.mn/laws#
Nair, R.T., Sankar, A., 2014. Dynamic pricing based on a cloud computing framework to support the integration of renewable energy sources. https://ietresearch.onlinelibrary.wiley.com/doi/epdf/10.1049/joe.2014.0239
Organization for Economic Co-operation and Development (OECD), 2019. Renewable energy feed-in tariffs. Online available at: https://stats.oecd.org/Index.aspx?DataSetCode=RE_FIT
Orolzodmaa, G., 2021. Impact of the Myangad 10 MW Solar Power Plant on the Western Energy System. In: Proceedings of Conference of Renewable Energy and Advanced Technology, Ulaanbaatar Mongolia.
Renewable Energy Law, 2019. https://www.legalinfo.mn/law/details/465
Statistical Yearbook of the Energy Regulatory Commission, 2019. Ulaanbaatar, Mongolia.
Steffen, B., 2020. Estimating the cost of capital for renewable energy projects. Energy Economics, 88, 104783, ISSN 0140-9883. https://doi.org/10.1016/j.eneco.2020.104783
Von der Fehr, Nils-Henrik, M., Ropenus, S., 2016. Renewable energy policy instruments and market power. The Scandinavian Journal of Economics, 119(2), 312–345. https://www.duo.uio.no/handle/10852/65051
Yang, D.X., Nie, P.Y., 2016. Influence of optimal government subsidies for renewable energy enterprises. IET Renewable Power Generation, 10(9), 1413–1421. https://ietresearch.onlinelibrary.wiley.com/doi/10.1049/iet-rpg.2015.0307
Zhou, L., Zhang, W., Liu, X., 2020. Economic, Energy, Energy and Ecological (4E) Evaluation of a CCHP System Considering Feed-in Tariff. In: Proceedings of the 39th Chinese Control Conference, Shenyang, China, pp. 6066–6070. https://ieeexplore.ieee.org/document/9188373

## Список источников

Altantsetseg, D., Ulam-Orgil, C., 2021. Impact of renewable energy feed in tariffs. In: Proceedings of Conference of Renewable Energy and Advanced Technology, Ulaanbaatar Mongolia.
Bakhtyar, B., Saadatian, O., Alghoul, M.A., Ibrahim, Y., Sopian, K., 2014. Solar electricity market in Malaysia: A review of feed-in tariff policy. Environmental Progress & Sustainable Energy, 34(2), 600–606. https://aiche.onlinelibrary.wiley.com/doi/10.1002/ep.12023
Bani Adam, K., Miyauchi, H., 2019. Optimal Planning of Solar PV Using Simple Model for New Feed-in Tariff in Indonesia," In: 2019 International Seminar on Intelligent Technology and Its Applications (ISITIA), pp. 171–176. https://doi.org/10.1109/ISITIA.2019.8937209.
Batzaya, B., Altantsetseg, D., Ulam-Orgil C., 2021. The Green Energy's Impact on the Energy Economy. In: Proceeding of Conference of Renewable Energy and Advanced Technology, Ulaanbaatar Mongolia, pp. 71–71. https://www.dbpia.co.kr/Journal/articleDetail?nodeId=NODE11027108
Buyankhishig, A., Ulam-Orgil, C., 2018. Comparative Study of Solar and Wind Power Plant Costs and Investment Costs, in: Proceedings of the 9th National Renewable Energy Forum - 2018, Renewable Energy and Advanced Technology Conference. Ulaanbaatar, Mongolia, pp. 53–57.
Chawla, K., Aggarwal, M., Dutt, A., 2020. Analyzing the falling solar and wind tariffs: Evidence from India. ADBI Working Paper Series, online available: https://www.adb.org/sites/default/files/publication/566266/adbi-wp1078.pdf
Eberhard, A., Kaberger, T., 2016. Renewable energy auctions in South Africa outshine feed in tariffs. Energy Science & Engineering, 4(3), 190–193. https://onlinelibrary.wiley.com/doi/epdf/10.1002/ese3.118
Frankfurt School of Finance & Management, 2020. Global Trends in Renewable Energy Investment 2020. Online available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/32700/GTR20.pdf?sequence=1
Fuyi, C., 2017. The Basic Structure of the Feed-in Tariff System in Japan. In: Proceedings of 2017 IEEE International Conference on Smart Grid and Smart Cities, Singapore, pp. 1–5. https://ieeexplore.ieee.org/document/8038539
Goodarzi, S., Aflaki, S., Masini, A., 2018. Optimal feed in tariff policies: The impact of market structure and technology characteristics. Production and Operation Management, 28(5). https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2664967
Goodarzi, S., Aflaki, S., Masini, A., 2018. Optimal feed-in tariff policies: The impact of market structure and technology characteristics. Production and Operations Management, 28(5), 1108–1128. https://onlinelibrary.wiley.com/doi/abs/10.1111/poms.12971
Guild, J., 2019. Feed-in-tariffs and the politics of renewable energy in Indonesia and the Philippines. Asia Pac

Policy Stud. 6, 417–431. https://onlinelibrary.wiley.com/doi/epdf/10.1002/app5.288

IRENA, 2020. Renewable energy report. https://irena.org/publications/2020/Mar/Renewable-Capacity-Statistics-2020

Javadi, M.S., Nezhad A.E., Shafie-khah M., Siano P., Catalão J.P.S., 2018. Assessing the benefits of capacity payment, feed-in-tariff and time-of-use programme on long-term renewable energy sources integration. https://ietresearch.onlinelibrary.wiley.com/doi/epdf/10.1049/iet-stg.2018.0298

Komiyama, R., Shibata, S., Fujii, Y., 2014. Assessment of optimal power generation mix considering extensive variable renewable energy and nationwide power interchange through tie lines. Electrical Engineering in Japan, 188(3), 11–21. https://onlinelibrary.wiley.com/doi/pdf/10.1002/eej.22576

Masuta, T., Oozeki, T., Fonseca, J.G.D. Junior, Murata, A., 2015. Evaluation of power surpluses and shortfalls due to error in forecasting of photovoltaic generation output. Electrical Engineering in Japan, 192(3), 34–45. https://onlinelibrary.wiley.com/doi/pdf/10.1002/eej.22736

Mongolian Government, 2020. Vision – 2050. http://parliament.mn/laws#

Nair, R.T., Sankar, A., 2014. Dynamic pricing based on a cloud computing framework to support the integration of renewable energy sources. https://ietresearch.onlinelibrary.wiley.com/doi/epdf/10.1049/joe.2014.0239

Organization for Economic Co-operation and Development (OECD), 2019. Renewable energy feed-in tariffs. Online available at: https://stats.oecd.org/Index.aspx?DataSetCode=RE_FIT

Orolzodmaa, G., 2021. Impact of the Myangad 10 MW Solar Power Plant on the Western Energy System. In: Proceedings of Conference of Renewable Energy and Advanced Technology, Ulaanbaatar Mongolia.

Renewable Energy Law, 2019. https://www.legalinfo.mn/law/details/465

Statistical Yearbook of the Energy Regulatory Commission, 2019. Ulaanbaatar, Mongolia.

Steffen, B., 2020. Estimating the cost of capital for renewable energy projects. Energy Economics, 88, 104783, ISSN 0140-9883. https://doi.org/10.1016/j.eneco.2020.104783

Von der Fehr, Nils-Henrik, M., Ropenus, S., 2016. Renewable energy policy instruments and market power. The Scandinavian Journal of Economics, 119(2), 312–345. https://www.duo.uio.no/handle/10852/65051

Yang, D.X., Nie, P.Y., 2016. Influence of optimal government subsidies for renewable energy enterprises. IET Renewable Power Generation, 10(9), 1413–1421. https://ietresearch.onlinelibrary.wiley.com/doi/10.1049/iet-rpg.2015.0307

Zhou, L., Zhang, W., Liu, X., 2020. Economic, Energy, Energy and Ecological (4E) Evaluation of a CCHP System Considering Feed-in Tariff. In: Proceedings of the 39th Chinese Control Conference, Shenyang, China, pp. 6066–6070. https://ieeexplore.ieee.org/document/9188373

The article was submitted 31.03.2022, approved after reviewing 29.04.2022, accepted for publication 16.05.2022.

Статья поступила в редакцию 31.03.2022, одобрена после рецензирования 29.04.2022, принята к публикации 16.05.2022.

About authors:

1. Ulam-Orgil Choijiljav, Ph.D, Associate professor Job position: Associate professor, Power Engineering School, Mongolian University Science and Technology, Ulaanbaatar, Mongolia. ulamorgil@must.edu.mn.

2. Uranchimeg Tudevdagva. Doctor of Science, ScD, Professor, Chemnitz University of Technology, Chemnitz, Germany, https://orcid.org/0000-0001-9239-0760, uranchimeg.tudevdagva@informatik.tu-chemnitz.de.

Информация об авторах:

1. Улам-Оргил Чойжилжав, Кандидат наук, Доцент, Монгольский Государственный Университет Науки и Технологий, Улан-Батор, Монголия. ulamorgil@must.edu.mn.

2. Уранчимэг Түдэвдагва, Доктор наук, Профессор, Технический Университет Кемница, Кемниц, Германия. https://orcid.org/0000-0001-9239-0760, uranchimeg.tudevdagva@informatik.tu-chemnitz.de.

SECTION 4

# MANAGEMENT OF KNOWLEDGE AND INNOVATION FOR SUSTAINABLE DEVELOPMENT

РАЗДЕЛ 4

# УПРАВЛЕНИЕ ЗНАНИЯМИ И ИННОВАЦИЯМИ В ИНТЕРЕСАХ УСТОЙЧИВОГО РАЗВИТИЯ

**Research article**
**DOI:** https://doi.org/10.48554/SDEE.2022.2.4

# STUDY AND ASSESSMENT OF THE STRUCTURAL CAPITAL OF AN INNOVATION INDUSTRIAL CLUSTER

Aleksandr Babkin[1], Natalia Alekseeva[1*], Larissa Tashenova[2], Diyor Karimov[3]

[1]Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia,
al-vas@mail.ru, alekseeva_ns@spbstu.ru
[2]Buketov Karagandy University, Karaganda, Kazakhstan, larisatash_88@mail.ru
[3]National University of Uzbekistan named after Mirzo Ulugbek, Tashkent, Uzbekistan,
karimov.diyor65@gmail.com
[*]Corresponding author: alekseeva_ns@spbstu.ru

**Abstract**

The relevance of this study is underscored by the intellectualisation of industrial and business processes, the growth of the knowledge intensity of products, and the increased complexity of organisational interaction between economic entities. This study aims to formulate the concept and assess the structural capital of an innovation industrial cluster on the basis of the developed methodology. The object of the study is the structural capital of the innovation industrial cluster "Development of information technologies, radioelectronics, instrumentation, and means of communication and infotelecommunications of Saint Petersburg". Using various research methods, including observation, surveys, questionnaires, analysis, synthesis, and mathematical modelling, the study focuses on the process of assessing the structural capital of the innovation industrial cluster. This paper presents a study of the types of intellectual capital of an innovation industrial cluster that analysed the internal and external environment of the cluster. We designed a methodology for assessing the structural capital of the innovation industrial cluster and assessed the structural capital of the innovation industrial cluster, providing recommendations for its development based on the study's findings. Future research should focus on the development of theoretical, methodological, and practical provisions for assessing the capital of innovation industrial clusters. Insights from this study can inform management decisions in innovation clusters and enterprises when evaluating intellectual property.

**Keywords:** cluster associations, innovation industrial cluster, intellectual capital, structural capital, value

**Citation:** Babkin, A., Alekseeva, N., Tashenova, L., Karimov, D., 2022. Study and assessment of the structural capital of an innovation industrial cluster. Sustainable Development and Engineering Economics 2, 4. https://doi.org/10.48554/SDEE.2022.2.4

**Научная статья**
**УДК** ***332.1***
**DOI:** https://doi.org/10.48554/SDEE.2022.2.4

# ИССЛЕДОВАНИЕ И ОЦЕНКА СТРУКТУРНОГО КАПИТАЛА ИННОВАЦИОННО-ПРОМЫШЛЕННОГО КЛАСТЕРА

Александр Бабкин[1], Наталья Алексеева[1*], Лариса Ташенова[2], Диёр Каримов[3]

[1]Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия, al-vas@mail.ru, alekseeva_ns@spbstu.ru
[2]Карагандинский университет имени академика Е.А. Букетова, Караганда, Казахстан, larisatash_88@mail.ru
[3]Национальный университет Узбекистана имени Мирзо Улугбека, Ташкент, Узбекистан, karimov.diyor65@gmail.com
[*]Автор, ответственный за переписку: alekseeva_ns@spbstu.ru

## Аннотация

Актуальность исследования обусловлена интеллектуализацией промышленных и бизнес-процессов, ростом наукоемкости выпускаемой продукции и усложнением организационного взаимодействия хозяйствующих субъектов. Цель работы – сформулировать понятие и провести оценку структурного капитала инновационно-промышленного кластера на основе разработанной методики. Объектом исследования является структурный капитал инновационно-промышленного кластера «Развитие информационных технологий, радиоэлектроники, приборостроения, средств связи и инфотелекоммуникаций Санкт-Петербурга». Предметом исследования выступает процесс оценки структурного капитала инновационно-промышленного кластера. Методы исследования, примененные в работе – наблюдения, опроса и анкетирования, анализа и синтеза, математического моделирования. В работе представлено исследование видов интеллектуального капитала инновационно-промышленного кластера. Проведен анализ внутренней и внешней среды исследуемого кластера. Предложена методика оценки структурного капитала инновационно-промышленного кластера. Проведена оценка структурного капитала инновационно-промышленного кластера. На основе полученных результатов даны рекомендации по его развитию. Направлением дальнейшего исследования является развитие теоретическо-методологических и практических положений, по оценке капитала инновационно-промышленного кластера. Представленные материалы могут быть использованы при принятии управленческих решений в инновационных кластерах и предприятиях, при проведении оценки интеллектуальной собственности.

**Ключевые слова:** кластерные объединения, инновационно-промышленный кластер, интеллектуальный капитал, структурный капитал, стоимость

**Цитирование:** Бабкин, А., Алексеева, Н., Ташенова, Л., Каримов, Д., 2022. Исследование и оценка структурного капитала инновационно-промышленного кластера. Sustainable Development and Engineering Economics 2, 4. https://doi.org/10.48554/SDEE.2022.2.4

## 1. Introduction

Today, great hopes are placed on cluster associations for developing Russia's economy to strengthen its competitiveness in the world arena. An analysis of cluster development in Russia shows that there are problems and significant growth potential, making the study of cluster formations relevant (Babkin et al., 2020; Druzhinin and Alekseeva, 2020; Saadatyar et al., 2020). The modern sustainable development of industries is accompanied by constant technological and product improvement (Babkin et al., 2021), which leads to an increase in added value due to the intellectual component. The intellectual component can provide a competitive advantage that determines the interest in its research (Zaytsev et al., 2020). To date, research on value creation through intellectual components has been conducted using the theory of intellectual capital (Vetrenko et al., 2017). The theory of intellectual capital is used in studies of various industries. Here, intangible assets of various kinds and their influence on all functions of the management of economic entities are investigated.

Due to the large number of very heterogeneous assets within the framework of intellectual capital, the different types of capital included in it are investigated. The most actively studied is human capital (Yeoh, 2008) which is a constituent part of intellectual capital. Recently, studies of social capital, which was adopted into economic science from social disciplines, and network capital, which is associated with the development of internet interaction, have been actively developed. Less attention is paid to intellectual property at all stages of its life cycle, which forms structural capital. We consider this an omission because it increases the dependence on the human factor, the management of which is the riskiest. The development of cluster formations, their special role in the development of the Russian economy, and the tasks entrusted to their development stimulate the need to study the theory of intellectual property management, which has not been given enough attention recently. Thus, the purpose of this study is to evaluate the structural capital of the Russian innovation industrial cluster by addressing the following objectives:

1. To present the structure of the intellectual capital for the innovation industrial cluster and define its structural capital, which is part of the intellectual capital.
2. To analyse the internal and external environments of the innovation industrial cluster in Russia under study.
3. To propose a methodology for assessing the structural capital of the innovation industrial cluster.
4. To perform an assessment of structural capital of the innovation industrial cluster.

## 2. Literature review

The theory of cluster development continues to be a relevant subject of research by both domestic and international scientists (Saadatyar et al., 2020) due to the constant evolution of cluster associations (Ye et al., 2020). To a greater extent, the object of previous studies in the field has been industrial sectors of the economy (Stavroulakis et al., 2020), although research in health care (Yeoh, 2008), shipping (Stavroulakis et al., 2020), media industry (Komorowski, 2020), entertainment industry (Lehtonen et al., 2020), and other industries is relevant. The problems faced by cluster associations in their development are being clarified and classified (Saadatyar et al., 2020), with recent exploration of the influence of the geographical factor (Beck et al., 2019; Wang et al., 2018)we argue that in addition to facilitating organizational learning and specialization, an industry cluster related to tradition or to the practice of a craft influences audience expectations through the definition of the prototypical features that define an organizational form. Analyzing the population of northern Bavarian (Franconian and analysis of the interaction of cluster members (Fromhold-Eisebith et al., 2021; Wang et al., 2018). Particular attention has been paid to the innovative development of cluster associations (Sarvan et al., 2011; Žižka et al., 2018).

Recently, studies combining the application of intellectual capital theory and cluster development have begun to emerge, although their number remains insignificant. In 2013 (Jiang and Zhang, 2013), a study was conducted on the impact of intellectual capital on the production performance of technical innovation in the industrial cluster and revealed their insignificant influence (Zhilenkova et al., 2019).

The paper of Zhilenkova et al. shows the missed opportunities and offers guidelines for the production participants of the industry cluster, allowing for strengthening the position of cluster participants in the market through the management of intellectual capital. In 2020, the rapid industrial transformation (Alekseeva et al., 2020) appealed to the theory of intellectual capital to find an answer to the question of how to support regional innovation and entrepreneurship. Mikhaylov and Peker (2019) presented an assessment of the imbalance in the geographical distribution of leading universities, which are part of the cluster system during the transition to a knowledge economy, and an assessment of their integration into regional innovation systems. Chandrashekar (2019) examined the reasons for creating structural capital by cluster enterprises. Cho and Cho (2020) conducted a study on the exchange of elements of structural capital among cluster participants in the software industry. The study surveys entrepreneurs and employees of software start-ups and SMEs, and analyses the data collected using statistical analysis methods. In the present study, we extend the field by performing an assessment of structural capital in the software cluster.

## 3. Materials and methods

The study was performed on a sample of the innovation industrial cluster "Development of information technologies, radioelectronics, instrumentation, and means of communication and infotelecommunications of Saint Petersburg". The key specialisation of the cluster is information and communication technologies.

According to the analysis of information on cluster participants, most of them work under OKVED 62.0, "Development of computer software, consulting services in this field, and other related services". Therefore, the profitability indicators of Russian enterprises operating under this code were used as data for the type of activity.

Profitability indicators for the industry were obtained from the database created using the financial statements of Russian enterprises collected by the Federal Service for State Statistics and the Federal Tax Service, and posted on the website https://www.testfirm.ru. Information on the financial conditions of the enterprises-participants of the cluster, which was used to calculate performance indicators, was also obtained.

Calculations were made in February 2022; therefore, the analysis horizon was limited to 2020. The effectiveness of the cluster was assessed using profitability indicators according to the following formulas (1-3):

$$ROS_{OI} = \frac{OI}{Sales} \times 100\% \tag{1}$$

$ROS_{OI}$ (Return on Sales) is the return on sales calculated from the operating income; OI is the operating income for the year; and *Sales* are the total revenue for the year.

$$ROS_{NI} = \frac{NI}{Sales} \times 100\% \tag{2}$$

$ROS_{NI}$ is the net income margin, and NI is the total net income for the year.

$$ROA = \frac{NI}{(TA[b] + TA[e]) / 2} \times 100\% \tag{3}$$

ROA is the return on assets, and TA[b] and TA[e] are the value of assets (at the beginning [b] and the end [e] of the analysed period according to the balance sheet data).

The number of enterprises for which the values of profitability indicators by the type of activity were determined amounted to 23,935 in 2020. The list of analysed profitability indicators was limited to those available in public sources. The revenue and net profit of the cluster were defined as the sum of the revenues and net profits of all enterprises in the cluster, respectively.

The research methods used in this study are observation, surveys, questionnaires, analysis, synthesis, and mathematical modelling.

The structural capital of the innovation industrial cluster was assessed using the cost approach. Features of its implementation followed from addressing the study's Objective 1, "To present the structure of the intellectual capital in the innovation industrial cluster and define its structural capital, which is part of the intellectual capital", and Objective 2 "To analyse the internal and external environments of the innovation industrial cluster under study". The description of the proposed methodology is presented in Section 4.3 "Methodology for assessing structural capital of an innovation industrial cluster".

## 4. Results

### 4.1. Types of intellectual capital of the innovation industrial cluster

The innovation industrial cluster, as a type of cluster association, consists of a set of enterprises and organisations that participate directly or indirectly in the industrial sector of the economy and implement innovative activities. Human capital is an integral part of any enterprise or organisation and thus becomes a necessary part of the innovation industrial cluster. The innovativeness of the implemented activity determines the presence of structural capital, elements of which are registered and unregistered results of the intellectual activity. The peculiarity of cluster functioning in the market economy with a high level of competition determines the presence of relational capital consisting of trust, established connections, and created business reputation with internal and external stakeholders. Babkin et al. (2020) presented detailed composition and elements of the intellectual capital of the innovation industrial cluster. Thus, the intellectual capital of the innovation industrial cluster consists of human, structural, and relational capital.

As mentioned above, structural capital consists of registered and unregistered results of intellectual activity. In connection with the study of the industrial innovation cluster, such a cluster is expected to have the results of intellectual activity used to create innovations. The peculiarity of the operation of any economic entity leads to the emergence of the results of intellectual activity. They can include instructions, templates, forms, samples of documents, methodological guidelines, internal standards of activity, implementation of operations, and so on. Relying on the above list, we present the proposed structure of intellectual capital in the innovation industrial cluster (Figure 1).

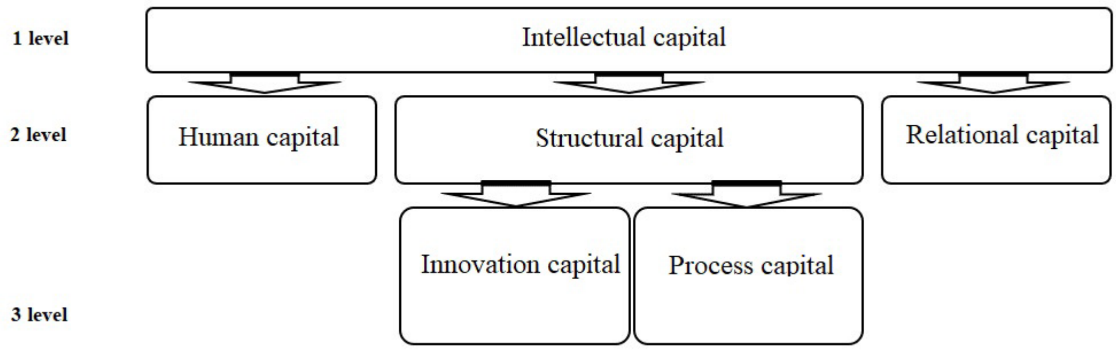



**Figure 1.** Structure of the intellectual capital in the innovation industrial cluster

The figure shows the types of capital that make up the three-level structure of intellectual capital in the innovation industrial cluster. One of the capitals of the second level is structural capital, which is further divided into innovation and process capital. The peculiarity of the elements of structural capital is their separability from both the individual who created them, and from the organisation-rights holder. This property distinguishes this type of capital from other types of capital that are part of the intellectual capital. Thus, we define structural capital as part of the intellectual capital of the innovation industrial cluster, which consists of the results of the intellectual activity, separable from individuals and legal entities, used in the innovation and process activity of the innovation industrial cluster.

### 4.2. Analysis of the internal and external environments of the cluster under study

In 2009, the government of the Russian Federation approved the rules for granting subsidies to Russian organisations for partial reimbursement of the costs of developing digital platforms and software products in order to create and enhance the production of high-tech industrial products. Support of developers of Russian software is carried out within the framework of the national programme "Digital Economy"[1]. The amount of funds allocated to support the national IT industry during 2020–2022 is 2 billion rubles annually. The share of necessary private financing is defined as not less than 50%. Subsidies can be provided to both small- and medium-sized enterprises. Apart from subsidising projects on the creation of software and digital platforms, other measures to support the IT industry are also provided, including reduction of tax deductions, demand stimulation, and expansion of the personnel base in the industry.

The state supports the development of the electronic and radioelectronic industry by granting subsidies for its development. According to the Ministry of Industry and Trade of the Russian Federation, the amount of spending by all regions of the Russian Federation in 2021 was 4.14 billion rubles, 16% of which were allocated to St. Petersburg. The dynamics of budget spending on St. Petersburg enterprises are given in Table 1.

**Table 1.** Expenditure of funds under the programme "Development of the electronic and radioelectronic industry for 2013-2025 in St. Petersburg", rub.

| 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|
| 0 | 548 861 656 | 1 354 893 403 | 1 007 439 725 | 1 605 336 214 | 965 844 068 |

The innovation industrial cluster under study was created in 1999 by the initiative of the companies that later became their participants. The legal form of the association of the participants was a non-profit partnership. In 2012, the analysed cluster underwent significant transformations, and it was recognised by the state as a cluster supported by the government of St. Petersburg. The current name of the innovation and industrial cluster under consideration is "Development of information technologies, radioelectronics, instrumentation, means of communication".

According to the analysis of the information on cluster participants, most of them work under OKVED 62.0 "Development of computer software, consulting services in this field, and other related services".

As of March 1, 2022, 316 participating enterprises were registered in the cluster, and more than 22,000 people were employed. The cluster's annual revenue for 2021 was 42 billion rubles.

Figure 2 shows the dynamics of return on sales, net profit margin, and return on assets. The figure also shows the dynamics of the same indicators in the industry.


**Figure 2.** Return on sales, net profit margin, and return on assets by cluster and industry

[1]Available online at https://expert.minpromtorg.gov.ru/sphere/radio (accessed on 25.05.2022)

The return on sales by cluster for the period under consideration exceeded this indicator by type of activity. The only exception was 2018. Further dynamics of the compared indicators demonstrated a single case of such an excess, which allows us to conclude that the return on sales of the cluster as a whole was higher than the return on sales of the type of activity. The net profit margin of the cluster in each year of the period under consideration 2015–2020 exceeds the net profit margin by a type of activity, indicating a more efficient operation of the innovation industrial cluster.

The return on assets of the cluster for the period under consideration exceeded this indicator by type of activity. The only exception was 2019. The overall dynamics of the compared indicators demonstrated a single case of such an excess, allowing for the conclusion that the return on asset sales was higher than the return on sales by a type of activity.

Generally, the analysis of the presented indicators showed more effective work of the innovation industrial cluster in comparison with individual enterprises operating in the same type of activity, which indicates the presence of intellectual capital in the cluster.

### 4.3. Methodology for assessing the structural capital of the innovation industrial cluster

As discussed above, structural capital consists of innovation and process capital, which determines the need to summarise innovation and process capital to determine the amount of the structural capital in our target cluster (formula 4):

$$C_{SC} = C_{IC} + C_{PC} \tag{4}$$

Where $C_{SC}$ is the cost of the structural capital;

$C_{IC}$ is the cost of the innovation capital;

$C_{PC}$ is the cost of the process capital.

To determine the cost of the structural capital, the cost approach is used, the essence of which is to determine the cost by summing up the costs of creation. The costs of creation will include expenses on payroll with social deductions, materials, and expenses on operation and depreciation of equipment used to conduct the research and development work required to create elements of the structural capital. Here, we must consider expenses for business trips, consultations, and purchase of necessary property rights if they took place during the creation of elements of the structural capital. If an element of the structural capital was acquired, the costs of its creation would be the costs of acquisition.

Considering that when creating elements of the structural capital, the future right holder bears risks and takes money out of circulation for the creation of the structural capital, which could have been used in another way, the amount of creation costs should be increased by the value of the money used. We propose using the return on assets of the innovation industrial cluster determined earlier as the value of money used to create elements of the structural capital.

The evaluation of intellectual property, performed on the basis of the cost approach, has its own peculiarities. It is necessary to take into consideration not only the expenses made but also their effectiveness. In this case, we propose doing so based on the assessment of the influence of an element of the structural capital on the activities of participating enterprises that use it. It is also necessary to allow for the fact that this study considers the assessment of the structural capital of a cluster association. Therefore, we propose considering the scope of their use to allow for the effectiveness of the use of elements of the structural capital.

We also propose assessing the influence of an element and the scope of its use with an expert survey. The experts are employees of the participating enterprises. There is no need to involve external parties, as they do not have the necessary information.

To assess the influence of the structural capital element on the activity of participating enterprises, experts are asked the following question: “To what extent does this element influence such measures as time, quality, money, prospects of development of the innovation industrial cluster?” An expert writes down the answer in numerical form, guided by the scale of responses given in Table 2.

**Table 2.** Scale of responses by strength of influence

| Score | Response |
|---|---|
| 0 | Has no influence |
| 1 | Has little influence |
| 2 | Has a medium influence |
| 3 | Has a strong influence |

To assess the scope of the use for structural capital elements, the experts are asked to answer the following question: “How many enterprises participating in the innovation industrial cluster use this element in their activity?”. The response options and their scoring are given in Table 3.

**Table 3.** Scale of responses by influence size

| Score | Response |
|---|---|
| 0 | None |
| 1 | Less than 25% of enterprises in the cluster |
| 2 | 25%-50% of enterprises in the cluster |
| 3 | More than 50% of enterprises in the cluster |
| 4 | More than 75% of enterprises in the cluster |

Taking into consideration the nature of the questions and possible responses, we recommend involving leading specialists and top management in the expert survey. The results of the survey are processed to determine the integrated assessment of the influence of the intellectual capital element on the activity of the innovation industrial cluster, calculated by the following formula (5):

$$EIC = EPI * ESI \tag{5}$$

*EIC* is the expert assessment of the importance of contributions to the cluster;

*EPI* is the expert assessment of the power of influence;

*ESI* is the expert assessment of the scope of influence.

The proposed integral coefficient also takes into consideration the depreciation of the structural capital element; thus, there is no need to further include it in the assessment.

Based on the above, the formula for calculating the cost of structural capital is as follows (formula 6):

$$Csc = \sum Cs*(1+R)*EIC + \sum Ca*EIC \tag{6}$$

*Cs* is the cost of creating an element of the structural capital, currency units;

*Ca* is the cost of acquiring an element of the structural capital, currency units;

*R* is return on assets, %;

*EIC* is the expert assessment of the importance of contributions to the cluster.

### 4.4. Assessment of the structural capital of the innovation industrial cluster

The data for calculating the costs of creation were obtained through a survey of the enterprises participating in the cluster under study. The analysis of the results of the survey revealed that for the cluster under study, most of the creation costs are related to labour costs, which determines the structure of the costs presented below.

Table 4 presents the results of the assessment of the structural capital of the innovation industrial cluster under study, obtained using the proposed methodology.

**Table 4.** Results of calculating the value of the structural capital of the innovation industrial cluster

| Indicator | Value |
|---|---|
| Creation time, man-hours | 3,444 809 |
| Weighted average level of wages, rubles/person/month | 44,980 |
| Other expenses, % of payroll | 10% |
| Return on assets | 14% |
| Expert assessment of the importance of contributions to the cluster | 0.84 |
| Process capital, million rubles | 971 |
| Creation time, man-hours | 19,684,610 |
| Weighted average level of wages, rubles/person/month | 44,980 |
| Other expenses, % of payroll | 10% |
| Return on assets | 14% |
| Expert assessment of the importance of contributions to the cluster | 0.93 |
| Innovation capital, million rubles | 6,144 |
| Structural capital, million rubles | 7,115 |

Based on the calculations, we determined that the value of the structural capital in the innovation industrial cluster under study amounted to 7,115 million rubles.

## 5. Discussion

As stated earlier, cluster development in Russia does not meet the expected level, which makes the research on increasing the effectiveness of cluster operation relevant. In the present paper, emphasis is placed on the use of intangible components of the activity in the innovation industrial cluster. We proposed a methodology, and an assessment of the structural capital of the cluster was carried out, the results of which will allow for the evaluation of the current state of the use of intangible assets of the cluster, as well as identifying the prospects for development of the structural capital. Although previously published works investigated the reasons for creating structural capital by cluster enterprises (AlQershi et al., 2021; Chandrashekar and M.H., 2019) and identified the facts of the exchange of structural capital elements between cluster participants in the field of software (Andreeva et al., 2021; Cho and Cho, 2020), the presented work investigated the results of such exchange and determined the value of the structural capital in the innovation industrial cluster.

To substantiate the composition and elucidate the essence of the structural capital of the innovation industrial cluster, this paper presents the structure of the intellectual capital of the innovation industrial cluster, consisting of three levels and taking into consideration the innovative nature of operation in the cluster under study. This structure enables the proposal of a methodology for an accurate assessment of the intellectual capital of the innovation industrial cluster without mixing with its other types of capital, which is a unique feature of the work presented. The paper also provides a definition of structural capital for the innovation industrial cluster, which allows clear identification of the components of the structural capital in the innovation industrial cluster and ensures the absence of duplication of its elements during assessment.

The analysis of the factors of the external environment of the innovation industrial cluster allowed identifying the prospects created in the country for the growth of the structural capital in the innovation industrial cluster, and, accordingly, determining the relevance of the study of structural capital management to achieve competitive advantages. The analysis of the factors of the internal environment of the innovation industrial cluster indicated the presence of intellectual capital, which makes its assessment relevant to the current framework. The results of the analysis of the internal environment were used to assess the structural capital of the innovation industrial cluster.

The proposed methodology for assessing the structural capital of the innovation industrial cluster allows for exchanging elements of the structural capital between the cluster participants in the software industry identified earlier by Cho and Cho (2020) and allows for the effects of exchange in the assessment, which distinguishes the proposed methodology for assessing the structural capital of the innovation industrial cluster from assessing the structural capital of individual enterprises.

The results of calculating the value of the structural capital in the innovation industrial cluster made it possible to determine its value in the amount of 7,115 million rubles, while the innovation capital accounts for 86% of this value; the remaining part of 14% relates to the process capital of the cluster. This structure confirms the innovative nature of the cluster under study. The work carried out with the enterprises participating in the cluster revealed that the cluster had great potential to increase its structural capital through documenting and registering rights to the results of the intellectual activity. Implementation of the recommendations on registration of the results of the intellectual activity will allow the cluster to reduce the risks of dependence on personnel (Pavlov et al., 2022), as well as increase income through the transfer of proprietary rights to the results of intellectual activity.

Future research should develop theoretical, methodological, and practical provisions for assessing the capital of the innovation industrial cluster. The study presented materials that can be used to guide management decisions in innovation clusters and enterprises when evaluating intellectual property.

## 6. Conclusion

This paper presents the results of the study and the assessment of the structural capital of the innovation industrial cluster in Russia. The following summarises the main findings:

1. An analysis of internal and external environments of the innovation industrial cluster under study revealed that Russia allocates substantial funds to support the IT industry, as well as the electronic and radio-electronic industries. The comparison of indicators of the financial and economic activity in the cluster with similar indicators by type of activity revealed a higher effectiveness of the cluster, which indicates the presence of intellectual capital in the innovation industrial cluster under study.

2. A methodology was proposed for assessing the structural capital of the innovation industrial cluster, which is based on the application of the cost approach to assessment and with allowance for the available in the studied cluster documented and undocumented results of the intellectual activity.

3. Structural capital of the innovation industrial cluster assessed by the proposed methodology was valuated as 7, 15 million rubles.

In collaboration with the enterprises participating in the cluster, this study showed that the cluster had great potential to increase its structural capital by documenting and registering the rights to the results of intellectual activity. The implementation of recommendations on registration of the results of intellectual activities will allow the cluster to reduce the risks of dependence on personnel, as well as to increase income through the transfer of proprietary rights to the results of intellectual activity. The presented work makes it possible to assess the growth reserves available to the cluster on the use of its intellectual capabilities. Other types of the intellectual capital of the innovation industrial cluster are subject to further research.

**Acknowledgements**

The study was carried out with the financial support of the Russian Foundation for Basic Research within the framework of scientific project No. 20-010-00942.

## References

Alekseeva, N., Babkin, A., Yung, A., Krechko, S., Barabaner, H., 2020. Digital transformation impact on the intellectual capital of an innovatively active industrial cluster, in: Proceedings of the International Scientific Conference - Digital Transformation on Manufacturing, Infrastructure and Service. Presented at the DTMIS ’20: International Scientific Conference - Digital Transformation on Manufacturing, Infrastructure and Service, ACM, Saint Petersburg Russian Federation, pp. 1–7. https://doi.org/10.1145/3446434.3446442

AlQershi, N., Mokhtar, S.S.M., Abas, Z., 2021. The relationship between strategic innovations, human capital and performance: An empirical investigation. Sustainable Futures 3, 100056. https://doi.org/10.1016/j.sftr.2021.100056

Andreeva, T., Garanina, T., Sáenz, J., Aramburu, N., Kianto, A., 2021. Does country environment matter in the relationship between intellectual capital and innovation performance? Journal of Business Research 136, 263–273. https://doi.org/10.1016/j.jbusres.2021.07.038

Babkin, A., Alekseeva, N., Makhmudova, G., Yung, A., 2020. Research and assessment of innovatively-active industrial cluster development, in: Proceedings of the 2nd International Scientific Conference on Innovations in Digital Economy: SPBPU IDE-2020. Presented at the SPBPU IDE ’20: SPBPU IDE-2020, ACM, Saint Petersburg Russian Federation, pp. 1–6. https://doi.org/10.1145/3444465.3444485

Babkin, A., Glukhov, V., Shkarupeta, E., Kharitonova, N., Barabaner, H., 2021. Methodology for assessing industrial ecosystem maturity in the framework of digital technology implementation. Int J Tech 12, 1397. https://doi.org/10.14716/ijtech.v12i7.5390

Beck, N., Swaminathan, A., Wade, J.B., Wezel, F.C., 2019. Industry clusters and organizational prototypes: Evidence from the Franconian brewing industry. Journal of Management 45, 2978–3008. https://doi.org/10.1177/0149206318773411

Chandrashekar, D., 2019. Determinants of firm’s propensity to patent its inventions: An evidence from Bengaluru high-tech manufacturing cluster. CR 29, 375–400. https://doi.org/10.1108/CR-02-2018-0011

Cho, S.-E., Cho, J., 2020. Software firm’s knowledge exchange activities and performances in industry clusters: Focus on start-ups and small and medium enterprises. International Journal of Entrepreneurship 24, 1–15. https://doi.org/10.1016/1099-9264-1939-4675

Druzhinin, A., Alekseeva, N., 2020. Efficiency assessment and research of the internal risks in the innovation-active industrial cluster, in: Proceedings of the 2nd International Scientific Conference on Innovations in Digital Economy: SPBPU IDE-2020. Presented at the SPBPU IDE ’20: SPBPU IDE-2020, ACM, Saint Petersburg Russian Federation, pp. 1–7. https://doi.org/10.1145/3444465.3444501

Fromhold-Eisebith, M., Marschall, P., Peters, R., Thomes, P., 2021. Torn between digitized future and context dependent past – How implementing ‘Industry 4.0’ production technologies could transform the German textile industry. Technological Forecasting and Social Change 166, 120620. https://doi.org/10.1016/j.techfore.2021.120620

Jiang, W.J., Zhang, Y.R., 2013. Influence of intellectual capital on technical innovation performance of clustered manufacturing enterprises. AMR 712–715, 3173–3180. https://doi.org/10.4028/www.scientific.net/AMR.712-715.3173

Komorowski, M., 2020. Identifying industry clusters: A critical analysis of the most commonly used methods. Regional Studies, Regional Science 7, 92–100. https://doi.org/10.1080/21681376.2020.1733436

Lehtonen, M.J., Ainamo, A., Harviainen, J., 2020. The four faces of creative industries: Visualising the game industry ecosystem in Helsinki and Tokyo. Industry and Innovation 27, 1062–1087. https://doi.org/10.1080/13662716.2019.1676704

Mikhaylov, A.S., Peker, I.Y., 2019. Spatial distribution of the intellectual capital of Russia. Vysš. obraz. Ross. (Print) 28, 28–39. https://doi.org/10.31992/0869-3617-2019-28-6-28-39

Pavlov, N., Klimin, A., Tikhonov, D., Trykov, A., 2022. Instrumentation for mastering classification trees to develop skills of marketing specialists in organizations, in: Manakov, A., Edigarian, A. (Eds.), International Scientific Siberian Transport Forum TransSiberia - 2021, Lecture Notes in Networks and Systems. Springer International Publishing, Cham, pp. 1151–1158. https://doi.org/10.1007/978-3-030-96383-5_128

Saadatyar, F.S., Al-Tabbaa, O., Dagnino, G.B., Vazife, Z., 2020. Industrial clusters in the developing economies: Insights from the Iranian carpet industry. Strategic Change 29, 227–239. https://doi.org/10.1002/jsc.2324

Sarvan, F., Durmuş, E., Köksal, C.D., Başer, G.G., Dirlik, O., Atalay, M., Almaz, F., 2011. Network based determinants of innovation performance in yacht building clusters. Procedia - Social and Behavioral Sciences 24, 1671–1685. https://doi.org/10.1016/j.sbspro.2011.09.118

Stavroulakis, P.J., Papadimitriou, S., Tsioumas, V., Koliousis, I.G., Riza, E., Tsirikou, F., 2020. Exploratory spatial analysis of maritime clusters. Marine Policy 120, 104125. https://doi.org/10.1016/j.marpol.2020.104125

Vetrenko, P.P., Chernysheva, E.A., Levitina, I.Y., Voronkova, O.V., Mikheeva, D.G., 2017. Encouraging employees to increase the labor intellectualization level as a factor of evolution of the intellectual capital. European Research Studies Journal 20, 568–577.

Wang, L., Tan, J., Li, W., 2018. The impacts of spatial positioning on regional new venture creation and firm mortality over the industry life cycle. Journal of Business Research 86, 41–52. https://doi.org/10.1016/j.jbusres.2018.01.020

Ye, D., Wu, Y.J., Goh, M., 2020. Hub firm transformation and industry cluster upgrading: Innovation network perspective. MD 58, 1425–1448. https://doi.org/10.1108/MD-12-2017-1266

Yeoh, K.-C., 2008. Singapore’s biomedical sciences landscape. JCB 14. https://doi.org/10.5912/jcb236

Zaytsev, A., Rodionov, D., Dmitriev, N., Ilchenko, S., 2020. Assessing intellectual capital from the perspective of its rental income performance. Int J Tech 11, 1489. https://doi.org/10.14716/ijtech.v11i8.4545

Zhilenkova, E., Budanova, M., Bulkhov, N., Rodionov, D., 2019. Reproduction of intellectual capital in innovative-digital economy environment. IOP Conf. Ser.: Mater. Sci. Eng. 497, 012065. https://doi.org/10.1088/1757-899X/497/1/012065

Žižka, M., Valentová, V.H., Pelloneová, N., Štichhauerová, E., 2018. The effect of clusters on the innovation performance of enterprises: Traditional vs new industries. JESI 5, 780–794. https://doi.org/10.9770/jesi.2018.5.4(6)

## Список источников

Alekseeva, N., Babkin, A., Yung, A., Krechko, S., Barabaner, H., 2020. Digital transformation impact on the intellectual capital of an innovatively active industrial cluster, in: Proceedings of the International Scientific Conference - Digital Transformation on Manufacturing, Infrastructure and Service. Presented at the DTMIS '20: International Scientific Conference - Digital Transformation on Manufacturing, Infrastructure and Service, ACM, Saint Petersburg Russian Federation, pp. 1–7. https://doi.org/10.1145/3446434.3446442

AlQershi, N., Mokhtar, S.S.M., Abas, Z., 2021. The relationship between strategic innovations, human capital and performance: An empirical investigation. Sustainable Futures 3, 100056. https://doi.org/10.1016/j.sftr.2021.100056

Andreeva, T., Garanina, T., Sáenz, J., Aramburu, N., Kianto, A., 2021. Does country environment matter in the relationship between intellectual capital and innovation performance? Journal of Business Research 136, 263–273. https://doi.org/10.1016/j.jbusres.2021.07.038

Babkin, A., Alekseeva, N., Makhmudova, G., Yung, A., 2020. Research and assessment of innovatively-active industrial cluster development, in: Proceedings of the 2nd International Scientific Conference on Innovations in Digital Economy: SPBPU IDE-2020. Presented at the SPBPU IDE '20: SPBPU IDE-2020, ACM, Saint Petersburg Russian Federation, pp. 1–6. https://doi.org/10.1145/3444465.3444485

Babkin, A., Glukhov, V., Shkarupeta, E., Kharitonova, N., Barabaner, H., 2021. Methodology for assessing industrial ecosystem maturity in the framework of digital technology implementation. Int J Tech 12, 1397. https://doi.org/10.14716/ijtech.v12i7.5390

Beck, N., Swaminathan, A., Wade, J.B., Wezel, F.C., 2019. Industry clusters and organizational prototypes: Evidence from the Franconian brewing industry. Journal of Management 45, 2978–3008. https://doi.org/10.1177/0149206318773411

Chandrashekar, D., 2019. Determinants of firm's propensity to patent its inventions: An evidence from Bengaluru high-tech manufacturing cluster. CR 29, 375–400. https://doi.org/10.1108/CR-02-2018-0011

Cho, S.-E., Cho, J., 2020. Software firm's knowledge exchange activities and performances in industry clusters: Focus on start-ups and small and medium enterprises. International Journal of Entrepreneurship 24, 1–15. https://doi.org/10.1016/1099-9264-1939-4675

Druzhinin, A., Alekseeva, N., 2020. Efficiency assessment and research of the internal risks in the innovation-active industrial cluster, in: Proceedings of the 2nd International Scientific Conference on Innovations in Digital Economy: SPBPU IDE-2020. Presented at the SPBPU IDE '20: SPBPU IDE-2020, ACM, Saint Petersburg Russian Federation, pp. 1–7. https://doi.org/10.1145/3444465.3444501

Fromhold-Eisebith, M., Marschall, P., Peters, R., Thomes, P., 2021. Torn between digitized future and context dependent past – How implementing 'Industry 4.0' production technologies could transform the German textile industry. Technological Forecasting and Social Change 166, 120620. https://doi.org/10.1016/j.techfore.2021.120620

Jiang, W.J., Zhang, Y.R., 2013. Influence of intellectual capital on technical innovation performance of clustered manufacturing enterprises. AMR 712–715, 3173–3180. https://doi.org/10.4028/www.scientific.net/AMR.712-715.3173

Komorowski, M., 2020. Identifying industry clusters: A critical analysis of the most commonly used methods. Regional Studies, Regional Science 7, 92–100. https://doi.org/10.1080/21681376.2020.1733436

Lehtonen, M.J., Ainamo, A., Harviainen, J., 2020. The four faces of creative industries: Visualising the game industry ecosystem in Helsinki and Tokyo. Industry and Innovation 27, 1062–1087. https://doi.org/10.1080/13662716.2019.1676704

Mikhaylov, A.S., Peker, I.Y., 2019. Spatial distribution of the intellectual capital of Russia. Vysš. obraz. Ross. (Print) 28, 28–39. https://doi.org/10.31992/0869-3617-2019-28-6-28-39

Pavlov, N., Klimin, A., Tikhonov, D., Trykov, A., 2022. Instrumentation for mastering classification trees to develop skills of marketing specialists in organizations, in: Manakov, A., Edigarian, A. (Eds.), International Scientific Siberian Transport Forum TransSiberia - 2021, Lecture Notes in Networks and Systems. Springer International Publishing, Cham, pp. 1151–1158. https://doi.org/10.1007/978-3-030-96383-5_128

Saadatyar, F.S., Al-Tabbaa, O., Dagnino, G.B., Vazife, Z., 2020. Industrial clusters in the developing economies: Insights from the Iranian carpet industry. Strategic Change 29, 227–239. https://doi.org/10.1002/jsc.2324

Sarvan, F., Durmuş, E., Köksal, C.D., Başer, G.G., Dirlik, O., Atalay, M., Almaz, F., 2011. Network based determinants of innovation performance in yacht building clusters. Procedia - Social and Behavioral Sciences 24, 1671–1685. https://doi.org/10.1016/j.sbspro.2011.09.118

Stavroulakis, P.J., Papadimitriou, S., Tsioumas, V., Koliousis, I.G., Riza, E., Tsirikou, F., 2020. Exploratory spatial analysis of maritime clusters. Marine Policy 120, 104125. https://doi.org/10.1016/j.marpol.2020.104125

Vetrenko, P.P., Chernysheva, E.A., Levitina, I.Y., Voronkova, O.V., Mikheeva, D.G., 2017. Encouraging employees to increase the labor intellectualization level as a factor of evolution of the intellectual capital. European Research Studies Journal 20, 568–577.

Wang, L., Tan, J., Li, W., 2018. The impacts of spatial positioning on regional new venture creation and firm mortality over the industry life cycle. Journal of Business Research 86, 41–52. https://doi.org/10.1016/j.jbusres.2018.01.020

Ye, D., Wu, Y.J., Goh, M., 2020. Hub firm transformation and industry cluster upgrading: Innovation network perspective. MD 58, 1425–1448. https://doi.org/10.1108/MD-12-2017-1266

Yeoh, K.-C., 2008. Singapore's biomedical sciences landscape. JCB 14. https://doi.org/10.5912/jcb236

Zaytsev, A., Rodionov, D., Dmitriev, N., Ilchenko, S., 2020. Assessing intellectual capital from the perspective of its rental income performance. Int J Tech 11, 1489. https://doi.org/10.14716/ijtech.v11i8.4545

Zhilenkova, E., Budanova, M., Bulkhov, N., Rodionov, D., 2019. Reproduction of intellectual capital in innovative-digital economy environment. IOP Conf. Ser.: Mater. Sci. Eng. 497, 012065. https://doi.org/10.1088/1757-899X/497/1/012065

Žižka, M., Valentová, V.H., Pelloneová, N., Štichhauerová, E., 2018. The effect of clusters on the innovation performance of enterprises: Traditional vs new industries. JESI 5, 780–794. https://doi.org/10.9770/jesi.2018.5.4(6)

The article was submitted 13.04.2022, approved after reviewing 7.05.2022, accepted for publication 18.05.2022.

Статья поступила в редакцию 13.04.2022, одобрена после рецензирования 7.05.2022, принята к публикации 18.05.2022.

About authors:

1. Aleksandr Babkin, Doctor of Economic Sciences, Professor, Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia. https://orcid.org/0000-0002-0941-6358, al-vas@mail.ru

2. Natalia Alekseeva, PhD, Associate Professor, Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia. https://orcid.org/0000-0002-7355-3277, alekseeva_ns@spbstu.ru

3. Larissa Tashenova, PhD, Associate Professor, Buketov Karagandy University, Karaganda, Kazakhstan. https://orcid.org/0000-0001-5022-0421, larisatash_88@mail.ru

4. Diyor Karimov, PhD, Associate Professor, National University of Uzbekistan named after Mirzo Ulugbek, Tashkent, Uzbekistan. https://orcid.org/0000-0002-6050-1806, karimov.diyor65@gmail.com

Информация об авторах:

1. Александр Бабкин, д.э.н., профессор, Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия. https://orcid.org/0000-0002-0941-6358, al-vas@mail.ru

2. Наталья Алексеева, к.э.н., доцент, Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия. https://orcid.org/0000-0002-7355-3277, alekseeva_ns@spbstu.ru

3. Лариса Ташенова, к.э.н., доцент, Карагандинский университет имени академика Е.А. Букетова, Караганда, Казахстан. https://orcid.org/0000-0001-5022-0421, larisatash_88@mail.ru

4. Диёр Каримов, к.э.н., доцент, Национальный университет Узбекистана имени Мирзо Улугбека, Ташкент, Узбекистан. https://orcid.org/0000-0002-6050-1806, karimov.diyor65@gmail.com

**Research article**

**DOI:** https://doi.org/10.48554/SDEE.2022.2.5

# DEVELOPMENT OF A MECHANISM FOR ADAPTING DIGITAL INNOVATION POTENTIAL OF AN ORGANISATION WITH ALLOWANCE FOR PECULIARITIES OF DIGITAL INNOVATION PROJECTS

Anastasiia Shmeleva[1*], Svetlana Suloeva[1]

[1]Peter the Great Saint Petersburg Polytechnic University, Saint Petersburg, Russia,
O.2908@mail.ru, suloeva_sb@spbstu.ru
*Corresponding author: O.2908@mail.ru

## Abstract

This paper is devoted to the problem of forming the innovation potential of an organisation that implements digital innovation projects. The authors have developed a mechanism for adapting the digital innovation potential (DIP) of an enterprise to the strategic goals and objectives of its innovative development, taking into consideration the factors of the innovation climate and internal environment. The relevance of the study is rooted in the increasing dynamism, unpredictability, and turbulence of the external and internal environments of organisations and the high rate of implementation of advanced digital technologies. These changes should be reflected in enterprise management systems, including innovation management systems. Different types of digital technologies are characterised by specific factors of development and implementation. This determines the peculiarities in the formation of the innovation potential required to implement such projects, as well as the ambiguity of the number and composition of analytical indicators in its evaluation. The theoretical and methodological basis of the study were the publications of international and Russian authors devoted to the problems of adapting economic systems to the conditions of a dynamically changing environment, as well as the study of the essence, formation, and evaluation methods of the innovation and digital potential of an organisation. The paper presents the author's interpretation of the concept of digital innovation potential. The authors substantiate the sequence of stages for identifying priority areas of adaptation and development of necessary measures for the formation of the target level of digital innovation potential, and propose a methodology that allows identifying key factors and determining the degree of influence for each of them. Based on the developed methodology, the most significant areas of adaptation of the digital innovation potential of an oil and gas enterprise during implementing the project of introducing virtual and augmented reality technologies were identified.

**Keywords:** digital innovation projects; innovation potential of an organisation; adaptation mechanism; innovation climate; external and internal environment factors; digital technologies

**Citation:** Shmeleva, A., Suloeva, S., 2022. Development of a mechanism for adapting digital innovation potential of an organisation with allowance for peculiarities of digital innovation projects. Sustainable Development and Engineering Economics 2, 5. https://doi.org/10.48554/SDEE.2022.2.5

**Научная статья**
**УДК 334.02**
**DOI:** https://doi.org/10.48554/SDEE.2022.2.5

# РАЗРАБОТКА МЕХАНИЗМА АДАПТАЦИИ ЦИФРОВОГО ИННОВАЦИОННОГО ПОТЕНЦИАЛА ОРГАНИЗАЦИИ С УЧЕТОМ ОСОБЕННОСТЕЙ ЦИФРОВЫХ ИННОВАЦИОННЫХ ПРОЕКТОВ

Анастасия Шмелева[1*], Светлана Сулоева[1]

[1]Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия, O.2908@mail.ru, suloeva_sb@spbstu.ru
*Автор, ответственный за переписку: O.2908@mail.ru

**Аннотация**

Статья посвящена проблеме формирования инновационного потенциала организации, реализующей цифровые инновационные проекты. Авторами разработан механизм адаптации цифрового инновационного потенциала предприятия к стратегическим целям и задачам его инновационного развития с учетом факторов инновационного климата и внутренней среды. Актуальность исследования обусловлена ростом динамичности, непредсказуемости и турбулентности внешней и внутренней среды организаций, высокими темпами внедрения передовых цифровых технологий. Эти изменения должны находить отражение в системах управления предприятиями, в том числе в системах управления инновационной деятельностью. Различные виды цифровых технологий отличаются специфическими факторами разработки и внедрения, это обуславливает особенности в формировании инновационного потенциала, необходимого для реализации таких проектов, а также неоднозначность количества и состава аналитических показателей в его оценке. Использование предложенного авторами механизма позволит обеспечить необходимый уровень цифрового инновационного потенциала для эффективной реализации цифровых проектов. Теоретическую и методологическую основу исследования составили публикации зарубежных и российских авторов, посвященные проблемам адаптации экономических систем к условиям динамично меняющейся внешней среды, а также изучению вопросов сущности, формирования и методов оценки инновационного и цифрового потенциалов организации. В работе дана авторская трактовка понятия цифровой инновационный потенциал. Обоснована последовательность этапов по выявлению приоритетных направлений адаптации и разработке необходимых мероприятий для формирования целевого уровня цифрового инновационного потенциала, предложена методика, позволяющая выявить ключевые факторы и определить степень влияния каждого из них. На основании разработанной методики выявлены наиболее значимые направления адаптации цифрового инновационного потенциала предприятия нефтегазовой отрасли при реализации проекта внедрения технологий виртуальной и дополненной реальности.

**Ключевые слова:** цифровые инновационные проекты; инновационный потенциал организации; механизм адаптации; инновационный климат; факторы внешней и внутренней среды; цифровые технологии.

**Цитирование:** Шмелева, А., Сулоева, С., 2022. Разработка механизма адаптации цифрового инновационного потенциала организации с учетом особенностей цифровых инновационных проектов. Sustainable Development and Engineering Economics 2, 5. https://doi.org/10.48554/SDEE.2022.2.5

## 1. Introduction

The current development stage of the global and Russian economic systems is characterised by the following features: (1) increasing dynamism, unpredictability, and turbulence of external and internal environments and (2) the high rate of adoption of advanced digital technologies (Issa et al., 2018; Schumacher et al., 2018). The introduction and use of advanced digital technologies allows companies in various sectors of the economy not only to reduce costs but also to transform existing business models, providing themselves with competitive advantages in the global market. Today, digital technologies are the main driver of their sustainable development and the main tool for enhancing their competitiveness and investment attractiveness. All these changes should be reflected in enterprise management systems, including innovation management systems. The current digital transformation requires developing and improving methods for managing digital innovation projects to improve the efficiency of companies and maintain a leading position in a competitive and high-tech market.

Strategic goals of innovative development of an organisation are achieved through implementing innovation and investment projects characterised by creation of digital products, focus on improving the existing and developing new business models, high level of uncertainty, high technological and organisational complexity, critical pace of implementation, focus on new needs, and use of agile approaches to project management (Shmeleva et al., 2019). Since different types of digital technologies are characterised by specific factors of development and adoption, they also determine the peculiarities in the formation of the innovation potential required to implement such projects, as well as the ambiguity of the number and composition of analytical indicators in their evaluation (Aldea, 2018).

The purpose of the research was to develop a mechanism for adapting the digital innovation potential (DIP) of an enterprise to the strategic goals and objectives of its innovative development, taking into consideration the needs of digital innovation and investment projects.

## 2. Literature Review

Currently, many scientific papers presented by leading international and Russian scientists are devoted to the formation of the innovation potential of organisations, but the tools proposed in them do not provide enough flexibility to respond to external changes and to quickly adapt to them, and do not take into consideration specifics of digital innovation projects. In particular, the problems of adapting economic systems to the conditions of a dynamically changing external environment are the subject of research by Chanias et al. (2019) and Park et al. (2021). The essence, formation, and methods of evaluating the innovation and digital potential of economic systems have been studied by scientists such as Babkin et al. (2021), Eremin et al. (2019), and Kotarba (2017).

To clarify the concept of “innovation potential” with allowance for the features of digital innovation projects, we conducted a review of different approaches to its interpretation. One of the most common is the resource-based approach, in which innovation potential is understood as an ordered aggregate of the various resources necessary for carrying out innovation activities. The evaluation methodologies of different authors differ in the set of resource groups and the list of components. However, it should be noted that the same set of resources does not provide the same result of innovation activity; therefore, the innovation potential in an organisation may be limited by internal barriers that do not allow it to be properly harnessed.

From the point of view of a number of authors, innovation potential can be considered a measure of an enterprise’s ability to create, introduce, and disseminate new ideas, technologies, and products. In this case, the focus is on the effectiveness of its use. Thus, in accordance with the results-based approach, innovation potential is characterised by the totality of the results of the innovation activity. Advocates of the systematic approach consider innovation potential to be the ability of an economic system to change, improve, and progress based on the transformation of available resources into a qualitatively new state.

The approaches considered above do not contradict each other; each reveals one aspect of innovation potential. However, we believe that the concept of innovation potential is broader and includes the analysis of the organisation's ability to implement innovation projects related not only to digitalisation. In this regard, there is a need to clarify this category, taking into consideration the specifics of implementing digital innovation and investment projects.

We examined the approaches of various authors to the interpretation of the concept of "digital potential" (Babkin et al., 2021; Salko, 2021, Kozlov et al., 2019). The review of the scientific literature showed that most sources focus on groups of factors directly related to the adoption of information and communication technologies. Some authors suggest limiting consideration solely to the digital component of the organisation's potential.

In our opinion, when analysing the readiness of an enterprise to implement digital innovation projects, it is advisable to use the concept of "digital innovation potential", and its evaluation requires a balanced approach that takes into consideration both the level of resources for the implementation of digital innovation projects and the organisation's ability to implement such projects. From such a perspective, the factors of the digital component should have greater weight in the formation of this potential (Sola et al., 2021).

## 3. Materials and Methods

The methodological basis of the study was the works by international and Russian authors in the field of formation and evaluation of innovation potential of economic systems, adaptation, and adaptability of organisations in a changing environment, as well as management of digital innovation and investment projects (Shmeleva et al., 2021; Zhu, 2021). When developing the mechanism of adaptation of the digital innovation potential of an organisation, we used general scientific research methods, in particular methods of system analysis, SWOT analysis, comparative analysis, the expert scoring method, the method of calculating the Kendall rank correlation coefficient, the method of assessing the consistency of experts using Pearson's chi-squared test and tabular and graphical methods of data interpretation (Muñoz-La Rivera et al., 2020).

The study included several stages. In the first stage, based on the analysis of the previously described sources, we synthesised our interpretation of the concept of digital innovation potential. We defined DIP as the ability of an enterprise to effectively solve the problems of innovation activities using digital technologies, both within the existing business processes and transformed on the basis of new technological capabilities, with optimal use of available resources, which enables moving the enterprise to a qualitatively new state. Next, we analysed the factors that determine the level of the digital innovation potential of an enterprise. Figure 1 shows the process of formation of the actual level of digital innovation potential under the influence of factors of the external and internal environments of the organisation.

In the next stage of the study, we developed the mechanism of adapting the innovation potential of an organisation to the objectives of its innovative development, which can be represented in the scheme illustrated in Fig. 2. The specifics of this mechanism for digital innovation projects are expressed in a set of factors subject to analysis.

The *adaptation mechanism* is understood as a system of interrelated elements that includes the principles and functions of adaptation management, as well as the subject's leverage on the object to achieve the goal. The following structural elements can be distinguished with regard to the adaptation mechanism of the organisation's digital innovation potential:

*Goal:* Adaptation of the digital innovation potential of an organisation for effective implementation of a digital innovation project.

*Management entity:* The project's management committee is the main collegial decision-making body of the project, and includes representatives of the customer and the executor, if the project is implemented by a third-party organisation. The committee finds importance in carrying out activities that are beyond the authority of the project manager at the target level of the innovation potential.

*Object of management*: This refers to the innovation potential of an organisation that introduces digital technologies.

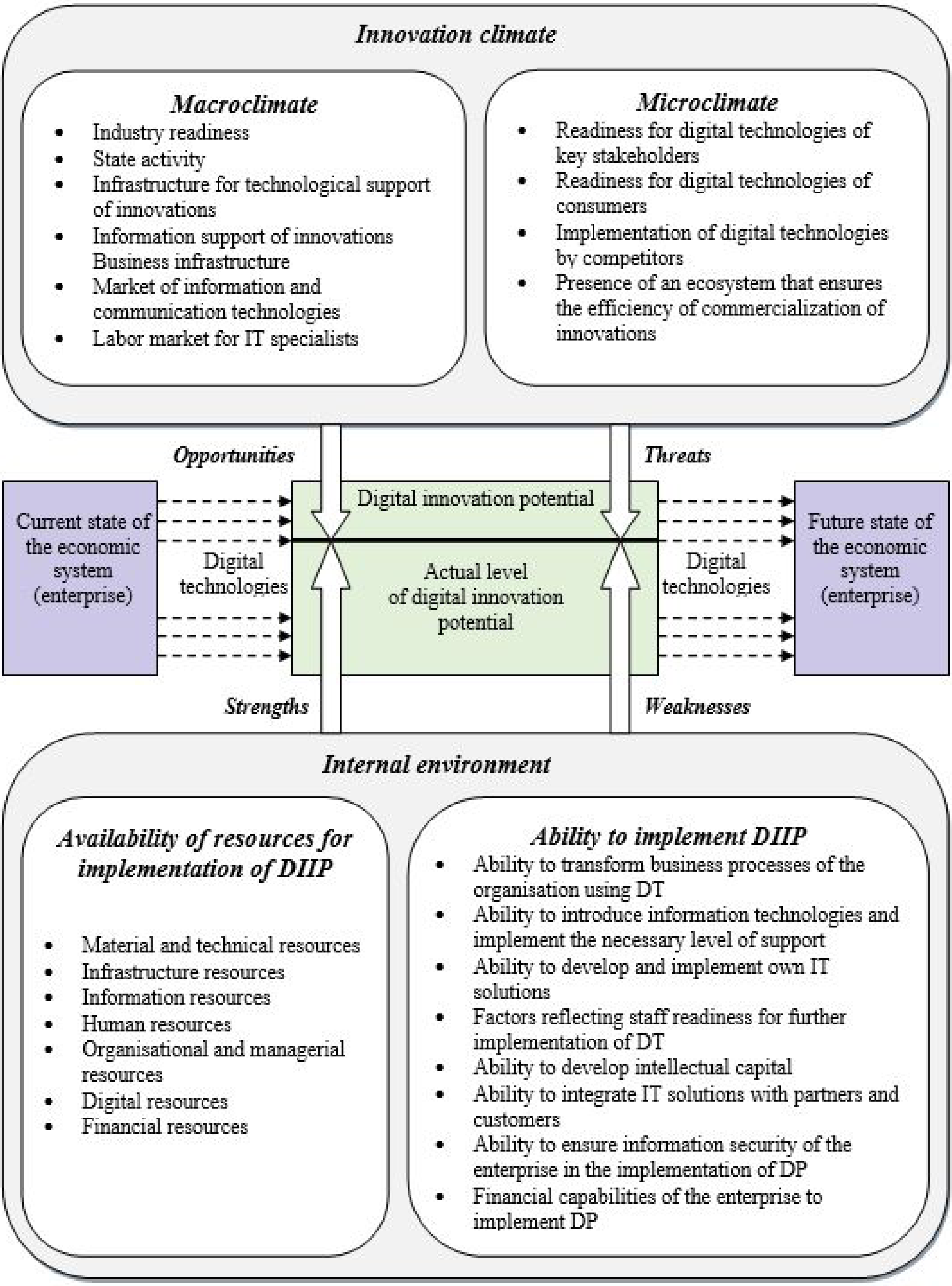



**Figure 1.** The process of forming the actual level of the digital innovation potential of an organisation

The *main principles* in this case are consistency, flexibility, and adaptability.

*Management functions* are presented in the form of the following blocks: analysis includes selecting priority areas of adaptation of the innovation potential; planning – development of a portfolio of adaptation programmes; organisation implies implementation of these programmes; control – monitoring and regulation in the form of feedback. The formation of a portfolio of adaptation programmes is the development of a programme of specific actions to bring the level of individual elements of the innovation potential to the required level. If the project is long-term, there will always be elements of the potential that need to be adjusted due to dynamic changes in the conditions of project implementation.

The choice of *leverage* for specific elements of the innovation potential (adaptation tools and the means to provide them) is made at the planning stage.

*Result:* This captures the formed level of innovation potential necessary for the effective implementation of a digital innovation and investment project.

The degree of influence on the implementation of an innovative project of various factors from the considered groups can vary significantly; therefore, it is necessary to identify the most important factors and evaluate the level of influence of each of them. Such gradation is important because when developing a portfolio of adaptation programmes, it is advisable to focus resources on the main areas rather than waste them on factors that have a weak impact on the project (Shmeleva et al., 2020). The level of factors' target values and the need for adaptation measures depend on the significance of factors for implementing digital projects.

Following the crafting of the adaptation mechanism, we then proposed a methodology that allows identifying the key factors in the formation of digital innovation potential and determining the degree of influence for each of them. Figure 3 shows a matrix set that allows the identification of the priority areas of adaptation. For this purpose, with the expert analysis, an evaluation of the level and significance of factors for implementing a digital innovation project was carried out. We developed a matrix set consisting of four matrices for analysing the strengths and weaknesses of the current state of the organisation's innovation potential, as well as opportunities and threats to achieve its target level. Further, guidelines were developed regarding the factors from the various quadrants of the matrix set.

$S_I$ and $O_I$ were factors that were highly evaluated by experts and also have a significant impact on the effectiveness of project implementation. Any action in relation to the factors from the $S_I$ group should be taken only if there is a tendency for their level to decrease and the possibility of moving into the second group. Factors of the $O_I$ group should be included in the group of priority areas for the adaptation of the innovation potential.

$S_{II}$ and $O_{II}$ were factors to which experts assigned low scores while highly rating their impact on the possibility of successful project implementation. Therefore, it is necessary to concentrate efforts on the intensive development of the factors of the $S_{II}$ group. For the external environment factors $O_{II}$, it is necessary to provide alternative options for the use of opportunities to reduce their significance. Given that the impact of factors from groups $S_{III}$, $O_{III}$, $S_{IV}$, $O_{IV}$ on implementing an innovation project is insignificant, it is sufficient to maintain $S_{III}$ and $S_{IV}$ at the current level, and exclude the use of groups $O_{III}$ and $O_{IV}$ factors from further analysis.

$W_I$ and $T_I$ are internal and external risk factors. Their impact is considerable on a project, and the probability of their occurrence during its implementation is also significant. It is necessary to pay close attention to these factors. To make a decision on actions in relation to the factors in this group, it is necessary to analyse which activities for their minimisation can be carried out with the least expenditure of time and resources. Depending on the results of the analysis, anti-risk measures should be implemented to move the $W_I$ factors to the second group by reducing the level of risk, and factors from the $T_I$ group to the third group by reducing the impact.

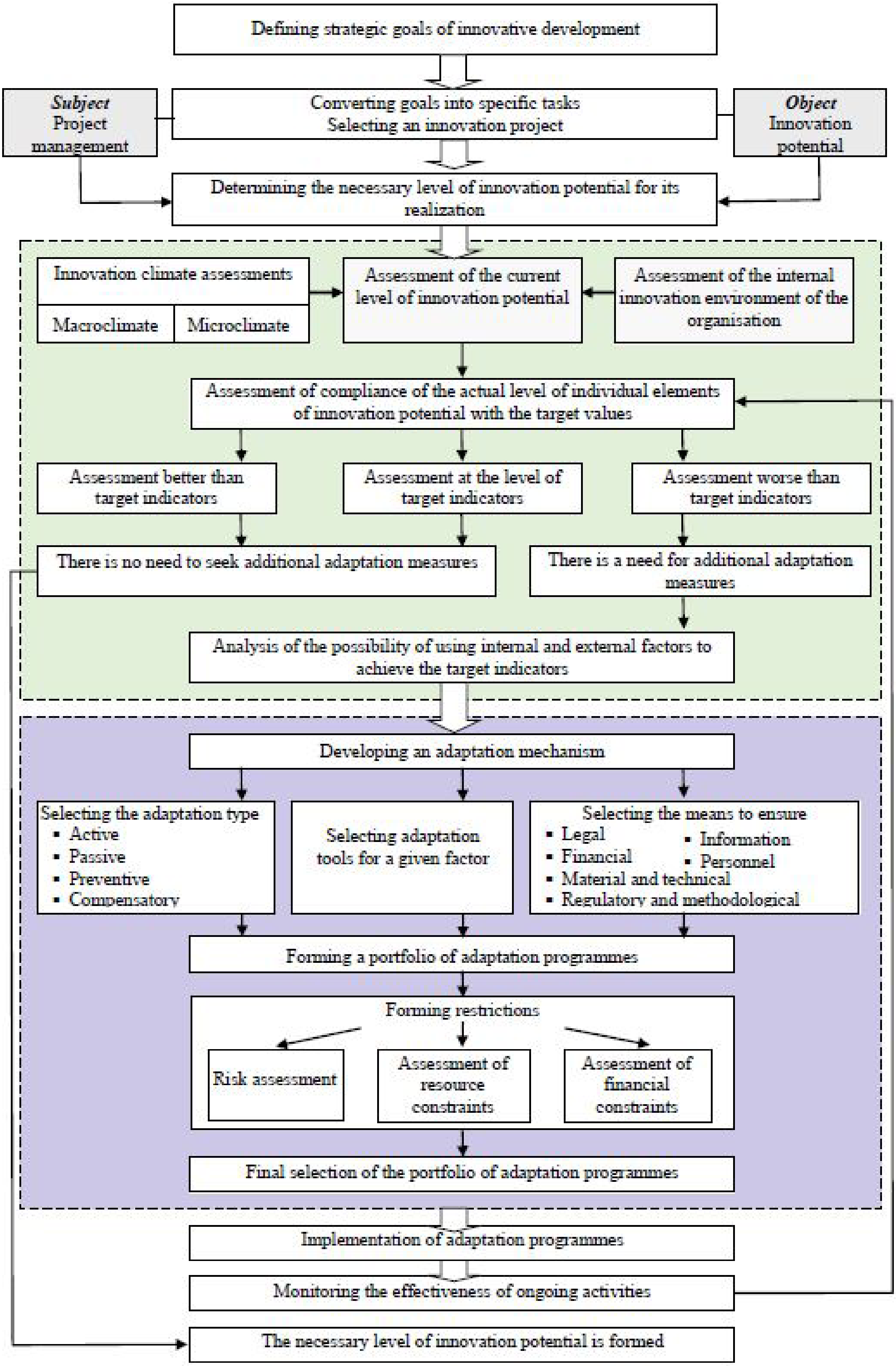



**Figure 2.** Mechanism of adaptation of the digital innovation potential of an organisation

$W_{II}$ and $T_{II}$ are threat factors, the negative impact of which was recognised by the experts as significant, but the level of probability of their occurrence was found to be insignificant. Despite the low probability of occurrence, the elements of these groups require special attention due to the significant negative consequences of a project. For these factors, anti-risk measures should be taken to reduce the degree of their impact, which will allow them to move to the fourth group.

$W_{III}$ and $T_{III}$ are risk factors whose negative impact was not rated highly by the experts, although they noted a significant probability of their occurrence. Although the factors in this group were not rated highly enough for their impact on project implementation, the high probability of their occurrence makes it necessary to pay close attention to possible consequences due to the negative impact on the project at later stages of its implementation. In relation to the elements of this group, it is necessary to develop anti-risk measures to reduce the probability of their occurrence and move them into the fourth group.

$W_{IV}$ and $T_{IV}$ are factors that were given low scores by the experts in terms of their impact on a project, and their probability of occurrence was also found to be low. The elements from these groups can be excluded from further planning of anti-risk measures.

From the analysis, we can conclude that the main efforts should be concentrated on groups $S_{II}$, $O_I$, $O_{II}$, $W_I$, $T_I$, and $W_{II}$. The areas of adaptation corresponding to these factors should be recognised as a priority.

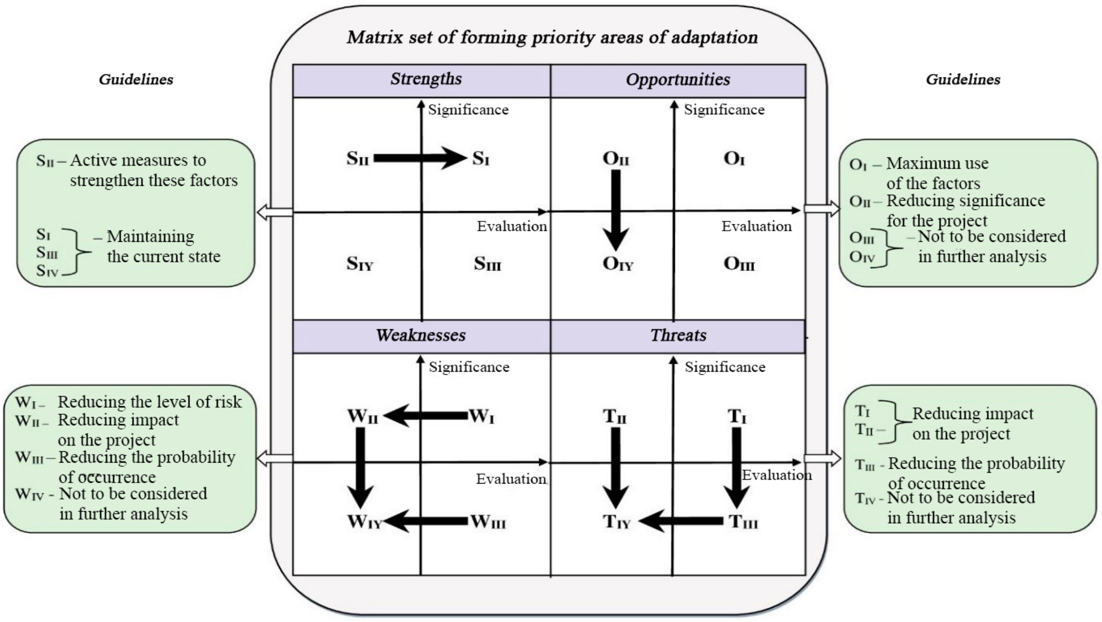



**Figure 3.** Matrix set for forming priority areas of adaptation

For a quantitative assessment of the level and significance of the factors from the matrix sets, we used the expert evaluation method, given that most of the identified factors are difficult to assess quantitatively. The method also allows for combining their assessments with a single quantitative measure. In assessing the level of innovation potential, we considered only internal factors, which allowed for assessing the readiness of an organisation to implement the innovation project under consideration. In forming the priority directions of adaptation, all four groups of factors were assessed for their possible impact on the formation of the necessary level of the innovation potential of the external environment factors.

The integral indicator of the innovation potential *IIP* is calculated on the basis of the assigned scores according to the formula:

$$I_{IP} = \frac{\dfrac{\sum_{i=1}^{n} d_i^S * S_i}{n}}{\dfrac{\sum_{j=1}^{m} d_j^W * W_j}{m}} \qquad (1)$$

where: n is the number of strength factors, *m* is the number of weakness factors, $S_i$ is the estimate of the level of the i-th strength factor, $d_i^S$ is the significance of the i-th strength factor, $W_j$ is the estimate of the level of the j-th weakness factor, and $d_j^W$ is the significance of the j-th weakness factor.

## 4. Results and Discussion

### 4.1. Identification of external and internal environment factors of an organisation, affecting the formation of digital innovation potential

The proposed methodology for forming priority areas of adaptation was tested in developing a project that introduced virtual and augmented reality technologies into the processes of training employees of maintenance crews and performing repairs of downhole equipment, which was planned for implementation at the company Gazprom Neft.

The prerequisites for initiating the project are as follows:

– The need for a wide range of specialists due to the complexity and variety of equipment used in the oil and gas industry, which was complicated by the remoteness of facilities and difficulties with logistics;
– Production losses due to downtime of the well stock because of long-time waiting for workover and maintenance crews in the case of well shutdowns;
– The risk of oil pipelines freezing in winter due to forced downtime, which led to fluid fluctuations in the collection system, increased line pressure in upstream pipelines, and the operation of booster pump stations and oil metering units in an abnormal mode;
– The lack of effective coordination of crews in the well repair process led to an increase in non-productive repair time, which increased the time and cost of well workover and maintenance activities (Azieva et al., 2021; Panjaitan et al., 2021).

Reducing equipment downtime and improving the quality of repair works can be accomplished through the use of augmented reality (AR) technology. The following functions can be implemented in an AR system: visualisation of necessary actions of experts, highlighting details that require special attention in a 3D model, display of process parameters in real time and their values in dynamics as trends; display of expert advice in the form of a scrolling text, video communication with an expert and a service engineer directly as a single viewing window, and output of analytics and service information documents (Garcia et al., 2019).

In addition to the prerequisites related to technical difficulties, the company faced some problems related to employee training, namely:

– practical training is possible only during planned shutdowns;
– lack of understanding of the real level of knowledge of employees before certification;
– the need for long training of maintenance crews for downhole equipment leads to a shortage of qualified personnel;
– incidents of injuries and equipment downtime due to employee errors (Flaksman et al., 2020).

The content of a virtual reality (VR) simulator would enable the creation of an exact copy of the workplace and downhole equipment, generating scenarios for operational switching and undergoing both full-fledged training and testing. Practical training would not take place on real equipment but in classrooms with the use of VR headsets

(Al Qrain et al., 2020). A virtual learning environment would allow for creating training sessions on equipment operation, simulating emergency situations, and reproducing other necessary scenarios for training, as well as providing an opportunity to consider objects and processes that are difficult to trace in reality.

Based on the analysis of external and internal environment factors shown in Figure 1 as well as the source study (Krishnan et al., 2020; Stoianova et al., 2020), we identified the factors most important for the formation of the digital innovation potential of the organisation in implementing a project that introduces virtual and augmented reality technologies (Baker, 2022) (Table 1, Table 2).

**Table 1.** Internal factors significant for the formation of digital innovation potential

| Strengths of the organisation | Weaknesses of the organisation |
|---|---|
| 1. The enterprise has the software necessary to implement VR/AR projects. | 1. A diverse equipment fleet, difficulty in scaling, and uniqueness of products for different divisions. |
| 2. The enterprise has the necessary equipment to implement VR/AR projects. | 2. Difficulties integrating AR/VR with other information systems. |
| 3. The possibility of timely and secure access to databases, ensuring a high level of reliability, accuracy, and quality. | 3. Insufficient ability to ensure the information security of the enterprise when implementing digital projects. |
| 4. High level of access to modern digital infrastructure: data processing centres, cloud solutions and working on all types of devices. | 4. Simultaneous launch of several disparate «digital» projects that are not tied to strategic goals, which end up being insufficiently successful. |
| 5. The use of process management methods and the readiness of the organisation to change business processes in accordance with the objectives of digitalisation. | 5. The long process of alignment and approval of the transition to new business processes using AR/VR. |
| 6. There is a well-established process for creating new digital products, including product analytics and end-to-end integration of development and maintenance processes. | 6. Fragmentary introduction of AR/VR technologies, implementation of only pilot versions, weak effects of digitalisation. |
| 7. High level of organisational culture that supports innovation processes, and change management processes. | 7. When forming teams, specialists with in-depth knowledge of the specifics of production are not included. |
| 8. Availability of employees capable of developing and implementing their own IT solutions. | 8. Conservatism: the reluctance of managers to restructure the models of process organisation accumulated over the years. |
| 9. Employees have the necessary competencies to perform their functions using information systems. | 9. Reluctance of the workforce to retrain and extensively use digital technologies. |
| 10. Availability of employees capable of generating non-standard ideas and developing innovative solutions. | 10. Employees do not have the necessary competencies to implement digital projects. |
| 11. Availability of a top-level executive in the company, who supervises VR/AR implementation and has the necessary competencies. | 11. Low level of interest and engagement of potential users due to mistrust in the effectiveness of digital products. |
| 12. Ability to form feedback from users in order to create a product with the necessary characteristics. | 12. Inconsistency of the finished product with functional and business requirements due to a lack of regular interaction with the customer. |
| 13. The existence of a large number of departments, which in the future may use the developed products to improve efficiency, the use of economies of scale. | 13. Absence of clear mechanisms for calculating the effectiveness of introducing AR/VR technologies. |
| 14. The enterprise has extensive financial capabilities to implement digital projects. | 14. Lack of economic incentives for the enterprise to implement digital technologies, no possible positive effects of implementation have been identified. |

**Table 2.** External factors significant for the formation of digital innovation potential

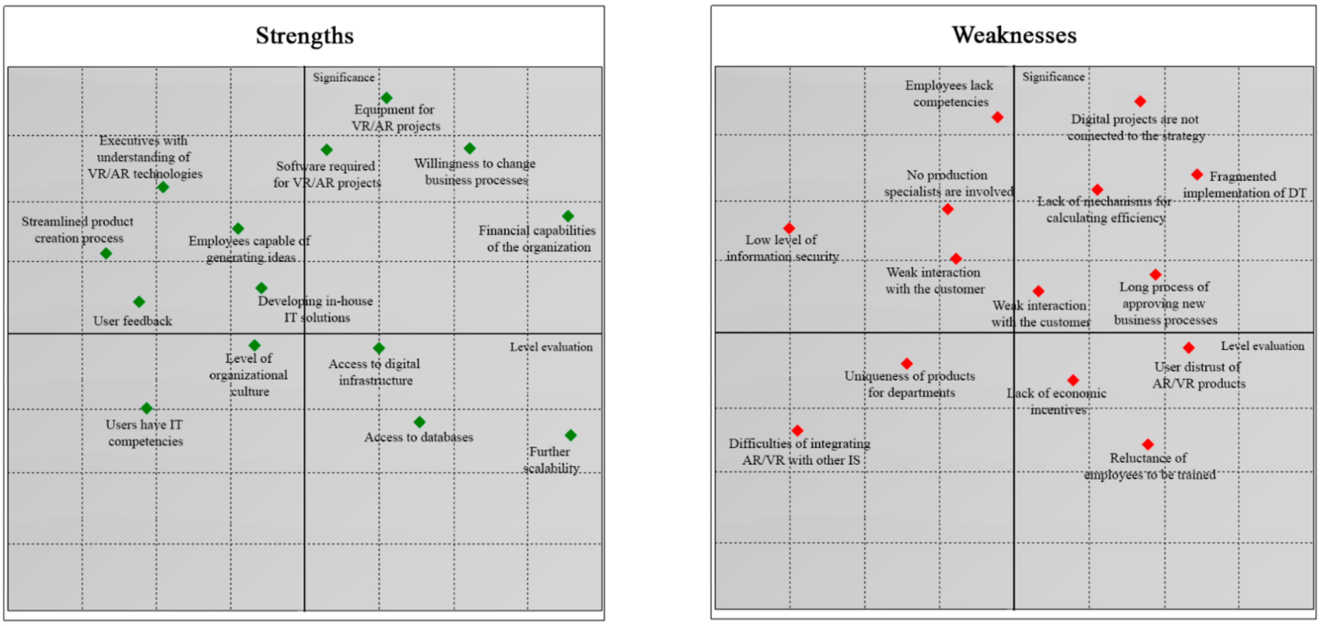
| Opportunities | Threats |
|---|---|
| 1. High dynamics of technological development of VR/AR devices and the necessary software. | 1. Problems with access to certain types of IT resources required to implement digital technologies. |
| 2. Capacity and availability of external data banks in the field of VR/AR technology. | 2. Due to import substitution, it is impossible to use the most advanced AR/VR devices in Russian industrial enterprises. |
| 3. Availability of infrastructure for technological support of VR/AR projects. | 3. High level of cyberthreats when implementing digital projects. |
| 4. Creation of leading research centres to effectively solve the tasks of development of sub-technologies necessary for VR/AR. | 4. Incomplete legislation regarding the development of the digital economy and the use of ICTs. |
| 5. High degree of readiness of the oil and gas industry to use VR/AR technologies. | 5. Implementation of digital technologies by competitors, increasing their competitiveness. |
| 6. Availability of an ecosystem that ensures the efficiency of the commercialisation of innovations. | 6. Key stakeholders are not ready for digital technologies. |
| 7. Clearly defined prospects for the use of VR/AR technologies, the development of roadmaps for development. | 7. Difficulties with certification of educational VR/AR courses and licensing of VR/AR products. |
| 8. Intensive legislative activity of the state at all levels of government to enhance the implementation of digital technologies. | 8. High cost of high-skilled labour due to increased demand in the labour market. |
| 9. Availability of training and retraining structures for competencies required for implementation of digital projects. | 9. There is a market deficit of specialists in various fields with the competencies necessary for implementing VR/AR technologies. |
| 10. Opportunities to use digital platforms to quickly find specialists with the necessary competencies. | 10. Rapid obsolescence of technologies, inconsistency of AR/VR product with consumer expectations. |
| 11. Technical and psychological readiness of consumers to use VR/AR technologies. | 11. Low level of adaptation of the technology for users, not achieving target indicators for the development of sub-technologies. |
| 12. Reduced cost of hardware and software for VR/AR projects. | 12. High cost of AR/VR technologies and the required equipment. |
| 13. Financial preferences of the state for companies that develop digital technologies (grants, co-financing, soft loans). | 13. High cost of providing infrastructure for technology implementation. |
| 14. Developed business infrastructure, including investment companies, banks, insurance companies, stock exchanges, etc. | 14. Insufficiently developed system for ensuring the legal, economic, and financial security of participants. |

In the quantitative analysis of the factors, we asked experts to evaluate the factors of each group on a five-point scale. The results of the survey made it possible to assess the level and significance of the strengths and weaknesses of the organisation's digital innovation potential for effective project implementation, as well as the impact of opportunity and threat factors on the formation of the digital innovation potential. After each stage of the evaluation, tables of results were compiled, and the degree of consistency of expert opinions was determined on the basis of Kendall's coefficient of concordance. For a more accurate calculation, we used Pearson's chi-squared test.

The resulting value of the integral indicator of the digital innovation potential $I_P < 1$ indicates that the weaknesses of the digital innovation potential of the organisation exceed the strengths, indicating the need for measures to adapt it to the objectives of the project.

**4.2. Identification of priority areas of adaptation of the digital innovation potential based on the analysis of matrix sets**

Relying on the information obtained from the expert evaluation, matrix sets of "Strengths", "Weaknesses", "Opportunities", and "Threats" were created, the analysis of which made it possible to identify the most significant areas of adaptation of the organisation's innovation potential to the tasks of implementing AR/VR projects (Garcia et al., 2019; Lokuge et al., 2018) (Figure 4, Figure 5).




(a) (b)

**Figure 4.** Matrix set of (a) "Strengths" and (b) "Weaknesses"

***Matrix "Strengths"***

The SI quadrant included the strengths of the organisation, which, in the opinion of experts, can have a significant impact on the effectiveness of project implementation. These included "Willingness to change business processes" and "Financial capabilities of the organisation". This group also included such factors as "Equipment for VR/AR projects" and "Software required for VR/AR projects". However, in connection with an insufficient level of development of sub-technologies, which are basic for the implementation of a content of necessary quality, it is necessary to constantly monitor the latest trends in their development and to use the most interesting ideas in designs.

The SII category included factors that were scored low by the experts for their level in the organisation, but they were highly evaluated in terms of their impact on the possibility of successful implementation of the project. It is necessary to concentrate efforts on the intensive development of the factors in this group. This quadrant included "Ability to develop in-house solutions" and "Availability of employees capable of generating ideas" due to the lack of specialists in the labour market with the necessary competencies and the lack of experience with VR/AR among the company's existing employees. The same group included the factor "Availability of executives with understanding of VR/AR". According to the findings, the organisation's top managers have insufficiently formed competencies related to the use of digital technologies, resulting in reluctance to restructure process organisation models accumulated over the years. To increase the level of factors "Feedback from users" and "Streamlined product creation process", flexible development methodologies should be used, and business processes of creating new digital products, including product analytics and end-to-end integration of development and maintenance processes, should be improved.

Quadrant SIII included "Access to digital infrastructure" and "Access to databases". These factors were sufficiently developed in the organisation; thus, they only need to be maintained at the current level in the future. Due to the fact that "Gazpromneft" had a large number of divisions that could further use the developed products, the organisation could further scale pilot projects to other departments and use the economies of scale to improve the efficiency of its activities.

The SIV factors "Level of IT competencies of users" and "Level of organisational culture" of the company were significant for the project, but they did not have a critical impact on it. Strengthening these factors is important for improving the overall digital culture of the organisation.

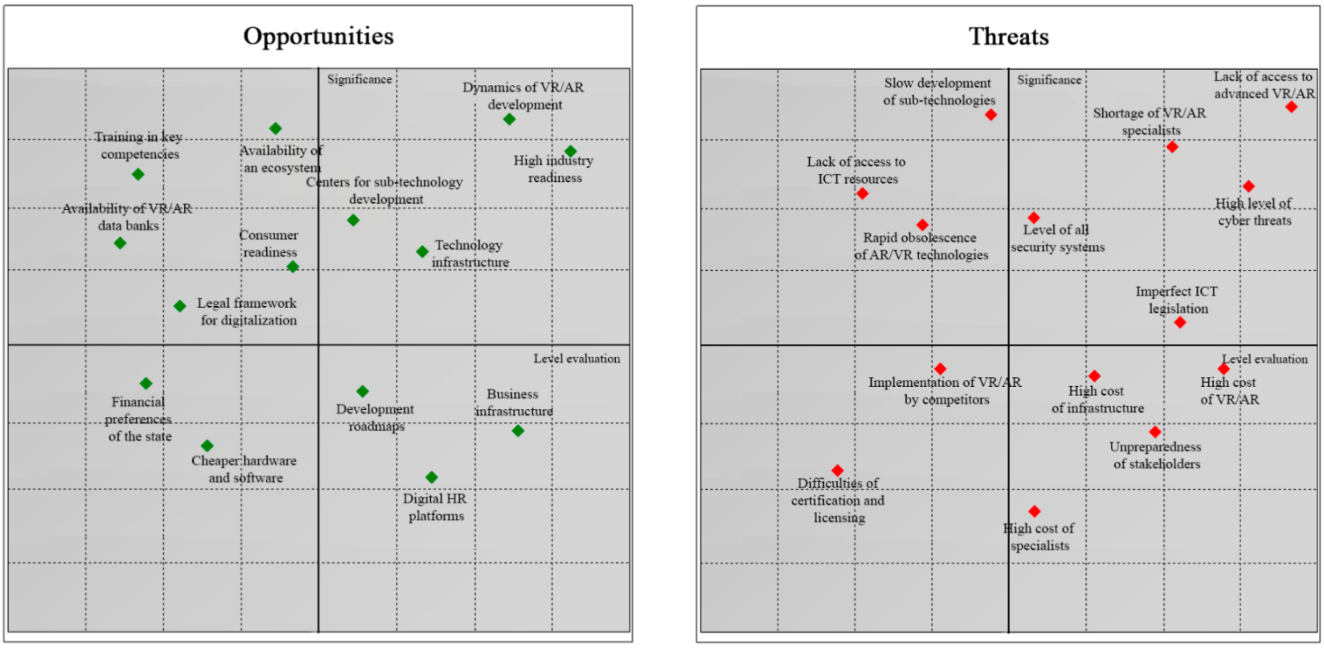
***Matrix "Weaknesses"***

The WI quadrant included internal risk factors with high impact and a significant probability of occurring during the implementation of the project. These included "'Digital projects are not connected to the strategy" and "Lack of clear mechanisms for calculating the effectiveness of implementation". Thus, several disparate projects were launched simultaneously, resulting in insufficient success. Fragmentary implementation of AR/VR technologies and the implementation of only pilot versions led to the weak effects of digitalisation. This group also included "Conservatism of leadership" and a lengthy "Process of alignment and approval of the transition to new business processes" with the use of AR/VR. Often, this was due to a lack of confidence in the effectiveness of using digital products. These factors need to be given close attention. To decide on actions regarding the factors in this group, it is necessary to analyse which activities for their minimisation can be performed with the minimum amount of time and resources. Depending on the results of the analysis, it is necessary to implement anti-risk measures to move the WI factors into the second group by reducing the level of risk.

The WII category included factors whose negative impact on AR/VR projects was recognised by experts as significant, but their occurrence was not as significant. This was a result of project teams that became inefficient, as participants did not always have enough competencies to implement digital projects, and the teams did not include specialists with deep knowledge of the specifics of production. Additionally, it is worth noting the likelihood of inconsistency of the finished product with functional and business requirements due to the lack of regular interaction with the customer, which can be avoided by using agile development methods. The level of information security in the organisation was quite acceptable.

Quadrant WIII represents the weaknesses of the organisation, the negative impact of which was not highly evaluated by the experts, who, however, noted a significant probability of their occurrence. The factors of this group were closely interrelated. Due to the fact that the possible positive effects of the introduction of AR/VR technologies were often not identified, potential users had a low level of interest and engagement, the consequence of which was reluctance of the workforce to retrain and widely use digital technologies. The highly likely occurrence of these factors necessitates careful attention to the possible consequences of the negative impact on the project. In relation to the elements of this group, it is necessary to develop anti-risk measures to reduce the likelihood of their occurrence and to move to the fourth group.

WIV and TIV are factors that were given lower scores by the experts for their impact on the project, and their probability of occurrence was also found to be low. They included the difficulty of integrating AR/VR with other information systems, the diverse equipment fleet, and the uniqueness of products for different departments, which led to difficulties in scaling the technologies.




(a) (b)

**Figure 5.** Matrix set of (a) "Opportunities" and (b) "Threats"

***Matrix "Opportunities"***

The OI quadrant included opportunities provided by the external environment of the organisation, which could have a significant impact on the project and were rated highly by experts. One of the most significant opportunities was the high dynamics of the technological development of VR/AR devices and the necessary software. As noted earlier, a fivefold increase in the virtual and augmented reality markets is predicted to occur by 2025 due to the intensive development of sub-technologies. The road-map for the development of "end-to-end" digital virtual and augmented reality technology includes a set of measures to accelerate their development, including the creation of leading sub-technology research centres (Linnik et al., 2019).

The high degree of readiness of the oil and gas industry to use VR/AR technologies is associated with the strategy development and restructuring of business processes. In connection with tightening competition in the market and the need to reduce costs, there is a high degree of readiness of the oil and gas industry to use advanced digital technologies, including VR/AR. In this regard, the availability of technological support for innovative solutions in the industry is receiving increased attention. Factors in the OI group should be included in the priority areas used to adapt the digital innovation potential of an organisation.

The OII category included factors of the external environment that were important for the project but whose level of development was currently insufficient. This was the legal framework at all levels of government for the support and maintenance of implementation of digital technologies, the capacity and availability of external data banks in the field of VR/AR technologies, and the presence of full-fledged ecosystems that ensure the effectiveness of commercialisation of innovations.

Further, there is no comprehensive state programme or system of structures for training and re-training personnel in the competencies necessary not only for implementing VR/AR projects but also for their further use in professional activities. Currently, the technical and psychological readiness of con-sumers to use VR/AR technologies is not at a high level and is noted only among certain groups of users.

Quadrant OIII included factors of opportunity, the level of which in the innovation climate is quite high. These include the presence of clearly defined prospects for the use of VR/AR technologies, the creation of development roadmaps, a developed business infrastructure, including investment companies, banks, insurance companies, stock exchanges, etc., and opportunities to use digital platforms to quickly find specialists with the necessary competencies. Since these external environmental factors were sufficiently developed, they need to be maintained at current levels, and the organisation can fully rely on them in forming its digital innovation potential.

Factors in the OIV group were the financial preferences of the state for companies developing digital technologies, as well as reducing the cost of equipment and software for VR/AR projects, which are important for the mass development of these technologies and their penetration into all sectors and areas of life. However, a company planning to implement a virtual and augmented reality project should have high financial potential; therefore, these factors are less significant. Notably, the two factors in this group have yet to show their full potential.

***Matrix "Threats"***

The TI quadrant includes threats that have a high level in the innovation climate of the organisation and are also of great importance to the innovation project. The most critical threat, according to the experts, was the lack of specialists in the market with the necessary competencies to implement VR/AR technologies. Apart from this, there is the impossibility of using the most advanced AR/VR devices in Russian industrial enterprises due to the import substitution policy and their high cost. Further, when implementing any digital projects, there is currently a high level of cyber threats, namely cyber-attacks, hacking of information systems and databases, the lack of national information security standards, and undeveloped regulatory and legal support for combating cybercrime. All of the above-mentioned factors make digital projects very vulnerable. In this regard, the group of the most significant threats included imperfect legislation in the development of the digital economy and the use of ICT, as well as an underdeveloped system of legal, economic, and financial security of participants.

Category TII included factors whose negative impact on the project was recognised by experts as significant, but the probability of their occurrence was recognised as moderate. In particular, this quadrant included the probability of slow development of sub-technologies as well as problems of access to certain types of IT resources necessary for implementation of digital technologies due to the imposition of sanctions. However, an analysis of trends in recent years, as well as the existence of a large number of measures to support them in regulatory documents, suggests a low probability of the occurrence of this threat. The rapid obsolescence of various technologies, including digital ones, is an inevitable pattern. Despite the low probability of occurrence, the elements of this group require special attention due to the significant negative consequences for the project.

Quadrant TIII included factors with a highly likely occurrence, but their negative impact on this project was assessed by the experts as low. The impact of interactions with key stakeholders on this project was insignificant, as it mainly affected internal business processes. This group of factors also included the high cost of AR/VR technologies and necessary equipment, the high cost of highly qualified personnel due to increased demand in the labour market, and the high cost of infrastructure for implementation of the technologies. Due to the high level of financial potential of the organisation, the factors of this quadrant could not currently have too negative an impact on the project, but the high probability of their occurrence in the future necessitates attention to their possible consequences at later stages of its implementation.

Regarding group TIV, the experts identified the factors whose level and impact on the project were not very significant. The dynamics of implementation of digital technologies by competitors and the increase in their competitiveness should be systematically monitored to make certain changes in strategic plans; however, in this particular project, their actions would not have a significant impact. There were also certain difficulties with the certification of educational VR/AR courses and licensing of VR/AR products. Thus, it is necessary to carefully prepare documentation for these procedures.

This study allowed for the identification of the following priority areas of adaptation of the digital innovation potential of “Gazpromneft”:

1. The technological readiness of the organisation where the implementation is carried out should be increased. The compliance of equipment and software for AR/VR solutions should be aligned with the requirements of real production conditions and the use of the latest sub-technologies for the implementation of specific technological solutions. The level of access to modern digital infrastructure, such as data centres, cloud solutions, and working on all types of devices, should be increased. Information security should be ensured.

2. Cross-functional teams with a high level of competencies in the field of VR/AR should be formed to include full-cycle specialists in the field of immersive technologies, employees capable of generating non-standard ideas, and experienced professionals with deep knowledge of the specifics of production.

3. The necessary profile competencies of managers supervising AR/VR implementation in the organisation should be enhanced, which allows understanding potential opportunities of using AR/VR technologies and correctly forming development tasks.

4. The objectives of digital projects should be coordinated with the innovation strategy of the organisation. The disparate, fragmented implementation of AR/VR technologies has led to a significant reduction in the effects of digitalisation. There is a need to increase the transparency of the mechanism for calculating the effectiveness of digital projects.

5. The organisation should be ready to change business processes in accordance with the objectives of digitalisation by simplifying procedures for alignment and approving the transition to new business processes using AR/VR, and increasing the interest and involvement of potential users.

## 5. Conclusion

In this paper, we propose a mechanism for adapting the innovation potential of an enterprise to the strategic goals and objectives of its innovative development, taking into consideration the factors of the innovation climate and the internal innovation environment of the organisation. We interpreted the concept of digital innovation potential based on the analysis of specific factors that are important for implementing digital projects, and which allows for the peculiarities of their implementation. The paper also presents the sequence of stages for identifying priority areas of adaptation based on matrix sets and the development of necessary measures for the formation of the target level of the innovation potential and outlines a methodology that allows identifying key factors and determining the degree of influence for each of them. Based on the developed methodology, the most significant areas of adaptation of the digital innovation potential of the oil and gas industry enterprise in implementing the project for the introduction of virtual and augmented reality technologies were identified.

It should be noted that the mechanism of adaptation of digital innovation potential should not be considered in isolation but in the system of flexible management of innovation activities, which includes a number of other tools based on the principles of flexibility and adaptability. The complex nature of these tools will ensure the implementation of a flexible approach in the management of digital innovation projects characterised by a high level of uncertainty. The conclusions and recommendations of this study can be used by enterprises in forming a system of flexible management of digital innovation projects in various areas.

## References

Al Qrain, A., Reddy, G., Jadhav, S., 2020. Virtual reality simulators in the oil & gas industry review of existing solutions and method for evaluation, in: Abu Dhabi International Petroleum Exhibition & Conference. Abu Dabi, UAE. https://doi.org/10.1007/s11831-020-09455-9

Aldea, A., 2018. Modelling and analyzing digital business ecosystems: An approach and evaluation, in: 2018 IEEE 20th Conference on Business Informatics (CBI). Vienna, Austria, pp. 156–163. https://doi.org/10.1109/CBI.2018.10064

Azieva, R.K., Tayamaskhanov, H.E., Zelimhkanova, N.Z., 2021. Assessing the readiness of oil and gas companies for digital transformation. Eur Proc Soc Behav Sci 117, 1852–1862. https://doi.org/10.15405/epsbs.2021.11.244

Babkin, A., Tashenova, L., Eliseev, E., 2021. Digital potential of a systemically important innovation-active industrial cluster: Concept, essence, assessment. Economics and Management 26(12), 1324–1334. https://doi.org/10.35854/1998-1627-2020-12-1324-1334

Baker, C., Fairclough, S., 2022. Adaptive virtual reality. Current Research in Neuroadaptive Technology 159–176. https://doi.org/10.1016/

B978-0-12-821413-8.00014-2
Chanias, S., Myers, M.D., Hess, T., 2019. Digital transformation strategy making in pre-digital organisations: The case of a financial services provider. J Strateg Inform Syst 28(1), 17–33. https://doi.org/10.1016/j.jsis.2018.11.003
Eremin, N., Sardanashvili, O., 2017. The innovative potential of digital technologies. Actual Probl Oil and Gas: Sci Net Edit 3(18), 1–9. https://doi.org/10.29222/ipng.2078-5712.2017-18.art13
Flaksman, A., Kokurin, D., Khodzhaev, D., Ekaterinovskaya, M., Orusova, O., Vlasov, A., 2020. Assessment of prospects and directions of digital transformation of oil and gas companies. IOP Conference Series Materials Science and Engineering, 976(1), 012036. https://doi.org/10.1088/1757-899X/976/1/012036
Garcia, C., Naranjo, J., Gallardo-Cardenas, F., Garcia, M., 2019. Virtual environment for training oil & gas industry workers. Augmented Reality, Virtual Reality, and Computer Graphics, 379–392. https://doi.org/10.1007/978-3-030-25999-032
Garcia, C., Naranjo, J., Gallardo-Cardenas, F., Garcia, M., 2019. An approach of virtual reality environment for technicians training in upstream sector. IFAC-Papers, 52(9), 285–291. https://doi.org/10.1016/j.ifacol.2019.08.222
Issa, A., Hatiboglu, B., Bildstein, A., Bauernhans, T., 2018. Industrie 4.0 roadmap: Framework for digital transformation based on the concepts of capability maturity and alignment. Procedia CIRP, 72, 973–978. https://doi.org/10.1016/j.procir.2018.03.151
Kotarba, M., 2017. Measuring digitalization – Key metrics. Found Manage 9(1), 123–138. https://doi.org/10.1515/fman-2017-0010
Kozlov, A., Teslya, A., 2019. Digital potential of industrial enterprises: essence, determination and calculation methods. Transbaikal State University Journal 25(6), 101-110. https://doi.org/10.21209/2227-9245-2019-25-6-101-110
Krishnan, B., Arumugam, S., Maddulety, K., 2020. Critical success factors for the digitalization of smart cities. Int J Technol Manage Sust Dev 19, 69–86. https://doi.org/10.1386/tmsd_00016_1
Linnik, Yu., Kiryukhin, M., 2019. Digital technologies in the oil and gas industry. Vestnik Universiteta 1(7), 37-40. https://doi.org/10.26425/1816-4277-2019-7-37-40
Lokuge, S., Sedera, D., Grover, V., 2018. Organisational readiness for digital innovation: Development and empirical calibration of a construct. Information & Management 56(3), 445–461. https://doi.org/10.1016/j.im.2018.09.001
Muñoz-La Rivera, F., Mora-Serrano, J., Valero, I., Oñate, E., 2020. Methodological-technical framework for construction 4.0. Arch Comput Method E 28(2), 689–711. https://doi.org/10.1007/s11831-020-09455-9
Panjaitan, R., Moonti, A., Adam, E., 2021. Technology readiness and digital competing capabilities: Digital value resonance. J Econ Bus 6(2), 205–226. https://doi.org/10.22515/SHIRKAH.V6I2.385
Park, H., Anderson, T.R., Seo, W., 2021. Regional innovation capability from a technology-oriented perspective: An analysis at industry level. Comput Ind 129, 103441. https://doi.org/10.1016/j.compind.2021.103441
Salko, M., 2021. Developing the innovative potential of digital transformation of enterprises of the fuel and energy complex. Tyumen State University Herald. Social, Economic and Law Research 7(2), 200–218. https://doi.org/10.21684/2411-7897-2021-7-2-200-218
Schumacher, A., Nemeth, T., Sihn, W., 2018. Roadmapping towards industrial digitalization based on an Industry 4.0 maturity model for manufacturing enterprises. Procedia CIRP, 79, 409–414. https://doi.org/10.1016/j.procir.2019.02.110
Shmeleva, A., Shirokova, S., Kislova, E., Rostova, O., 2020. Company efficiency improvement using agile methodologies for managing IT projects, in: International Scientific Conference on Digital Transformation on Manufacturing, Infrastructure and Service. Saint Petersburg, Russia, 25, 1–10. https://doi.org/10.1145/3446434.3446465
Shmeleva, A., Sokolitsyna N., Rostova, O., 2019. Management of investment process in alternative energy projects, in: International Science Conference SPbWOSCE-2018 "Business Technologies for Sustainable Urban Development", 110, 02032, 1–9. https://doi.org/10.1051/e3sconf /20191100
Shmeleva, A., Suloeva, S., 2021. Informacionnaya podderzhka upravleniya innovacionno-investicionnoj deyatel'nost'yu predpriyatiya neftegazovoj otrasli [Information support of innovation and investment activities of the oil and gas industry]. J Manage Stud 7(6), 57–67.
Sola, E., D'Angelo, V., Capo, F., 2021. Digital Transformation in the Energy Industry. Handbook of Research on IoT, Digital Transformation, and the Future of Global Marketing, pp. 97–111. https://doi.org/10.4018/978-1-7998-7192-7.ch006
Stoianova, O. V., Lezina, T. A., Ivanova, V.V., 2020. The framework for assessing company's digital transformation readiness. Vestnik SPbGU 36(2), 243–265. https://doi.org/10.21638/spbu05.2020.204
Zhu, F. (Xin X.), 2021. Digital project evaluation and development. Digitalization and Analytics for Smart Plant Performance 459–475. https://doi.org/10.1002/9781119634140.ch19

## Список источников

Al Qrain, A., Reddy, G., Jadhav, S., 2020. Virtual reality simulators in the oil & gas industry review of existing solutions and method for evaluation, in: Abu Dhabi International Petroleum Exhibition & Conference. Abu Dabi, UAE. https://doi.org/10.1007/s11831-020-09455-9
Aldea, A., 2018. Modelling and analyzing digital business ecosystems: An approach and evaluation, in: 2018 IEEE 20th Conference on Business Informatics (CBI). Vienna, Austria, pp. 156–163. https://doi.org/10.1109/CBI.2018.10064
Azieva, R.K., Tayamaskhanov, H.E., Zelimhkanova, N.Z., 2021. Assessing the readiness of oil and gas companies for digital transformation. Eur Proc Soc Behav Sci 117, 1852–1862. https://doi.org/10.15405/epsbs.2021.11.244
Babkin, A., Tashenova, L., Eliseev, E., 2021. Digital potential of a systemically important innovation-active industrial cluster: Concept, essence, assessment. Economics and Management 26(12), 1324–1334. https://doi.org/10.35854/1998-1627-2020-12-1324-1334
Baker, C., Fairclough, S., 2022. Adaptive virtual reality. Current Research in Neuroadaptive Technology 159–176. https://doi.org/10.1016/B978-0-12-821413-8.00014-2
Chanias, S., Myers, M.D., Hess, T., 2019. Digital transformation strategy making in pre-digital organisations: The case of a financial services provider. J Strateg Inform Syst 28(1), 17–33. https://doi.org/10.1016/j.jsis.2018.11.003
Eremin, N., Sardanashvili, O., 2017. The innovative potential of digital technologies. Actual Probl Oil and Gas: Sci Net Edit 3(18), 1–9. https://doi.org/10.29222/ipng.2078-5712.2017-18.art13
Flaksman, A., Kokurin, D., Khodzhaev, D., Ekaterinovskaya, M., Orusova, O., Vlasov, A., 2020. Assessment of prospects and

directions of digital transformation of oil and gas companies. IOP Conference Series Materials Science and Engineering, 976(1), 012036. https://doi.org/10.1088/1757-899X/976/1/012036

Garcia, C., Naranjo, J., Gallardo-Cardenas, F., Garcia, M., 2019. Virtual environment for training oil & gas industry workers. Augmented Reality, Virtual Reality, and Computer Graphics, 379–392. https://doi.org/10.1007/978-3-030-25999-032

Garcia, C., Naranjo, J., Gallardo-Cardenas, F., Garcia, M., 2019. An approach of virtual reality environment for technicians training in upstream sector. IFAC-Papers, 52(9), 285–291. https://doi.org/10.1016/j.ifacol.2019.08.222

Issa, A., Hatiboglu, B., Bildstein, A., Bauernhans, T., 2018. Industrie 4.0 roadmap: Framework for digital transformation based on the concepts of capability maturity and alignment. Procedia CIRP, 72, 973–978. https://doi.org/10.1016/j.procir.2018.03.151

Kotarba, M., 2017. Measuring digitalization – Key metrics. Found Manage 9(1), 123–138. https://doi.org/10.1515/fman-2017-0010

Kozlov, A., Teslya, A., 2019. Digital potential of industrial enterprises: essence, determination and calculation methods. Transbaikal State University Journal 25(6), 101-110. https://doi.org/10.21209/2227-9245-2019-25-6-101-110

Krishnan, B., Arumugam, S., Maddulety, K., 2020. Critical success factors for the digitalization of smart cities. Int J Technol Manage Sust Dev 19, 69–86. https://doi.org/10.1386/tmsd_00016_1

Linnik, Yu., Kiryukhin, M., 2019. Digital technologies in the oil and gas industry. Vestnik Universiteta 1(7), 37-40. https://doi.org/10.26425/1816-4277-2019-7-37-40

Lokuge, S., Sedera, D., Grover, V., 2018. Organisational readiness for digital innovation: Development and empirical calibration of a construct. Information & Management 56(3), 445–461. https://doi.org/10.1016/j.im.2018.09.001

Muñoz-La Rivera, F., Mora-Serrano, J., Valero, I., Oñate, E., 2020. Methodological-technical framework for construction 4.0. Arch Comput Method E 28(2), 689–711. https://doi.org/10.1007/s11831-020-09455-9

Panjaitan, R., Moonti, A., Adam, E., 2021. Technology readiness and digital competing capabilities: Digital value resonance. J Econ Bus 6(2), 205–226. https://doi.org/10.22515/SHIRKAH.V6I2.385

Park, H., Anderson, T.R., Seo, W., 2021. Regional innovation capability from a technology-oriented perspective: An analysis at industry level. Comput Ind 129, 103441. https://doi.org/10.1016/j.compind.2021.103441

Salko, M., 2021. Developing the innovative potential of digital transformation of enterprises of the fuel and energy complex. Tyumen State University Herald. Social, Economic and Law Research 7(2), 200–218. https://doi.org/10.21684/2411-7897-2021-7-2-200-218

Schumacher, A., Nemeth, T., Sihn, W., 2018. Roadmapping towards industrial digitalization based on an Industry 4.0 maturity model for manufacturing enterprises. Procedia CIRP, 79, 409–414. https://doi.org/10.1016/j.procir.2019.02.110

Shmeleva, A., Shirokova, S., Kislova, E., Rostova, O., 2020. Company efficiency improvement using agile methodologies for managing IT projects, in: International Scientific Conference on Digital Transformation on Manufacturing, Infrastructure and Service. Saint Petersburg, Russia, 25, 1–10. https://doi.org/10.1145/3446434.3446465

Shmeleva, A., Sokolitsyna N., Rostova, O., 2019. Management of investment process in alternative energy projects, in: International Science Conference SPbWOSCE-2018 “Business Technologies for Sustainable Urban Development”, 110, 02032, 1–9. https://doi.org/10.1051/e3sconf /20191100

Shmeleva, A., Suloeva, S., 2021. Informacionnaya podderzhka upravleniya innovacionno-investicionnoj deyatel’nost’yu predpriyatiya neftegazovoj otrasli [Information support of innovation and investment activities of the oil and gas industry]. J Manage Stud 7(6), 57–67.

Sola, E., D’Angelo, V., Capo, F., 2021. Digital Transformation in the Energy Industry. Handbook of Research on IoT, Digital Transformation, and the Future of Global Marketing, pp. 97–111. https://doi.org/10.4018/978-1-7998-7192-7.ch006

Stoianova, O. V., Lezina, T. A., Ivanova, V.V., 2020. The framework for assessing company’s digital transformation readiness. Vestnik SPbGU 36(2), 243–265. https://doi.org/10.21638/spbu05.2020.204

Zhu, F. (Xin X.), 2021. Digital project evaluation and development. Digitalization and Analytics for Smart Plant Performance 459–475. https://doi.org/10.1002/9781119634140.ch19

The article was submitted 24.03.2022, approved after reviewing 27.04.2022, accepted for publication 5.05.2022.

Статья поступила в редакцию 24.03.2022, одобрена после рецензирования 27.04.2022, принята к публикации 5.05.2022.

About authors:

1. Anastasiia Shmeleva, external PhD student, Peter the Great St. Petersburg Polytechnic University, Saint Petersburg, Russia. https://orcid.org/0000-0001-5555-8114, anastasiya_rostova@mail.ru

2. Svetlana Suloeva, Doctor of Economics, Professor, Peter the Great St. Petersburg Polytechnic University, Saint Petersburg, Russia. https://orcid.org/0000-0001-6873-3006, suloeva_sb@spbstu.ru

Информация об авторах:

1. Анастасия Шмелева, соискатель, Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия. https://orcid.org/0000-0001-5555-8114, anastasiya_rostova@mail.ru

2. Светлана Сулоева, д.э.н., профессор, Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия. https://orcid.org/0000-0001-6873-3006, suloeva_sb@spbstu.ru