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EDITORIAL ARTICLE

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SUSTAINABLE DEVELOPMENT AND ENGINEERING ECONOMICS

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Abstract

Environmental issues are currently a topic of interest throughout the world. Regarding further development of the world's socio-economic systems, we must not forget that development is accompanied by additional negative impact that may endanger the lives of future generations. In response to this danger, the Sustainable Development Goals developed by the UN are a kind of call to action to improve the well-being of and to protect our planet. The purpose of the Sustainable Development and Engineering Economics (SDEE) journal is to collect and systematise the opinions of authors and their advanced research in the field of sustainable development of countries, regions and organisations, as well as any related innovative technologies and engineering solutions. The journal consists of four sections, each of which contributes to the Sustainable Development Goals. The SDEE will allow the international scientific community to contribute to the solutions to global problems, even those in distant locations.

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УСТОЙЧИВОЕ РАЗВИТИЕ И ИНЖЕНЕРНАЯ ЭКОНОМИКА

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Аннотация

В настоящее время мировое сообщество широко обсуждает экологические проблемы. Говоря о дальнейшем развитии мировых социально-экономических систем, мы не должны забывать, что развитие также сопровождается дополнительными негативными последствиями, которые могут поставить под угрозу жизнь будущих поколений. В этой связи Цели устойчивого развития, провозглашенные ООН, являются своего рода призывом к действиям по улучшению благосостояния и защите нашей планеты. Журнал «Устойчивое развитие и инженерная экономика» (SDEE) ставит своей целью сбор и систематизацию мнений авторов, их передовых исследований в области устойчивого развития стран, регионов и организаций, а также инновационных технологий и инженерных решений. Журнал состоит из 4 разделов, каждый из которых вносит свой вклад в концепцию Целей устойчивого развития. SDEE позволит научному сообществу не быть вдалеке от глобальных проблем, а внести свой вклад в их решение.

Ключевые слова: устойчивое развитие, инженерная экономика, ЦУР.
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About the SDEE

Sustainable Development and Engineering Economics (SDEE) is an international scientific journal that was founded by Peter the Great St. Petersburg Polytechnic University in 2021. It was conceived as a platform for international knowledge exchange about the interrelations between sustainability, engineering economy, engineering infrastructure, management of innovations, management of enterprises and regional development. We expect that papers published in SDEE will fill in the research gaps that occur at the intersections of these topics. Therefore, the results of the papers published in this journal will contribute to the Sustainable Development Goals crafted by the United Nations (UN). The biggest contributions are expected to be made to the following goals: "7: ensure access to affordable, reliable, sustainable and modern energy for all»; «8: decent work and economic growth"; "9: industry, innovation and infrastructure"; "11: sustainable cities and communities"; and "12: Ensure sustainable consumption and production patterns". The first issue of the SDEE presents contributions in the four main sections of the journal:

- Economics of engineering and innovation decisions as a part of sustainable development;
- Enterprises and the sustainable development of regions;
- Sustainable development of regional infrastructure; and
- Management of knowledge and innovation for sustainable development.

These sections were explored through analysis of scientific literature in the field, the expertise of the editorial board members and leading international journals in this field, including: "Engineering Economics", "Engineering Economist", "Sustainable Production and Consumption", "Journal of Cleaner Production", "International Journal of Technology Management", and "Technological Forecasting and Social Change". Next, we will discuss the content and scope of each section, provide examples of related research written by leading scholars in the field and by members of the editorial board and present contributions to the fields of the papers published in current issue.

Economics of engineering and innovation decisions as a part of sustainable development

This section presents papers that examine the effects of new technology implementation at local and regional levels. In papers that address this topic, we expect researchers to discuss the economic and financial aspects of new technological developments, both for companies and for the regions in which they operate. Such engineering solutions may be derived from any field of engineering, including information-technology engineering. Some of the latest related research in this field discusses, for example, relations between the Circular Economy and Industry 4.0 (Ćwiklicki and Wojnarowska, 2020), micro-level quantification of determinants of eco-innovation adoption (in this example, regarding cotton production in Pakistan) (Zulfiqar et al., 2021) and the economic feasibility of investment in residential photovoltaic systems in Korea considering the effects of that nation's subsidy policies (Jang et al., 2021).

In addition, scholars can also present papers that discuss how new solutions can reshape both business operations and public services and how these solutions can result in either detrimental or beneficial effects for the complex development of regional territories. See, for example, research dedicated to the emerging challenges and prospects of digital transformation and to the integration of stakeholders in urban land administration in Ethiopia (Gebrihet and Pillay, 2021), to an effectiveness assessment of investments in robotic biological plant protection (Skhvediani and Kudryavtseva,

2020) or to a review of the results of an interconnection analysis of innovativeness, operations priorities and corporate performance (Kilic et al., 2015).

Papers devoted to the development of frameworks and models that support decision-making processes in this field are also welcomed. For instance, Galli (2020) discusses how to effectively use economic decision-making tools in various project environments and throughout project life cycle.

This issue presents the paper "Development of a system-synergetic approach to cost management for a high-tech industrial enterprise", which was written by Ekaterina Burova, Sergey Grishunin and Svetlana Suloeva. They present a system-synergetic approach to cost management and a mechanism for its implementation in high-tech industrial enterprises. Their approach allows high-tech industrial enterprises to calculate risks as well as measure correlation between them and the profitability of innovative products. Enterprises can also use this approach to more flexibly manage their innovation product portfolios and to ensure the sustainability of their operations.

Enterprises and the sustainable development of regions

The focus of this topic is the general impact of enterprises on the sustainable development of different regions around the globe. Therefore, we shift focus from precise technologies to enterprises and industries. See, for example, how Small and medium-sized enterprises (SMEs) maintain sustainable practices in Sweden (Tsvetkova et al., 2020).

We invite scholars to submit papers that present the systematic results of research on sustainable business models and on sustainable industry development. Emerging trends in sustainable manufacturing in Industry 4.0 can be found in the work of Machado et al. (2020).

This research might also contain assessments of the direct and indirect effects of certain companies and of industrial development in general. Direct effects should be measured through evaluation of the concrete damages or benefits that are generated by these companies. We also welcome papers that assess the different types of spillover that can be generated by enterprises, economic clusters, industries and global value chains. This spillover may occur in a variety of areas — including environmental, social and governmental (ESG) – and within corporations, knowledge or technology. Recent studies have explored cross-country evidence to determine if technological innovations reduce CO2 emissions (Chen and Lee, 2020) and firm-level evidence of technological spillover effects through industrial and regional linkages (Hu et al., 2020).

In addition, we expect authors to discuss the impact of regional policies and special economic regimes on enterprise development. Industry-specific research is also welcome; we look forward to reviewing studies related to, for example, energy economics, strategy and policy. Recent examples include research that contributes to the topic of clean energy development in the United States amidst augmented socioeconomic aspects and country-specific policies (Alola and Akadiri, 2021) and an analysis of technology diffusion policies for renewable energy (Bianco et al., 2021).

The current issue presents two papers in this section.

The first paper is entitled "Validation of factors for assessing the digital potential of the regional construction complex as a basis for sustainable development" and was written by Ekaterina Tereshko, Irina Rudskaya, Mario Claudio Dejaco and Sofia Pastori. This research presents an extensive review of the existing indexes that can be used to assess the digitalisation of a regional construction complex, and it presents an adjusted sample of factors for assessing the digital potential of that complex. These factors can also be used to manage and assess sustainable development in the region.

The second paper, "Sustainable business models and small- and medium-sized enterprises A literature review", was written by Susanne Durst, Basel Hammoda, Hoa Nguyen and Matin Moieny Asl. This paper presents the results of a review of 85 refereed articles and provides highlights of the most prominent topics and possible future research avenues, the main findings and the methods and theories that have most commonly been applied in the field. This review is useful for practitioners who are considering the adoption and promotion of sustainable business models in organisations.

Sustainable development of regional infrastructure

This topic is dedicated to research that discusses the role of different types of infrastructure – physical, innovation, digital, smart, financial, transportation and entrepreneurial – in the sustainable development of regions and enterprises. We expect authors to identify and assess the effects of infrastructure development on different aspects of economic, innovative, social and environmental regional development. Accordingly, we are open to submissions on topics such as waste management, smart logistics systems and smart cities, among others. Good ideas about sustainable construction investment can be found in the review by Kaklauskas et al. (2021). Another example of recent literature related to infrastructure is that by (Berawi et al., 2018), which discusses a concrete case of life cycle cost and public-private partnership in the development of the Walini City Technology Park. In addition, an analysis of special economic zones and industrial park development for the promotion of industrial clusters is presented by Sosnovskikh (2017).

The current issue presents two papers in this field.

The first is a paper entitled "Balance scoreboard for sustainable development in the Russian Arctic zone", which was written by Svetlana Gutman. The author provides a comparative analysis of the modified Balanced Scorecard models that can be used to manage the development of socio-economic systems. This study also develops strategic maps for the Arkhangelsk region and for the Cluster of Shipbuilding and Production of Marine Equipment of the Arkhangelsk region association.

The second paper, entitled "Analysis of territory energy security in the context of sustainable development (case of Georgia)", was written by Tengiz Magradze. The author provides a toolkit which allows for comparison of energy security level between different territories and for identification of influencing factors. Application of the proposed toolkit to the case of Georgia revealed that the energy security level of this country had decreased since 2008. The author concludes that the decrease has been negatively affected to sustainable development in the region.

Management of knowledge and innovation for sustainable development

Innovations help companies to avoid stagnation and foster economic growth. Usually, the focus of innovation is centred on the economic aspect of sustainability, but it can also be expanded to encompass both social and environmental aspects.

Innovation management is the structuring of a specific innovation process with a beginning (input), a middle (processing) and an end (output and generation of results). Innovation management involves establishing the means and methods to generate value and putting ideas into practice. This will usually lead to an organisation's productive, operational and managerial processes being updated, rationalised or, sometimes, disrupted.

This can improve outcomes for an organisation by making the services or products provided to customers more attractive and effective. Research in the area of this topic should contribute to innovation management at individual, enterprise or regional levels. Authors might also consider the relationship between universities and regional innovation development (Rodionov and Velichenkova, 2020).

We welcome papers that discuss both closed and open innovation models and their contribution to the achievement of sustainable development, as well as cluster analysis (Anguelov and Kaynakchieva, 2017). For example, the impact of a firm's commitment to learning and open-mindedness on its organisational innovation among Russian manufacturing firms (Dukeov et al., 2020) would be an interesting topic for further examination.

One article in the current issue, entitled "Clustering of territorial objects in the management of their sustainable development", focuses on innovation. It was written by Dmitrii Rodionov, Dmitrii Alferyev, Yulia Klimova and Kaisar Alpysbayev, who examine the tools of clustering territories. The authors emphasise that the cluster analysis can be beneficial to the sustainable development. Moreover, using the perceptron model, the authors have developed a universal algorithm for cluster analysis of territories. They claim that through this algorithm we can implement innovations in practice that will be one of the factors of socio-economic progress.

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SECTION 1.

ECONOMICS OF ENGINEERING AND INNOVATION DECISIONS AS A PART OF SUSTAINABLE DEVELOPMENT

РАЗДЕЛ 1.

ЭКОНОМИКА ИНЖЕНЕРНЫХ И ИННОВАЦИОННЫХ РЕШЕНИЙ КАК ЧАСТЬ УСТОЙЧИВОГО РАЗВИТИЯ

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DEVELOPMENT OF A SYSTEM-SYNERGETIC APPROACH TO COST MANAGEMENT FOR A HIGH-TECH INDUSTRIAL ENTERPRISE

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Abstract

This study develops a system-synergetic approach to cost management and a mechanism for its implementation in high-tech industrial enterprises. The relevance of the study is determined by the dominant role of the high-tech industrial sector in developing national economies and the increasing impact of costs on the performance of enterprises. The aim of the study is to eliminate methodological, functional, and systemic problems in cost management for high-tech industrial enterprises. In the study, the features of the function of high-tech industrial enterprises were determined, the approach to cost management for enterprises was proposed, and the cost management mechanism, including the description of the stages, was developed. The works of foreign and Russian researchers in cost management, risk management, and enterprise economics are the theoretical and methodological basis of the study. The authors propose a system-synergetic approach based on the systematisation of existing approaches to cost management. The following tools were used to develop a cost management mechanism: (1) a cost model of the company's profitability in terms of cash flow, (2) statistical data analysis, (3) a bow tie diagram to identify risk factors by key cost drivers, (4) simulation modelling using the Monte Carlo method, (5) a graph of accumulated profitability in terms of cash flow, and (6) a graph of strategic well-being by periods to trace the decline in profitability as innovative products lose their innovative nature. In comparison with existing approaches, the approach proposed in the study considers the specifics of a high-tech industrial enterprise and considers it as a complex open system operating under conditions of uncertainty and under the influence of external and internal risks on the cost management system. The cost management mechanism, based on the system-synergetic approach, calculates the profitability of an enterprise by cash flow, determines the target price of innovative products, analyses the impact of risks on key cost factors and their parameters, considers the correlations between risks, and calculates the expected level of profitability of innovative products under risk conditions. These advantages make the cost management process dynamic, responding to new threats and changes in the external and internal environment of the enterprise.

Keywords: system-synergetic approach, cost management, high-tech industrial enterprise, key cost drivers, risk factors.
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РАЗРАБОТКА СИСТЕМНО-СИНЕРГЕТИЧЕСКОГО ПОДХОДА К УПРАВЛЕНИЮ ЗАТРАТАМИ ДЛЯ ВЫСОКОТЕХНОЛОГИЧНОГО ПРОМЫШЛЕННОГО ПРЕДПРИЯТИЯ

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Аннотация

Целью данного исследования является разработка системно-синергетического подхода к управлению затратами для высокотехнологичного промышленного предприятия и механизма его реализации. Актуальность исследования объясняется доминирующей ролью высокотехнологичного промышленного сектора в развитии национальных экономик и увеличивающимся влиянием затрат на результаты деятельности предприятий. Исследование направлено на устранение существующих в литературе методологических, функциональных и системных проблем по управлению затратами для высокотехнологичных промышленных предприятий. Результаты включают определение особенностей функционирования высокотехнологичных промышленных предприятий, обоснование подхода к управлению затратами предприятий данного типа, разработку механизма управления затратами на основе предложенного подхода, а также описание и спецификации, входящих в него блоков. Теоретической и методологической базой исследования послужили труды зарубежных и российских исследователей в области управления затратами, управления рисками и экономики предприятия. На основе систематизации существующих подходов к управлению затратами в работе предложен системно-синергетический подход. При разработке механизма управления затратами применен следующий инструментарий: (1) стоимостная модель рентабельности компании по денежному потоку; (2) методы статистического анализа данных; (3) диаграмма «галстук-бабочка» для идентификации факторов риска по ключевым факторам затрат; (4) имитационное моделирование с помощью метода Монте-Карло; (5) график накопленной рентабельности по денежному потоку и (6) график стратегического благополучия по периодам, позволяющий проследить спад рентабельности по мере «старения» инновационной продукции. По сравнению с существующими подходами предложенный в исследовании подход позволяет учитывать особенности функционирования высокотехнологичного промышленного предприятия и рассматривать его как сложную открытую систему, функционирующую в условиях неопределенности и учитывающий влияние внешних и внутренних рисков на систему управления затратами. Функционал механизма управления затратами на основе системно-синергетического подхода включает расчет рентабельности предприятия по денежному потоку, определение целевой цены инновационной продукции, анализ влияния рисков на ключевые факторы затрат и их параметры, учет корреляций между рисками и расчет ожидаемого уровня рентабельности инновационной продукции в условиях риска. Эти преимущества делают процесс управления затратами динамичным и итеративным, реагирующим на изменения внешних и внутренних условий функционирования и появление новых угроз.

Ключевые слова: системно-синергетический подход; управление затратами: высокотехнологичное промышленное предприятие; ключевые факторы затрат; факторы риска.

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1. Introduction

The high-tech industrial complex is the backbone of the industrial sector in the era of the “fourth industrial revolution” (FIR). The performance indicators of high-tech enterprises determine the role of the state in the international competitiveness rating. One factor affecting the efficiency of production and the output of industrial enterprises are costs. Despite the existing methods and tools, there is a need for the development and improvement of approaches to cost management, allowing us to consider the specifics of high-tech industrial enterprises as complex open systems in continuous interaction with the external environment (Su and Wu, 2019; Khesal et al., 2019).

A literature review showed that high-tech industrial enterprises most often use use some combination of design and systemic approaches to cost management. Traditional methods consider the enterprise as an integral system that interacts with the external environment (Johannknecht et al., 2017; Wegmann, 2019). The main disadvantages of traditional approaches are: (1) the focus on the internal processes and relationships at the enterprise and (2) the lack of consideration of external influences (risks) and their impact on the cost management system. Traditional approaches to cost management do not allow the system to respond effectively to changes in the external environment, while the influence of external factors on the enterprises is constantly growing. McKinsey Global Institute directors note that the collision of four destructive forces – urbanisation, constantly accelerating scientific and technological progress, demographic shifts (ageing and slower reproduction rates), and globalisation – are leading to fundamental changes in the way enterprises operate (Bogoviz, 2019). In comparison with the industrial revolution of the 18th–19th centuries, these changes occur ten times faster, and their impact is 3000 times stronger (Zaycev, 2014). Such a sharp increase in the changes of the external environment and their unpredictability and irreversibility confirm the irrelevance of traditional approaches to managing the costs of a high-tech industrial enterprise.

The aim of the study is to develop a system-synergetic approach to cost management of a high-tech industrial enterprise (HTIE) and a mechanism for its implementation. This approach considers an enterprise as: (1) an integral manageable system (systemic approach); (2) an open complex system (synergetic approach). Within the framework of the proposed approach to cost management, there is a self-organisation mechanism (Sheth & Sinfield, 2019; Snow et al., 2017), which makes it possible to continuously adjust the cost management process to changing external and internal conditions through interaction with the risk management system. This will ensure sustainable, effective cost management. To substantiate the chosen approach, this study highlights the features of the organisation, management, and functioning of a high-tech enterprise in modern conditions.

2. Literature review

Today, industrial enterprises traditionally use the following approaches to cost management: functional, process, project and systemic (Johannknechtetal, 2017; Wegmann, 2019). Each of the above approaches has its own characteristics and limitations. The functional approach to cost management focuses on the achievement of functional targets, rather than on the targets of the cost management system, which does not allow for its application at the strategic level of cost management[1].

The project approach allows to get maximum results with limited resources, but not every activity of the enterprise can be a project. The process approach to cost management allows one to op-

[1] OECD. Main Science and Technology Indicators https://doi.org/10.1787/0bd49050-en

timise costs by identifying ineffective processes, but it does not consider the external relationships of the enterprise. Management of enterprise costs using a systematic approach allows you to coordinate the goals of the cost management system (CMS) with the strategic goals of the enterprise. The systematic approach considers not only the internal relationships of the enterprise, but also its interaction with the external environment. However, cost management within the framework of this approach is reduced only to " neutralizing" all random influences from the external and internal environment that do not correspond to the target settings of the system, which does not allow the system to develop under the influence of these factors. Thus, using traditional approaches cannot effectively manage the costs of a modern high-tech enterprise.

There is a wide variety of methods described by experts in cost management (Banker et al., 2018; Labunska et al., 2017). Target costing and kaizen-costing are now widely used among cost management methods in high-tech industrial enterprises (Manucharyan & Adamova, 2019; Olszewska, 2019). These methods allow enterprises to consider such features of HTIE as customer-oriented production and customised marketing (Dăneci-Pătrău & Coca, 2017), and also give the enterprise a valuable competitive advantage: lower production costs compared to competitors. To understand the origin of costs and their analysis for HTIE, it is necessary to use the concept of cost-generating factors (Andriushchenko et al., 2019). This concept implies an in-depth analysis of costs and their cost-generating factors, which improves the quality and efficiency of cost management, but does not allow tracking changes in cost factors due to the interaction of the enterprise with the external environment. One solution to this problem is the complex use of these methods combined with the concept of risk controlling, described in Grishunin et al. (2018), which will make it possible to implement the self-organisation mechanism inherent in the system-synergetic approach to cost management.

The review of scientific literature (Paté-Cornell et al., 2018; Samimi, 2020; Grishunin et al., 2020) has shown that modern risk management tools consider the peculiarities of the HTIE's functioning, but there is not enough research in integrating risk management and cost management. The scientific research on risk management at HTIE is highly specific, as it focuses on identifying and assessing risks in developing enterprise investment programmes.

3. Materials and methods

The theoretical and methodological basis of the study was the work of foreign and Russian researchers in cost management, risk management, and enterprise economics. Based on the systematisation of existing approaches to cost management, a system-synergetic approach based on the interaction of the CMS and the risk management system is proposed. Developing the cost management mechanism based on the proposed approach applies the main principles of target costing and kaizen-costing systems and the concept of cost-generating factors and risk controlling, providing an inextricable link between key cost factors, risk factors, and target profitability of innovative products. The integrated use of these methods will allow us to consider risk factors in cost management, which will increase the adaptability, flexibility, and sustainability of the CMS at HTIE.

The following tools were applied: (1) the cost model of the company's return on investment in terms of cash flow; (2) statistical data analysis; (3) a bow tie diagram to identify risk factors by key cost drivers; (4) simulation modelling using the Monte Carlo method; (5) a graph of accumulated profitability in terms of cash flow; and (6) a graph of strategic well-being by periods, which allows us to trace the decline in profitability as innovative products "age".

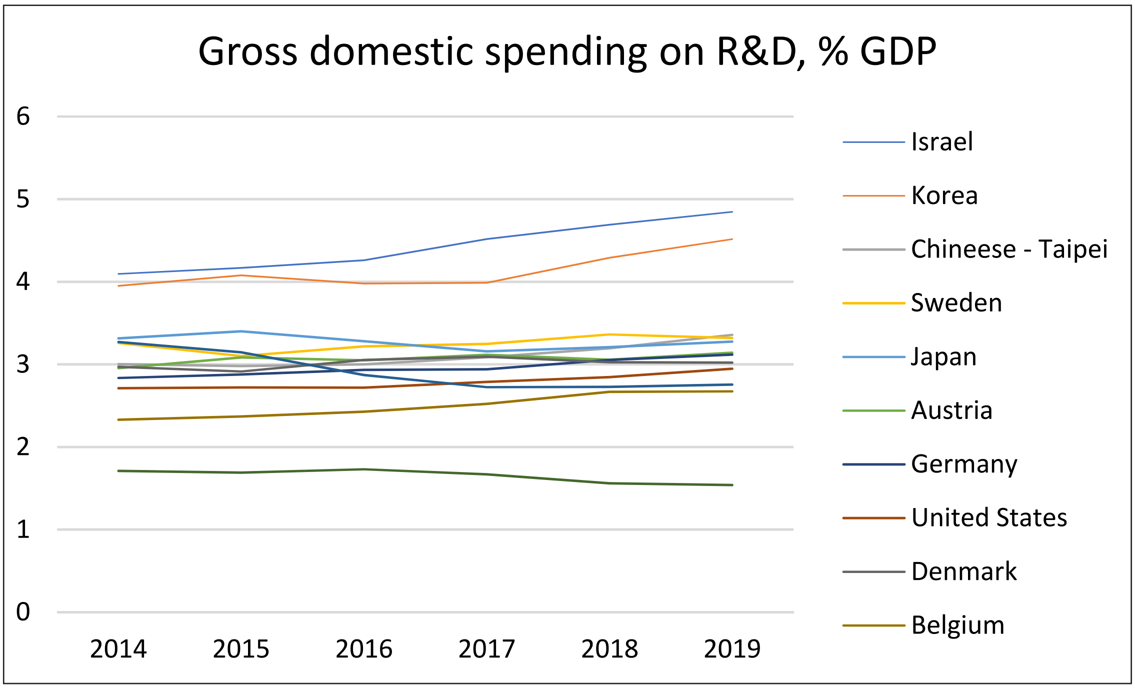

Figure 1. Gross domestic spending on R&D
(Compiled by the authors based on the data from the Organisation for Economic Community and Development[2])

4. Results

4.1 Determination of the features of high-tech industrial enterprises functioning and substantiation of an approach to cost management

According to the literature, the high-tech sector (HTS) determines the scientific, technical, and economic potential of the country and is an indicator of national economic status (Litvinenko & Ustuzhanina, 2016; Zherdev, 2017; Roberts & Wolf, 2018). Globally, there is a clear trend towards an increase in the share of R&D expenditures: in 2014, the total level of expenditures on R&D in the world amounted to 1.6% of global GDP; in 2019, it reached 2.1% of global GDP with a significant increase in the volume of gross output. The volume of gross domestic expenditure on R&D in advanced economies in the period from 2014 to 2019 is shown in Fig. 1.

The basis of HTS is HTIE, whose activities, under the modern concept of developing a high-tech industrial complex, are characterised by high uncertainty and risks. The review of the literature related to the HTIE's activities made it possible to highlight their main features (Fig. 2) (Su and Wu, 2019; Khesal et al., 2019; Korotkova, 2014). The main factor in developing modern HTIE is innovation (see Fig. 2), which explains its priority among the business projections of an industrial enterprise. Innovative activity is a source of structural changes for the entire industrial enterprise and affects all management processes (Vasilenko, 2019).

The highlighted features of the HTIE and the constantly increasing level of uncertainty in the external environment make it possible to study these enterprises from the standpoint of the theory of self-organisation of complex systems based on a synergetic approach:

[2] https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm

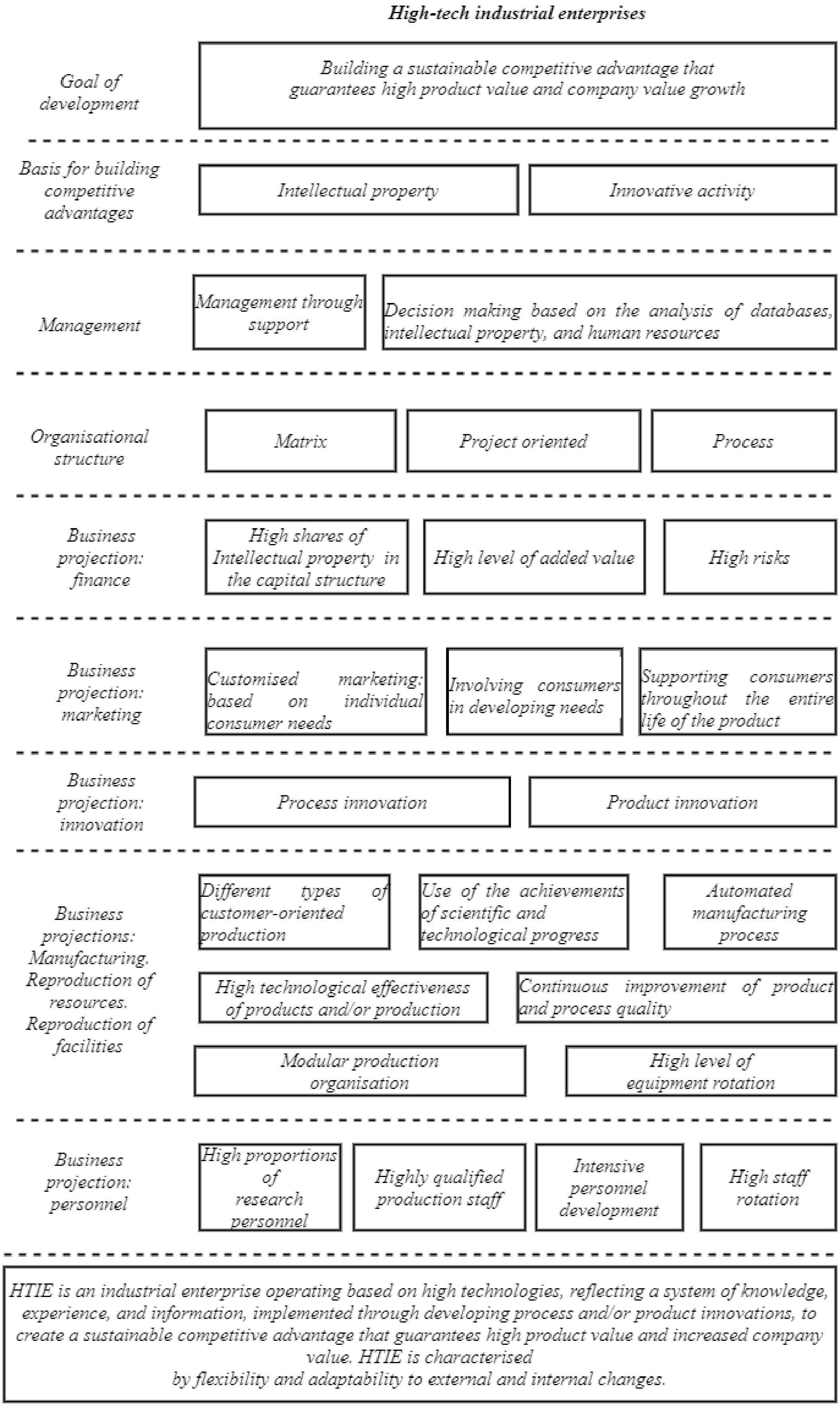

Figure 2. Features of HTIE

(1) HTIE is an open complex system characterised by intense and continuous interaction with the external environment, which leads to various uncertainties under the influence of external and internal environmental factors; (2) HTIE is a non-linear system in which quantitative changes in exposure lead to changes in qualitative characteristics; (3) HTIE is a self-organising system capable of adaptation to the external environment. Constant changes and high uncertainty in the functioning conditions of the HTIE can be one manifestation of chaos. In accordance with the synergetic approach, a new organised structure can emerge from chaos under the influence of internal mechanisms (self-organisation mechanism). Uncertainty in terms of the synergetic theory is a constructive mechanism for developing the system. Thus, it is advisable to use a synergistic approach when managing HTIE. A synergetic approach to control is based on the mechanism of resonant effects on a non-linear system, during which the system develops. The impact itself may be insignificant. The main task of management in a synergetic approach is to manage such impacts to ensure the development of the system in a favourable direction (Sheth & Sinfield, 2020; Snow et al., 2017).

In this work, we propose using a system-synergetic approach to cost management, which combines the principles of systemic and synergistic approaches. This approach, on the one hand, makes the process of cost management more effective since it considers the CMS as an integral controllable system. However, it considers the continuous interaction of the enterprise with the external environment in cost management and "focuses on the rejection of isolated cost management"[3]. We propose to implement a system-synergetic approach to cost management at the HTIE through the mechanism of interconnection of the CMS and risk management.

4.2 Development of the cost management mechanism based on a system-synergetic approach

Helped by the proposed mechanism, it is possible to analyse the influence of uncertainties and risks of the external and internal environment on the key cost factors and the assessment of this influence on the target profitability (TP) of the innovative product (IP). In the mechanism, using simulation modelling, the deviations of the expected TP level from the planned value are calculated for a specific period. If, at the established level of confidence, the calculated deviations exceed the established permissible values (risk appetite), measures are taken to reduce the cost using cost engineering methods and optimisation of business processes, or a decision is made that the product will not be put into production (Ibusuki & Kaminski, 2007). The diagram of the mechanism is shown in Fig. 3.

The first step in the mechanism is determining the TP indicator. Leaders can choose from a wide variety of possible metrics to measure ROI or ROI by Coverage[4]. However, their disadvantage is static; indicators can measure profitability only in one analysis period, and they do not consider the time factor and the volume and cost of capital required for IP production.

Therefore, we propose using monetary return on investment (CFROI) as an indicator of profitability, as designed by HOLT ValueAssociates[5]

[3] Yurjeva, L, Dolzhenkova, E, Kazakova, M, 2015. Management accounting of costs at industrial enterprises in an innovative economy. M. Knorus, p. 191

[4] Veber U., Shefer U., 2014. Introduction to Controlling. Per. s nem/Pod red i s predisl. prof, d.e.n. S.G. Fal'ko. M. «Ob»edineniekontrolllerov», p. 416

[5] Fabozzi, F., Grant, J., 2000. Value-Based Metrics: Foundations and Practice, Wiley, p. 294

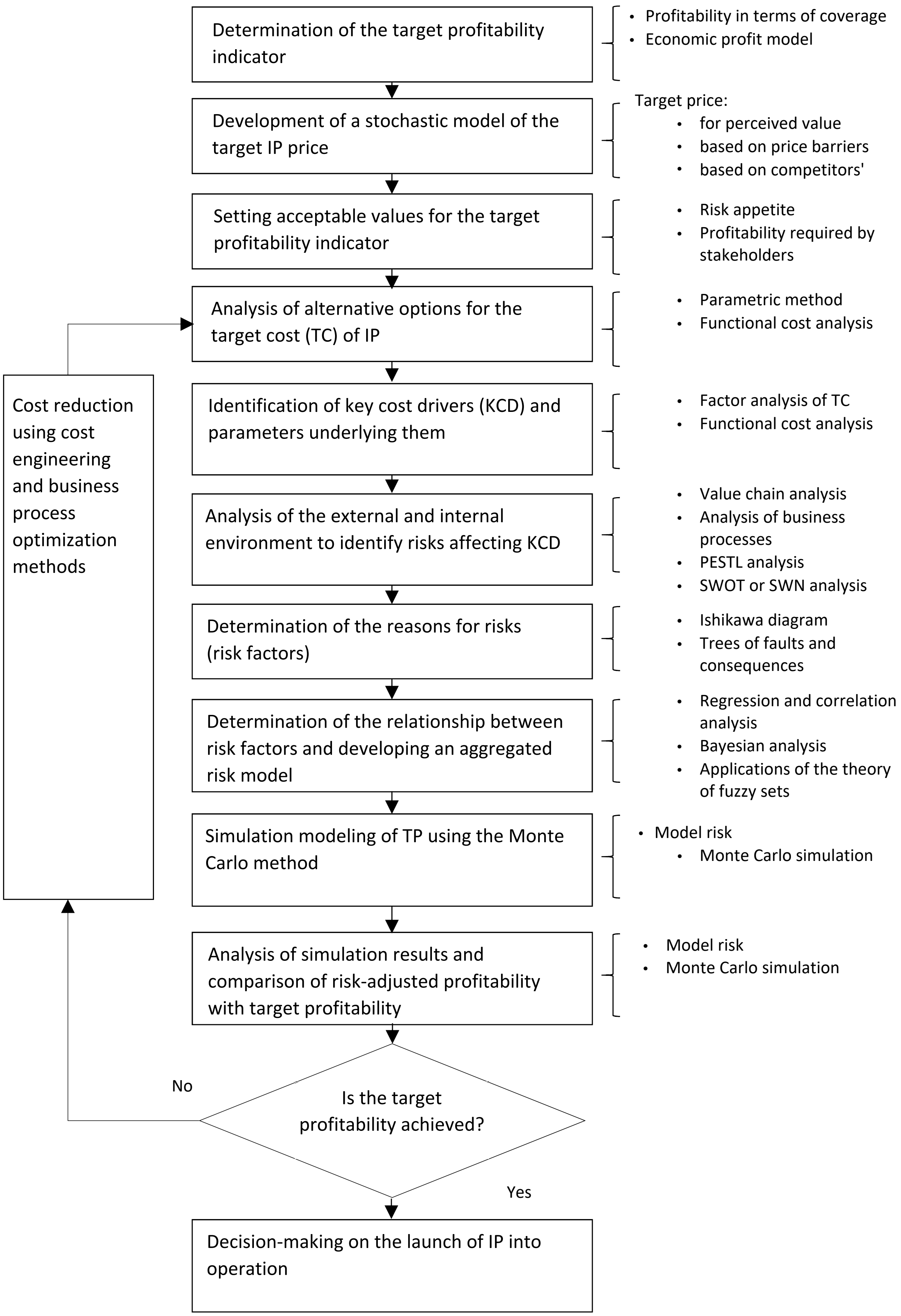

Figure 3. Block diagrams of the cost management mechanism based on the system-synergetic approach

$$CFROI = \frac{\sum_{t=0}^{T}\left(\frac{\left(CMC_t - ED_t\right)}{\left(1+WACC\right)^t}\right)}{\sum_{t=0}^{T}\frac{I_t}{\left(1+WACC\right)^t}} \tag{1}$$

$$ED_t = \frac{WACC}{\left(1+WACC\right)^t - 1} * \left(TA_t - NDA_t\right) \tag{2}$$

CMC_t is the coverage of cash costs (marginal profit) for period t; I_t is investments made in period t; ED_t is the economic depreciation for period t; TA_t is the average value of the company's assets used for period t; and NDA_t is the average asset value not subject to depreciation over period t.

The advantage of this indicator is the ability to consider changes in the marginal profit of the IP during its life cycle. Such changes can be due to the actions of competitors, improvements in the production process, the accumulation of experience in production and implementing continuous improvements of the IP, etc.

At the second stage of the mechanism's operation, the target price is determined depending on the period under consideration. To determine the target price, various methods of marketing analysis are used, such as studying the perceived value of the IP and its components, the prices of competitors and substitute products, possible price barriers, and others.[6]

Here, the marketing department must provide stochastic models (probability distributions) of the IP price for each period analysed. In the simplest case, the PERT distribution can be used, the main parameters of which are the minimum, maximum, and most probable price values during the period:

$$P\left(X / a,b.c\right) = \frac{\left(x-a\right)^{\alpha-1}\left(c-x\right)^{\beta-1}}{B\left(\alpha,\beta\right)\left(c-a\right)^{\alpha+\beta-1}}$$
$$\alpha = \frac{4b+c-5a}{c-a} \tag{3}$$
$$\beta = \frac{5c-a-4b}{c-a}$$

B is beta probability distribution, a, b, c – minimum (a), most probable (b), and maximum expected price value in the period under consideration. P (X / a,b,c) is the probability that the price will take one value in the interval from a to c.

At the third stage of the mechanism operation, the TP value (for example, the target value of CFROI) and the maximum allowable deviation from the TP (risk appetite, rCFROI) are determined, as well as the minimum deviation from the TP, which does not imply active actions on lower costs (tCFROI tolerance level).

At the fourth stage of the mechanism operation, the controlling service calculates the TC based on the interaction with engineering and R&D services. We suggest considering several options for TC, depending on the alternative methods of IP manufacturing. The deviations are set by decision-makers based on the results of implementing past projects for developing IP. Initially, the IP can be determined using the feasibility study of the project based on the parametric method. However, if the CFROI for the project without considering the risk goes beyond the permissible deviation from

[6] Nagle, T., 2017. The Strategy and Tactics of Pricing: A guide to growing more profitably. Routledge, 2017, p. 252

the TP, then it is necessary to use other methods to determine the TC, such as functional cost analysis or cost calculation based on functions (Ievtushenko & Hodge, 2012; Suloeva & Gulceva, 2017).

Attention should be paid not only to the methods of calculating the TC, but also to the interaction between engineering services, procurement and logistics services and controlling to avoid hidden costs. If these methods fail to achieve the TP of CFROI, then the R&D project should be abandoned. While calculating the TC, the key cost factors (KCF) and the parameters underlying them are identified. The main tool for this is also a functional cost analysis, which allows determining the KCF both in terms of functions and in terms of resources (Soekardan, 2016). Here, the Pareto principle should be used: the key factors will be 20% of all KCFs, which form 80% of all costs in the TC.

In the fifth stage of the mechanism, the analysis of the external and internal environment is carried out to identify the risks affecting the KCF and to determine the reasons for implementing these risks (risk factors). Here, risks are understood as uncertainties that affect the achievement of the target values of KCF. The source of information for this analysis can also be a functional cost analysis, within which business processes and a value chain are analysed. This makes it possible to trace the process of formation of the KCF from product functions to the source of KCF (including those outside the boundaries of the enterprise) and identify weaknesses and bottlenecks. To identify risks in the external environment, the following analysis methods can be used: (1) benchmarking of KCF and the business processes with competitors that form them; (2) analysis of strengths, weaknesses, opportunities, and threats (SWOT) or its simplified version of SWN (analysis of strengths, neutrals, and weaknesses); (3) analysis of various aspects of the external environment (PEST (STEP) analysis and its varieties).

At the sixth stage of the mechanism's operation, the sources of risks (S_i) are determined, the prerequisites for events, causing deviations from the target values for each KCF. The reasons and causes of risks are also determined. To do this, we propose using a bow tie diagram, which is a combination of a fault tree (FTA) and an effect tree (ETA) (Ferdousetal, 2011). The analysis of the chain of influencing events is carried out until (1) an external source is found that the company either cannot control or has limited control over; or (2) the ultimate source of risk is found; or (3) a source of

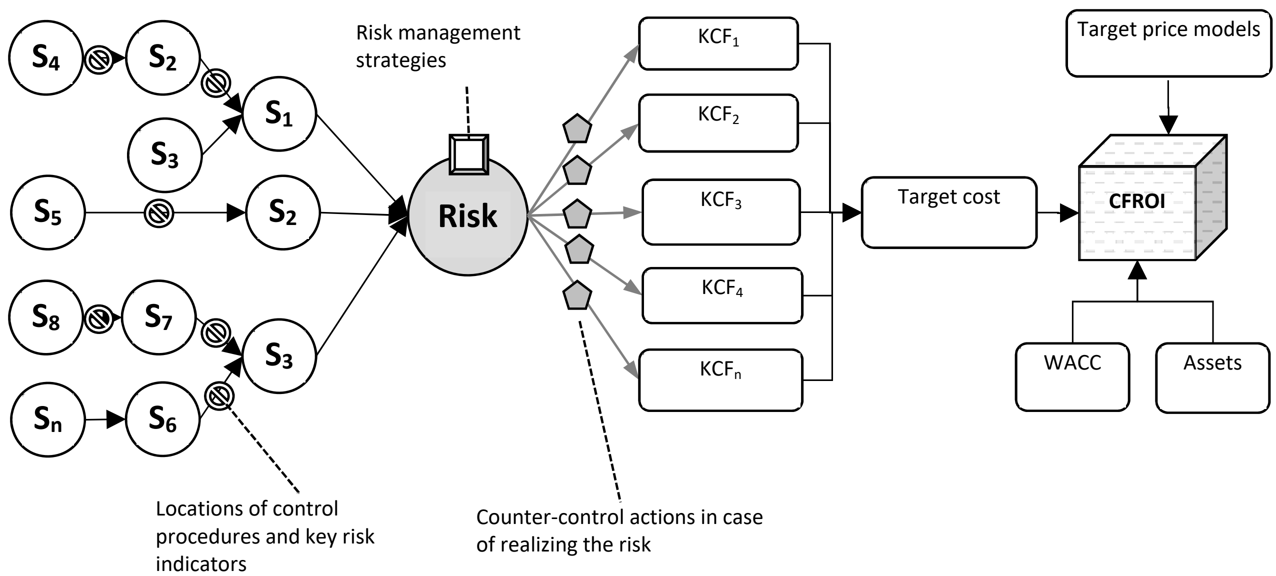

Figure 4. A bow tie diagram to analyse the causes and consequences of the risks

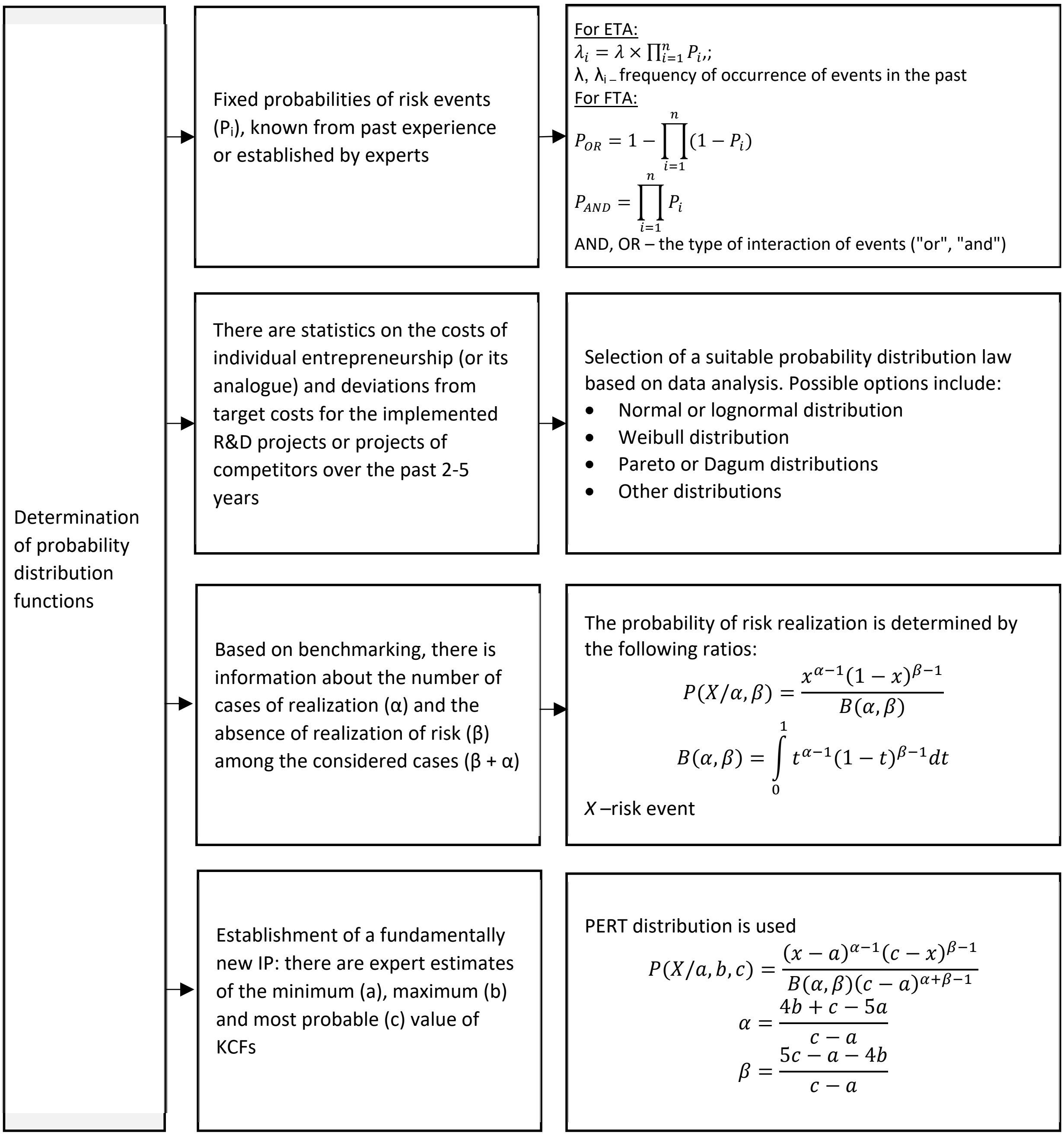

Figure 5. Approaches to assessing the probability distribution functions of risk events affecting KCF

risk is found that determines 80% or more causes of risk development; hence, further analysis is not advisable. An example diagram is shown in Fig. 4.

Analysis using a bow tie diagram allows us to determine the links between the risk and its sources and to build a model of their relationship. For the mechanism, we propose using a probabilistic approach (Ferdous et al., 2011), where for each node (S_i) (1) the probability distribution function of the event occurrence and the correlation coefficients between events are determined either according to the results of the past projects or by experts; (2) the probability of risk occurrence is determined either by building a Bayesian network connecting events, or by adding the probabilities considering correlations. However, for projects with high uncertainty, more sophisticated models can be used, such as (1) applications of fuzzy set theory; (2) applications of evidence-based theory; (3) artificial intelligence methods and neural networks; (4) probabilistic models of epidemic outbreaks and others (Ferdous et al., 2011). Once models for individual risks are built, they are (1) extended to key cost drivers and (2) associated with the TP formula considered at the first stage of the mechanism. The target price model must be included in the TP formula.

When using the probabilistic approach, we have developed the following options for approaches when choosing the probability distribution functions for risk events (Fig. 5).

In the seventh stage of the mechanism, the profitability indicator is modelled using the Monte Carlo method (Grishunin et al., 2018). The purpose of the modelling is to obtain the confidence interval of the TP, considering the exposure of the IP to risks. Its calculation methodology is comparable to the value-at-risk approach used in financial management (Grishunin et al., 2018). For modelling, it is recommended to use a specialised package of MS Excel applications (such as @Risk or Model Risk) or (for complex projects) to develop a program code (for example, in Phyton). Within this stage, these series of successive steps are carried out: (1) assessment of the correlation between risks and the calculation of correlation coefficients; (2) aggregation of stochastic models for all risks; (3) simulation modelling; (4) visual and quantitative analysis of results and comparison with risk appetite; and (5) deciding on the implementation of the IP project, developing risk management strategies, and the associated internal control system.

For a visual analysis of the TP considering risks, we recommend using tools such as the graphs of the accumulated CFROI (S-curve) and the graph of strategic well-being (U-curve) by period, which allows one to trace the decline in profitability as the IP ages (Fig. 6 and 7). The S-curve allows you to trace the accumulated monetary return on investment, considering the risks by period, to predict possible deviations from the TP even before the launch of the IP, and to determine the effectiveness of the planned risk management measures. The graph of strategic well-being allows enterprises to trace the change in monetary profitability over the life cycle of the product, locate critical points (simple payback, full payback, accumulation of productive capital, ageing and death) and

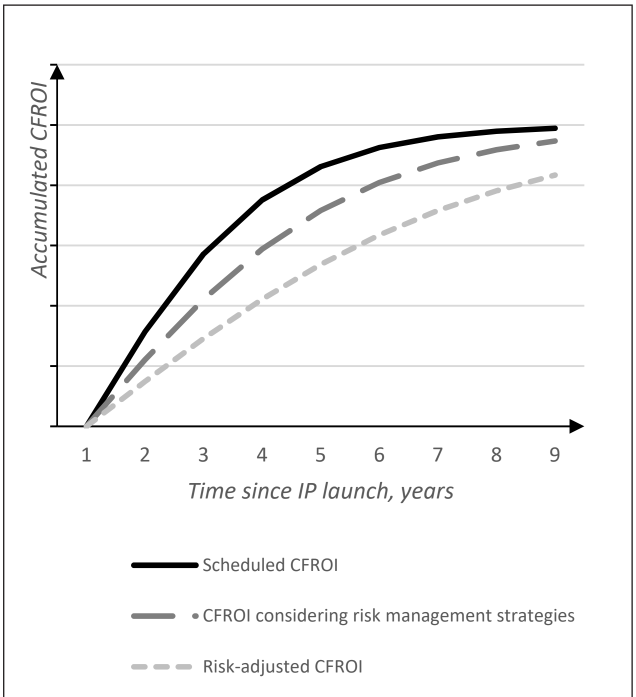

Figure 6. S-Curve of CFROI

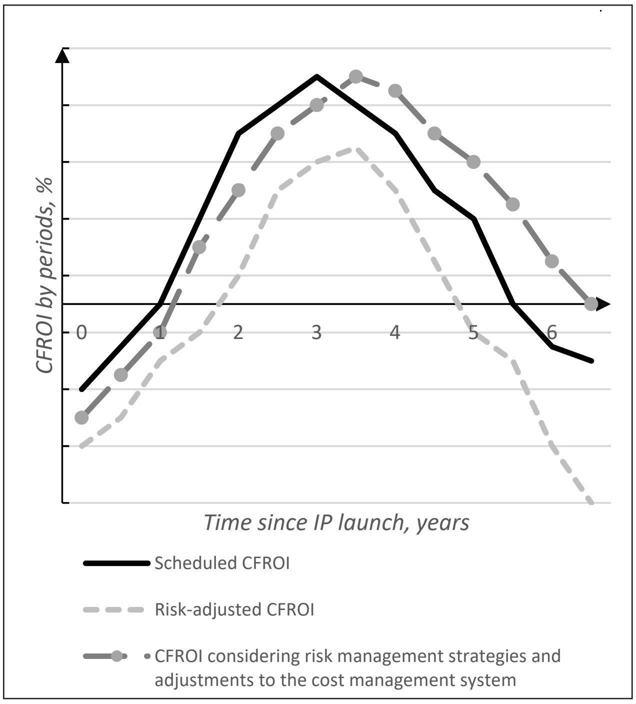

Figure 7. Graph of TP by periods of IP launch

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their “movement” considering the risks, and predict a possible “early old age” of the IP due to exposure to risks. For the convenience of analysis, this graph can be plotted by the elements of formula (1). This graph also allows enterprises to determine which CMS (standard-costing, kaizen-costing, lean manufacturing methods) should be used at what point in the life cycle (including passing critical points) to counter the decline in CFROI as the IP ages.

An important visual analysis tool is a histogram of distributing predicted values of TP, considering risks at a point or for a period (Fig. 8). It allows one to assess (1) the expected deviations of the TP from the strategic plan with a level of confidence (γ); (2) the most likely value of the TP, considering the risks; (3) the probability of a decrease in TP below the values of the level of tolerance and risk appetite (rCFROI and tCFROI); or (4) the likelihood of reaching the target value.

If the lower limit of the γ-confidence interval of TP is higher than the level of risk tolerance, then additional efforts to reduce the identified risks when developing an IP should not be undertaken. If the TP risk tolerance is excluded, it may mean that too few risks were considered in developing the projects. It is necessary, then, to consider accepting more uncertainties to obtain a higher TP (for example, increasing the price, proposing more complex technological solutions, using new materials, or adding additional options for the consumer).

If the lower limit of the s-confidence interval of TP is lower than tCFROI, but higher than rCFROI, then the project must involve active strategic risk management actions. Here, for each risk, (1) risk management strategies should be developed, aimed at reducing (managing), accepting, transferring, or refusing to accept risks; (2) detailed action plans based on these developed strategies; and (3) a system of monitoring key risk indicators (KRIs), which allows monitoring the implementation of risks for decision making. For developing detailed plans, a bow tie diagram determines the location and type of control procedure. Their task is to prevent the implementation of the threat factor (“barrier control procedure”), or to timely identify the threat factor and take counter-control measures (“revealing control procedure”). Second, the diagram defines action plans for counter-control

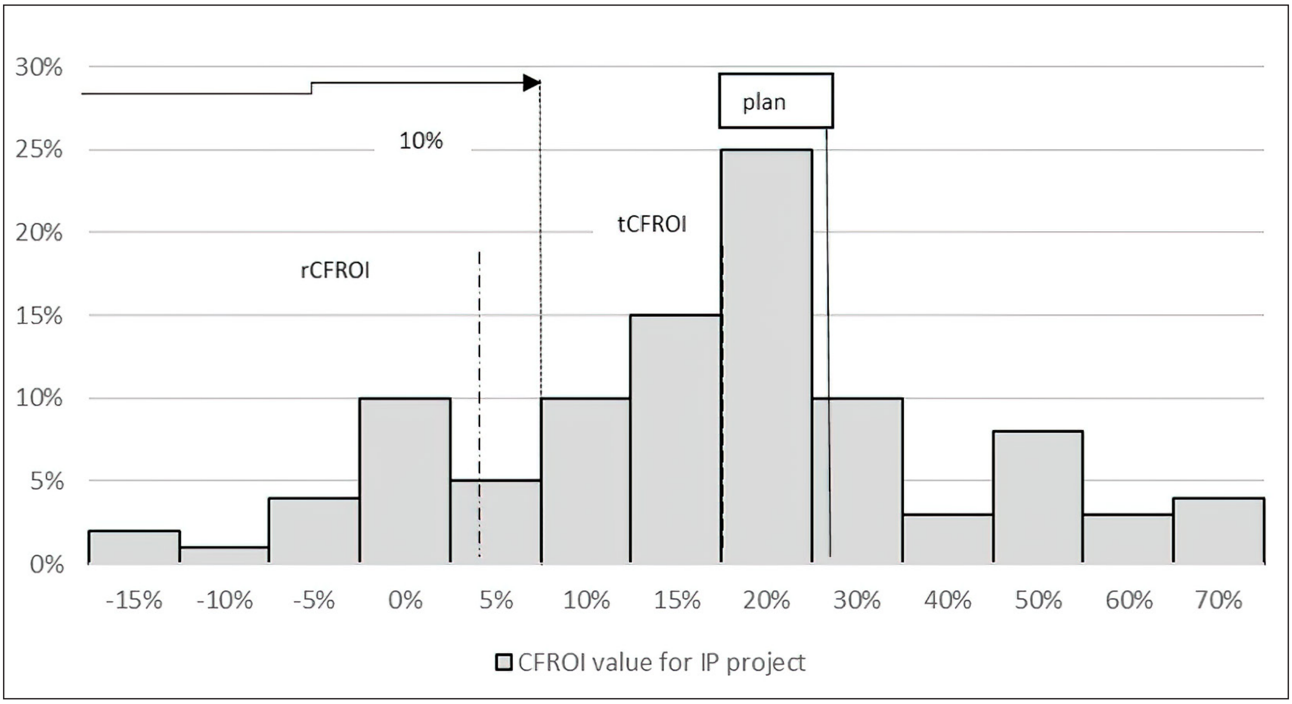

Figure 8. Histogram of the distribution of predicted TP values

if realising risks occur, allowing us to reduce the negative consequences. In addition, the diagram locates the KRI.

If the lower limit of the γ-confidence interval TP is lower than the value of risk appetite (rC-FROI), then this means that the IP development project is ineffective in terms of risk exposure and should either be terminated or sent for revision. The first step will be to develop the risk management actions described earlier. The likelihood of ineffectiveness of the actions and control procedures that make up the risk management plan should be assessed. These probabilities can be described by the Bernoulli or PERT laws of distribution. Second, actions are taken to reduce costs through functional cost analysis, cost reengineering, or alternative options to develop an IP are proposed. Then, the simulation is repeated (seventh stage of the mechanism), and the analysis of the results obtained is carried out. If the lower limit of the confidence interval is still below the value of the risk appetite, then it is necessary to repeat the steps for revision with tougher assumptions or to cancel the project, thus ensuring the principle of self-regulation of the system.

It is necessary to note that to maintain an acceptable level of TP throughout the entire life cycle of an IP, the mechanism for assessing the TP should be periodically repeated at the most important control points. After completing each stage of IP development, all steps to assess cost risks and the description of measures taken to counter them are to be submitted to the internal audit service to assess the effectiveness of the actions taken. The goal of the internal audit will be to develop recommendations for improving the risk assessment process.

5. Discussion

The developed system-synergetic approach to cost management of HTIE has significant advantages over the traditional approaches analysed in the second section of the study. The system-synergetic approach proposed by the authors (1) considers the specific of the HTIE functioning, (2) considers this enterprise as a complex open system operating under conditions of uncertainty and risks, (3) considers the influence of external and internal risks on the CMS and, (4) corresponds with the principles of adaptability, flexibility, sustainability, and consistency, which are necessary for effective cost management of HTIE. The developed mechanism underlying the system-synergetic approach evaluates the continuous interaction of an enterprise with a turbulent external environment and considers this interaction in the CMS.

To date, the problem of risks in cost management has not been sufficiently studied. Existing approaches to integrating the risk management system with the CMS are too specific since they focus on identifying and assessing risks when developing investment programmes for enterprises. Yin and other researchers (Yin et al., 2013) propose using the scenario method to account for risks in cost management. This approach to managing the costs of an HTIE is not effective and lacks flexibility, since it is limited by the number of scenarios (realistic, pessimistic, and optimistic), which will not allow for timely monitoring and consideration of all the risks arising from the interaction of the enterprise with the external environment. Feili, Anđelić and other researchers (Feili et al, 2012; Anđelić et al, 2020), propose an approach to managing the costs of investment projects using the synthesis of cost engineering and risk management. This approach is aimed at improving the risk management system, not the CMS, since it allows you to analyse and consider the risks arising at all stages of the life cycle of investment projects and decide on risk management depending on their cost. The mechanism proposed in the study is based on modern concepts of target costing, kaizen-costing, the concept of cost-generating factors, and risk controlling, which provide an inextricable link between KCF, risk factors, and TP of innovative products. The integrated use of these methods will consider risk factors in cost management, which will increase the adaptability, flexibility, and sustainability of the CMS in a HTIE.

Using a system-synergetic approach is limited by the need to ensure the following conditions: (1) a high level of digitalisation of the enterprise, (2) a high level of qualifications of personnel involved in the cost management process, and (3) a high level of development of the risk management system at the enterprise.

The authors see the prospects for further research in the following areas: (1) the development of individual cost management mechanisms, such as a mechanism for determining the KCF and their parameters, a mechanism for choosing an optimal cost management model based on risk; and (2) the adaptation of a system-synergetic approach to cost management for certain business fields of the VCCI (finance, marketing, personnel, etc.).

6. Conclusion

The article develops a system-synergetic approach to managing the costs of HTIE, considering the distinctive features and the conditions for their operation. The authors present a cost management mechanism based on the proposed approach. The system-synergetic approach has the following advantages: (1) it considers the specifics of modern HTIEs as complex self-organising systems operating in conditions of uncertainty and the impact of risks on the CMS, and also makes it possible to continuously adjust the cost management process in accordance with changing external and internal conditions; (2) the developed mechanism offers a holistic approach to identifying and assessing risks at the level of KCF using high-precision tools and methods for quantifying risks, calculating the aggregate effect of the project realisation of risks, and assessing the impact of this effect on indicators of investment attractiveness and project efficiency. These advantages make the cost management process dynamic, able to respond to new threats and changes in the external and internal environment of the enterprise.

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SECTION 2.
ENTERPRISES AND THE SUSTAINABLE DEVELOPMENT OF REGIONS

РАЗДЕЛ 2.
ПРЕДПРИЯТИЯ И УСТОЙЧИВОЕ РАЗВИТИЕ РЕГИОНОВ

Research article
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VALIDATION OF FACTORS FOR ASSESSING THE DIGITAL POTENTIAL OF THE REGIONAL CONSTRUCTION COMPLEX AS A BASIS FOR SUSTAINABLE DEVELOPMENT

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Abstract

It seems promising and relevant to consider digital processes of industries and complexes in the context of the digital transformation of a region, which encourages the region's sustainable development. Due to the digitalisation of the construction complex of a region we can evaluate the digital infrastructure development at the design and production stage (i.e. from the design documentation to the commissioning of facilities). The basis for the digitalisation of the construction complex is BIM technologies, which should be transferred from the micro level to the meso level (the level of a municipality or region) and later to the macro level (the level of the entire country). The study aimed to analyse and estimate groups of quantitative factors that characterise the digital potential of the construction complex. The research methods included quantitative and qualitative analysis. A comparative analysis of factors (i.e. indexes and rankings) was performed, and the groups of factors were ranked to determine whether regions are ready to digitalise the construction complex. This was done in accordance with expert assessments based on the results of a survey. The study compared the previously identified quantitative and qualitative factors with each other in order to eliminate duplication of the components of the qualitative factors, such as indices and ratings. Consequently, a necessary and sufficient sample of the factors was formed. This sample can be further used to correctly rank the degree to which Russian regions are prepared to digitalise the construction complex. To rank the factors to measure their importance and significance, the survey was conducted by groups: 1) socio-economic conditions for industry digitalisation; 2) development of science and innovation in the regions; 3) development of the construction complex in the regions; and 4) development of digital technologies in the regions. Based on the survey, the selected factors were ranked, particularly by groups. The results of this study can be used to refine the ranking of the regions' degree of readiness for the digitalisation of the construction complex as well as to determine the effectiveness of the ranking.

Keywords: digital economy, digital potential, sustainable development, regional development, construction complex, BIM technologies.

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ВАЛИДАЦИЯ ФАКТОРОВ ОЦЕНКИ ЦИФРОВОГО ПОТЕНЦИАЛА РЕГИОНАЛЬНОГО СТРОИТЕЛЬНОГО КОМПЛЕКСА, КАК ОСНОВЫ УСТОЙЧИВОГО РАЗВИТИЯ

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Аннотация

Рассмотрение цифровых процессов отраслей и комплексов через призму цифровой трансформации региона является перспективным и актуальным, что в дальнейшем способствует устойчивому развитию региона. Цифровизация строительного комплекса региона позволяет дать оценку цифрового инфраструктурного развития на проектно-производственном этапе, т.е. от проектной документации до ввода объектов в эксплуатацию. Основой цифровизации строительного комплекса являются BIM-технологии, которые должны транслироваться с микроуровня на мезоуровень – уровень муниципалитета/региона, а в дальнейшем и на макроуровень – уровень всей страны. Целью исследования является анализ и оценка групп количественных факторов, характеризующих цифровой потенциал строительного комплекса. Методами исследования являются методы количественного и качественного анализа, которые заключаются в проведении сравнительного анализа факторов – индексов и рейтингов, а также в ранжировании групп факторов характеризующих готовность регионов к цифровизации строительного комплекса в соответствии с экспертными оценками по итогу проведенного опроса респондентов. Проведенное исследование позволило сопоставить ранее выявленные количественные и качественные факторы между собой, с целью устранения дублирования составляющих качественных факторов – индексов и рейтингов. Следовательно, была сформирована необходимая и достаточная выборка факторов, которые в дальнейшем могут быть использованы для формирования скорректированного рейтинга по уровню готовности регионов России к цифровизации строительного комплекса. Для ранжирования факторов оценки цифрового потенциала строительного комплекса региона по важности и значимости был проведен опрос респондентов по группам: 1) социально-экономические условия для осуществления отраслевой цифровизации; 2) развитие науки и инноваций в регионах; 3) развитие строительного комплекса регионов; 4) развитие цифровых технологий в регионах. В соответствии с проведенным опросом респондентов отобранные факторы были ранжированы, в т.ч. по группам. В дальнейшем, данное исследование позволит сформировать уточненный рейтинг уровня готовности регионов к цифровизации строительного комплекса, а также определить границы эффективности рейтинговой оценки.

Ключевые слова: цифровая экономика, цифровой потенциал, устойчивое развитие, региональное развитие, строительный комплекс, BIM-технологии.

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1. Introduction

Digital transformation encourages regional development and contributes to socio-economic growth (Lygina, 2019; Chernykh et al., 2019). Measuring the digital potential of sectors and complexes is a primary objective in the formation of regional innovation systems, which build up and ensure the development of innovation potential

Measuring the digital potential of industries and complexes is a key task in stimulating the growth of regional innovation systems. These systems, together with the national innovation system and a system providing a mechanism for effective operation of the innovative economy, contribute to the development of the innovative potential of enterprises in the region (innovative infrastructure, innovation security, government regulation). In turn, this becomes a structural component of the economic development of the state, namely, the institutional foundation of the country's innovative economy (Litvinenko, 2015; Volkonitskaya and Lyapina, 2014; Rodionov et al., 2013). Regional technological planning institutions can be used to develop regional innovation systems. They are oriented on regional-specific industries, which have a relative competitive advantage due to their territorial position, as well as on the development of appropriate strategies to support these industries (Park et al., 2021). It is important to determine the potential for digital transformation of a particular territory, and thus the readiness for digitalisation must be evaluated within the sectors and complexes of the economy that define the specialisation of regions.

Digital technology is being actively introduced everywhere in sectors and complexes, for example, in the energy sector (Nguyen et al., 2021; Konovalov, 2020), the agricultural sector (Akmarov et al., 2021; Pfeiffer et al., 2021; Kovaleva, 2019), health care (Iakovleva et al., 2021), education (Akulenko et al., 2021; Ivanova et al., 2021) and construction (Tereshko et al., 2021; Muñoz-La Rivera et al., 2021; Berlak et al., 2021). One of the leading and rapidly growing sectors in the digital economy is the construction industry. It applies innovative technologies, with routine processes being digitalised and robotised, and work is optimised at various stages of the life cycle of a construction project[1]. Advanced technologies transform the process, in which working groups are organised and the work is systematised. The process, aimed at reaching strategically important goals given the sectoral specifics of the construction industry, from design documentation to the commissioning of capital development projects, should be called a construction complex (Tereshko and Rudskaya (Digital potential…), 2020). In the future, digital development of the construction complex at the regional level will bring about balanced agglomerations that can meet the challenges of modern society. Consequently, digital transformation of the construction complex can be seen as a driver of regional innovation systems, whose development is essential at the micro-, meso- and macro levels (Tereshko and Rudskaya (Digitalization of the construction…, 2020) of the digital processes evolving in the sector.

It should be noted that the indicators for the development of territories (regions) are influenced by the development of enterprises that operate in the area. Thus, construction enterprises that form the construction complex of a region play a significant role in sustainable regional development, as evidenced by the numerous studies (Stanitsas and Kirytopoulos, 2021; Ilhan and Yobas, 2019). Thus careful strategic planning and development of industrial complexes in the regions, particularly the construction complex, facilitates the formation and development of a sustainable urban environment (Vargas-Hernández, 2021; Ametepey et.al., 2020; Kozlov et.al., 2019).

[1] Talapov, V.V, 2015. BIM Technology: The Essence and Features of Building Information Modeling Implementation, DMK Press, Moscow, p. 410

Previously, the authors conducted a study entitled ‘Readiness of Regions for Digitalization of the Construction Complex’ and suggested a ranking of the regions’ readiness to digitalise the construction complex (Tereshko et al., 2021). The ranking relies on quantitative and qualitative factors. The qualitative factors include surveys, rankings and indices. Using an aggregated assessment of several parameters, the rankings and indices can give a summarised specification for a constituent entity, which is convenient for ranking and calculating the indicators of territories. However, the indicators that form a particular ranking or index can recur and lead to a distorted interpretation of the final outcome. Therefore, these qualitative factors must be revised to form the necessary and sufficient sample by group, mainly based on the quantitative data available.

The *aim* of the study is to validate the factors that constitute the ranking of the regions’ readiness to digitalise the construction complex in Russia to prevent the quantitative indicators included in the qualitative factors from being duplicated. In accordance with this aim, the following objectives must be achieved: 1) analyse the composition of controversial qualitative factors; 2) form the necessary and sufficient sample of parameters for characterising a concrete group of the formed ranking; and 3) assign weights to the formed sample of factors by group in accordance with the respondent survey.

2. Literature Review

The digital development of the construction complex relies on building information modelling (BIM) technologies. BIM implies that an information model of capital development object is built at all stages of the life cycle of a construction project (Rybin et al., 2019). BIM technologies are the basis for digital transformation of the construction industry at the micro level — the level of organisations and enterprises. Interconnected operation in a digital environment, which links the design stages (concept, detailed design, project documentation, detail engineering design documentation, executive documentation) with financial, economic and investment components helps to generate a comprehensive model at different stages of the life cycle. It is an integral part of creating an information system of municipalities and regions (Pertseva et al., 2017).

Scientists from all over the world study BIM technologies and suggest various research ideas, from improving the organisational structure to adapt it to work with BIM to structuring the algorithms to model specific processes in the design of buildings and structures. For example, Alshorafa and Ergen (2019) consider the use of BIM technologies in large-scale projects. Further, Sekisov (2019) and Lushnikov (2015) examine the effectiveness of construction production organised using BIM technologies as well as the problems and advantages of their application in construction companies. Akram et al. (2019) study bibliometric and scientific-metric databases and conclude that visualisation is the most promising function of BIM, while hazard identification is an important area where these technologies can be used to ensure construction safety.

It is challenging to research the digital transformation of the sector, the investment and construction complex and the construction complex of the region. Having analysed the studies in the SCOPUS reference and abstract database matching the search query ‘Digitalization of the construction industry’ filtered by the keyword *Digitalization*, 54 documents were identified from 2009 to 2021. Figure 1 shows the distribution of studies by year. It should be noted that the peak in publications in 2019 and their decline in 2020–2021 suggests that the process of indexing articles is often time-consuming, and therefore the sample for 2020–2021 will be gradually updated.

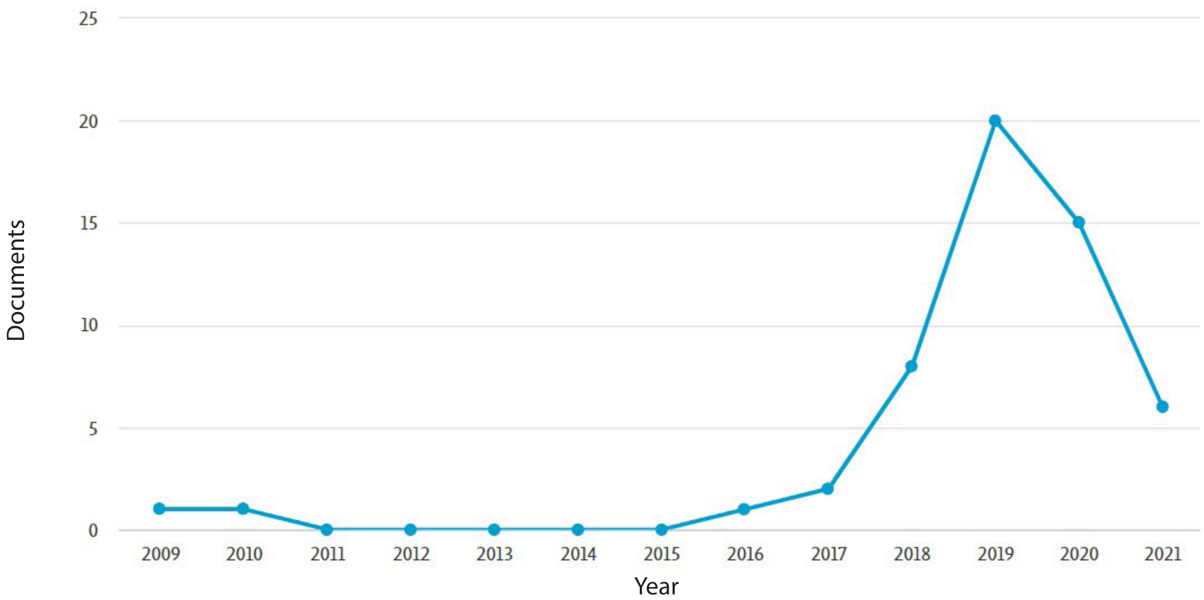

Figure 1. Researching the digitalisation of the construction industry by year in the SCOPUS database

Most of the studies on the digitalisation of the construction industry were written by authors from Germany (18 publications), Russia (8 publications), Australia (3 publications), the Czech Republic (3 publications) and the UK (3 publications). The following leading scientists in this field can be mentioned: Hosseini, Aghimien, Aigbavboa, Helmus, Jahanger, Kelm, Louis, Matejka, Zhou, Meins-Becker, Stoyanova, Oke A.E., Pestana, Stransky and Trejo. For example, Stoyanova (2020) studies advanced digitalisation practices in industrial sectors, using a selection of factors related to success potential and proposing recommendations to determine whether the digital technologies used in construction are successful.

Elghaish et al. (2020), Aghimien et al. (2019) and Golizadeh et al. (2019) show how pilotless flying vehicles and immersive technologies can be used for digitalising the construction industry and discuss the potential applications of these technologies individually or combined and integrated with each other. In their work, Aghimien et al. (2020) evaluate the aspects of the latent institutional environment that affect the digitalisation of the construction industry in South Africa. Meanwhile, Oke A. et al. (2020) analyse the challenges when the Internet of Things was introduced in the construction industry in Nigeria in order to increase awareness of and the degree to which the advantages were used by stakeholders.

Additionally, Zhou et al. (2020) describe a digital process platform that supports a wide range of users in the construction market. This platform provides more data about construction market players using an integrated cyber-physical system and contributes to the standardisation of communication infrastructure within the construction sector by combining various solutions based on information and communications technologies.

Assessing the development of the digital potential of the construction complex of the regions is advantageous, as in the initial stage it can be used to identify the regions prone to digital transformation, those that have a good technological base in their toolkit and the organisations developing together with the rapidly changing trends. No studies measuring the digital potential of the construction complex have been identified. Consequently, it is important to form the necessary and sufficient sample of factors to assess the potential of the territory or subject of the federation of a particular country, including the regions of Russia, for digitalising the construction complex.

3. Materials and Methods

The research methodology relies on qualitative and quantitative methods. Qualitative research methods involve validating the factors that characterise the regions' readiness to digitalise the construction complex, using a comparative analysis of the qualitative indicators – indices and rankings – in order to avoid duplication of the designed parameters of the sample that are used to measure the digital potential of the regional construction complex. The following ones were selected for the analysis: 1) Business Digitalization Index by constituent entities; 2) ranking of the socio-economic position of the constituent entities of the Russian Federation (RF); 3) Science and Technology Development Index; 4) innovative development ranking of the RF regions; and 5) ranking of innovative regions in Russia. These quantitative indicators assess the regions using the aggregate parameters of digital and innovative development.

The quantitative methods involve ranking the groups of factors that characterise the regions' readiness to digitalise the construction complex, using expert assessments from the survey of respondents. The assessment algorithm includes the following stages:

Stage 1. Conducting an online survey of respondents.

Stage 2. Analysing the results of the survey by groups of the formed assessment indicators.

Stage 3. Calculating the arithmetic mean value for the groups of factors and for individual parameters. Assigning ranks to the groups of indicators and the indicators within groups or subgroups.

4. Results and Discussion

The sample of factors previously presented in the study of Tereshko et al. (2021) can be used to reflect the necessary and sufficient characteristics for measuring the digital potential of the construction complex in a particular region of Russia. The measured digital potential is the basis for sustainable development of Russian regions (Jovovic et al., 2017; Feldhoff, 2002; Roberts, 1994; Zaborovskaya et al., 2019), as it provides a foundation for defining and developing the concept of digital transformation of the construction complex in these regions. This approach is useful because it leads to demonstrative indicators achieved through ranking the regions. Further, it simplifies the evaluation of possible scenarios for the development of the socio-economic system and can be used to build a long-term strategy for digital industrial development of the region by establishing development frameworks for the sectoral economy in the RF. The factors chosen for the ranking include both quantitative and qualitative indicators (Table 1).

Let us consider the groups of factors in more detail so that the calculated parameters are not misinterpreted when the ranking is compiled. This is important because these parameters can be based on the same quantitative data that form the qualitative indicators. The major quantitative factors to be considered are in groups 1 and 2: 'Socio-economic conditions for sectoral digitalisation of the regions' and 'Development of science and innovation in the regions', respectively.

To validate the factors in the first group, let us consider factors X3 and X4. Quantitative indicator X3, 'Index of business digitalisation by constituent entities'[2], includes the following indicators: 1) The specific weight of organisations (among other organizations), using broadband Internet (%), cloud services (%), RFID technologies (%) and ERP systems (%); and 2) The specific weight

[2] Digital Economy Indicators – 2019г. Statistics Digest, pp. 216–220. https://www.hse.ru/data/2019/06/25/1490054019/ice2019.pdf

Table 1. Factors for assessing the digital potential of the construction complex in the region

Group	Indicator		Indicator type	Commentary
1. Socio-economic conditions for sectoral digitalisation of regions	X1	Human Development Index by Russian regions	Qualitative	Formed by the analytical centre under the RF government
	X2	GRP by the type of economic activity 'Construction' (%)	Quantitative	Data are posted on Rosstat website
	X3	Business Digitalization Index by constituent entities	Qualitative	Formed by the HSE and published in the periodical 'Digital Economy Indicators'
	X4	Ranking of socio-economic position of constituent entities	Qualitative	Formed by the analytical agency RIA rating
2. Science and innovation development in regions	X5	Science and Technology Development Index	Qualitative	Formed by the analytical agency RIA rating
	X6	Ranking of innovative development of Russian regions	Qualitative	Formed by the HSE
	X7	Ranking of innovative Russian regions	Qualitative	Formed by the Association of Innovative Regions of Russia (AIRR)
3. Development of construction complex in regions	X8	Commissioning residential and non-residential buildings, (m2)	Quantitative	Data are posted on Rosstat website
	X9	Investments by type of economic activity 'Construction' (excluding small business enterprises), (mil. rubles)	Quantitative	Data are posted on Rosstat website
	X10	Number of enterprises and organisations by type of economic activity 'Construction', units for the end of year according to the state registration data	Quantitative	Data are posted on Rosstat website
	X11	Distribution of the average annual number of employed by type of economic activity 'Construction', (% of the total employed)	Quantitative	Data are posted on Rosstat website
4. Development of digital technology in regions	X12	Digital Literacy Index	Qualitative	Formed by regional non-government organisation 'Internet Technology Center' (ROCIT). Based on respondent surveys
	X13	Number of building information modelling (BIM) technology users	Qualitative	Formed by Konkurator company. Based on respondent surveys.
	X14	Experience in BIM projects (from three to five years)	Qualitative	Formed by Konkurator company. Based on respondent surveys.

of organisations engaged in e-commerce, using special forms posted on the website/Extranet and EDI systems, of the total organisations (%). These indicators are important for assessing the digital equipment of organisations in Russian territories, including construction enterprises. Regarding the data available in the Rosstat databases, the relevant statistics for the regions of Russia in 2019 do not include a subsection for the selected index parameters. Consequently, the index will not be valid in the future. Thus, for factor X4 we have to introduce a group of indicators to assess the digitalisation of business in the regions of Russia. These indicators include the specific weight of organisations, using (as %) 1) broadband Internet; 2) CRM, ERP and SCM systems; 3) electronic document management systems; 4) cloud services; and 5) local computer networks.

Table 2. Indicators of the Science and Technology Development Index (X5)

Indicator designation	Indicator	Factor is considered in evaluation (yes/no)
1st indicator group 'Human resources'		
X5.1.1	Number of staff members engaged in R&D per capita of working-age population	Yes
X5.1.2	Specific weight of researchers under the age of 39 of the total researchers	Yes
X5.1.3	Specific weight of highly qualified employees of the total qualified employees	Yes
X5.1.4	Share of employees by high-tech type of economic activity of the total workers employed by organisations	Yes
2nd indicator group 'Physical infrastructure'		
X5.2.1	Specific weight of machines and equipment up to 5 years of age of the total worth of the machines and equipment in R&D organisations	Yes
X5.2.2	Specific weight of organisations engaged in technology innovations	Yes
X5.2.3	Ratio of the salary of scientific workers to the cost of the minimum consumption basket	Yes
X5.2.4	Number of computers in organisations per 100 workers	Yes
X5.2.5	Internal R&D costs per capita of working-age population	Yes
X5.2.6	Specific weight of spending on technological innovations of the total of goods shipped, works executed and services rendered	Yes
X5.2.7	Innovative activity of organisations (specific weight of organisations engaged in technological, organisational and marketing innovations)	Yes
3rd indicator group 'Scale of scientific and technological activity'		
X5.3.1	Volume of shipped innovative goods, executed innovative work, rendered innovative services	Yes
X5.3.2	Volume of gross regional product from the products of high-tech and science-intensive industries	Yes
X5.3.3	Number of issued patents	Yes
4th indicator group 'Efficiency of scientific and technological activity'		
X5.4.1	Specific weight of innovative goods, work and services of the total goods shipped, works executed and services rendered	Yes
X5.4.2	Share of products of high-tech and science-intensive industries of the gross regional product	Yes
X5.4.3	Number of patents issued per capita of working age population	Yes
X5.4.4	Volume of shipped innovative goods, executed innovative work and rendered innovative services per capita	Yes
X5.4.5	Volume of gross regional product generated by products of high-tech and science-intensive industries per capita.	Yes

Factor X4 – 'Ranking of the socio-economic situation of the RF constituent entities'[3] – includes four subgroups of quantitative indicators: indicators of the scale of the economy; indicators of economic efficiency; indicators of the public sector; and indicators of the social sphere. The composition of the indicators gives quite an accurate picture of the socio-economic development of a particular Russian territory, which is one of the key aspects in measuring sectoral digitalisation. The quantitative indicators included in the subgroups are publicly available on the Rosstat website[4], where they are updated annually. The agency RIA rating constitutes the ranking annually. Therefore, this qualitative indicator can be used in the future, among other things, for convenient cumulative use of quantitative data for the socio-economic block.

Let us consider the following qualitative indicators outlining the development of science and

[3] Riarating. The ranking of socio-economic position of regions – 2018. https://riarating.ru/infografika/20180523/630091878.html

[4] Regions of Russia. Socio-economic indicators. https://rosstat.gov.ru/folder/210/document/13204

innovation in the Russian regions (X5, X6 and X7). These indicators may have repeated values that negatively affect the final ranking and present a distorted interpretation of the results. Therefore, it is necessary to scrutinise the factors that make up the group 'Science and Innovation Development in the Region'. Accordingly, we perform a comparative analysis of the qualitative factors and examine the indicators they include in detail.

The Science and Technology Development Index (X5), formed by the agency 'RIA rating'[5], includes four subgroups of indicators: human resources; physical infrastructure; the scale of scientific and technological activities; and the effectiveness of scientific and technological activities. The positions of the RF constituent entities in the final list were determined using the integral index, calculated by aggregating the ranking points of the regions for 19 analysed indicators, which were combined into the four subgroups listed above. Table 2 presents the analysis of the index and reflects the factors to be included in the assessment of the digital potential of the construction complex.

The indicators included in this index can be freely accessed on the Rosstat database, which is the advantage of using the index in the future. The final index can vary from 1 to the maximum value of 100. The index is updated annually, and the ranking of Russian regions is based on it.

The ranking of innovative development of the Russian regions[6] (X6) is published by the Institute for Statistical Studies and Economics of Knowledge of the National Research University - Higher School of Economics (HSE), the Russian Cluster Observatory. The rating analyses the innovative development of the Russian regions and considers a number of ranking assessments. The ranking includes five groups, each of which is divided into subgroups. In total, the ranking includes 53 quantitative and qualitative indicators. The ranking is divided into the following indicator groups and subgroups: 1) socio-economic conditions for innovation; 2) scientific and technical potential; 3) innovative activity; 4) export activity; and 5) the quality of innovation policy. Table 3 provides an analysis of the index, reflecting the factors that should be included in the assessment of the digital potential of the construction complex.

Table 3. Indicators of Innovative Development Ranking of the Russian regions (X6)

Indicator designation	Indicator	Factor is considered in evaluation (yes/no)
1st indicator group 'Socio-economic conditions for innovative activity'		
1.1 Key macro-economic indicators		
X6.1.1.1	GRP per one employed in the region's economy, thousand rubles	Yes
X6.1.1.2	Fixed assets renovation coefficient (%)	No
X6.1.1.3	Specific weight of the employed in high-tech and medium-tech (high-level) sectors of industrial manufacturing in the average number of workers in the region's economy (%)	No
X6.1.1.4	Specific weight of the employed in science-intensive service sectors in the average number of workers in the region's economy (%)	No
1.2 Educational potential of population		
X6.1.2.1	Specific weight of population aged 25–64 with higher education in the total population of this age group (%)	Yes
X6.1.2.2	Number of students enrolled in higher educational programmes – Bachelor's, Master's, specialist's programmes, per 10,000 people, persons	Yes

[5] Riarating. The level of science and technology development in the regions of Russia – 2018. https://riarating.ru/infografika/20181017/630109152.html

[6] Ranking of innovative development of the RF constituent entities. Issue 6. https://issek.hse.ru/mirror/pubs/share/315338500

Table 3 (continued)

Indicator designation	Indicator	Factor is considered in evaluation (yes/no)
X6.1.2.3	Specific weight of students specialising in mathematics, natural sciences, engineering, technology, technical sciences and fundamental medicine in the total students enrolled in higher educational programmes – Bachelor's, Master's, specialist's programmes (%)	No
X6.1.2.4	Employed population aged 25–64 involved in lifelong learning (%)	No
X6.1.2.5	Number of students enrolled in secondary vocational education programmes – programmes training medium specialists, per 10,000 people, persons	Yes
X6.1.2.6	Specific weight of students specialising in mathematics, natural sciences, engineering, technology and technical sciences in the total students enrolled in secondary vocational education programmes – programmes training medium specialists (%)	No
1.3 Digitalisation potential		
X6.1.3.1	Specific weight of organisations having access to broadband Internet with a maximum data transfer rate over 100 Mbit/sec in the total organisations (%)	Yes
X6.1.3.2	Specific weight of organisations engaged in training their personnel in digital skills in the total organisations (%)	Yes
X6.1.3.3	Specific weight of active Internet users in the total population aged 15–74 (%)	No
2nd indicator group 'Science and Technology Potential'		
2.1 Financing research and development		
X6.2.1.1	Internal R&D costs as a percentage of GRP (%)*	No
X6.2.1.2	Internal R&D costs per one researcher, thousand rub.	No
X6.2.1.3	Specific weight of organisations in the entrepreneurial sector in total internal R&D costs (%)	No
X6.2.1.4	Ratio of the average monthly salary of employees engaged in R&D to the average monthly nominal gross salary in the region (%)	No
2.2 Scientific personnel		
X6.2.2.1	Specific weight of people employed in research and development in the average annual number of people employed in the region's economy (%)	No
X6.2.2.2	Specific weight of people aged less than 39 in the number of researchers (%)	Yes
X6.2.2.3	Specific weight of people with a scientific degree in the number of researchers (%)	No
2.3 Research and development performance		
X6.2.3.1	Publications in journals indexed in the Web of Science, per 10 researchers, units	Yes
X6.2.3.2	Patent applications for inventions submitted to Rospatent by national applicants, per 1 million manpower aged 15–72, units.	Yes
X6.2.3.3	The number of advanced production technologies developed in the region, per 1 million manpower aged 15–72, units.	No
3rd indicator group 'Innovative Activity'		
3.1 Activity in the field of technological and non-technological innovations		
X6.3.1.1	Specific weight of organisations engaged in technological innovations in the total organisations (%)*	Yes
X6.3.1.2	Specific weight of organisations engaged in non-technological (marketing and/or organisational) innovations in the total organisations (%)*	No
X6.3.1.3	Specific weight of organisations that developed ready-to-use technological innovations in-house in the total organisations (%)*	No
X6.3.1.4	Specific weight of organisations engaged in joint R&D projects in the total organisations (%)*	No
3.2 Small innovative business		
X6.3.2.1	Specific weight of small enterprises engaged in technological innovations in the total small enterprises (%)*	No

Table 3 (continued)

Indicator designation	Indicator	Factor is considered in evaluation (yes/no)
3.3 Technological innovation costs		
X6.3.3.1	Specific weight of technological innovation costs in the total volume of goods shipped, work executed and services rendered by organisations (%)*	Yes
3.4 Innovative activity performance		
X6.3.4.1	Specific weight of innovative goods, works, services in the total of goods shipped, works executed and services rendered (%)	Yes
X6.3.4.2	Specific weight of newly launched or significantly technologically modified innovative goods, works and services for the market in the total goods shipped, works executed and services rendered (%)*	No
X6.3.4.3	Specific weight of organisations that consider reduced material and energy costs as the main outcome of their innovative activities in the total organisations engaged in technological innovations (%)	No
4th indicator group 'Export Activity'		
4.1 Export of goods and services		
X6.4.1.1	Exports of goods per 1,000 rub. of GRP, rub.	No
X6.4.1.2	Exports of non-raw material goods per 1,000 rub. of GRP, rub	No
X6.4.1.3	Exports of services 1,000 rub. of GRP, rub	No
X6.4.1.4	Specific weight of export in the total innovative goods, work and services (%)	No
4.2 Knowledge export		
X6.4.2.1	Number of patent applications for inventions registered abroad per 1 mil. people of manpower aged 15–72, units	No
X6.4.2.2	Technology export earnings per 1,000 rub. of GDP, rub	No
X6.4.2.3	Specific weight of international students in the total students enrolled in higher education programmes – Bachelor's, Master's and specialist's programmes, %	No
5th indicator group 'Quality of Innovation policy'		
5.1 Legal framework of innovation policy		
X6.5.1.1	Presence of an innovative development strategy (concept) (innovation strategy) and/or a specialised innovative development section (supporting innovations) in the regional development strategy	No
X6.5.1.2	Presence of the zones (territories) in the territorial planning scheme allocated for priority development of innovative activity	No
X6.5.1.3	Presence of a specialised legislative act that defines the basic principles, areas and measures of state support for innovative activities in the region	No
X6.5.1.4	Presence of a specialised programme or a set of state support measures for the development of innovations, innovative activities or subjects of innovative activities	No
5.2 Organisational support for innovation policy		
X6.5.2.1	Presence of specialised (advisory) bodies coordinating innovation policy (supporting innovative activity) under a senior official or the supreme executive body of state power of the RF constituent entity	No
X6.5.2.2	Presence of specialised regional institutions developing the base of regional legal acts (funds, agencies, development corporations, etc.) with the functionality to support the subjects of innovative activity and/or to implement innovative projects	No
5.3 Budgetary science and innovation expenditure		
X6.5.3.1	Specific weight of allocations for civil science from the consolidated budget of the RF constituent entity in the expenditures of the consolidated budget of the RF constituent entity (%)	No
X6.5.3.2	Specific weight of federal budget funds in total expenditures on technological innovations (%)	No

Table 3 (end)

Indicator designation	Indicator	Factor is considered in evaluation (yes/no)
X6.5.3.3	Specific weight of funds from the budget of the RF constituent entity and local budgets in the total technological innovation expenditure (%)	No
	5.4 Participating in federal science, technology and innovation policy	
X6.5.4.1	The number of research, scientific-technical and innovative projects supported by federal government bodies and development institutions, per 1 million people of manpower aged 15–72, units	No
X6.5.4.2	The number of federal development institutions supporting research, scientific-technical and innovative projects implemented in the RF constituent entity, units	No
X6.5.4.3	Funding from federal authorities and development institutions attracted for research, scientific-technical and innovative projects in the RF constituent entity, per 1 million rubles of GRP, rub.	No

The ranking reflects the whole picture of innovative development in the Russian regions. However, it includes some qualitative indicators that are hard to collect if no relevant ranking has been published yet.

The ranking of the innovative regions of Russia[7] (X7) was formed by the Association of Innovative Regions of Russia (AIRR) and includes four groups of indicators: research and development; innovative activity; socio-economic conditions for innovation; and innovative activity of the region. The ranking includes 29 indicators. Let us have a careful look at the ranking groups in Table 4 and focus on the factors that should be accepted to assess the digital potential of the construction complex.

Similar to indicator X6, the ranking of the innovative regions of Russia fully reflects the digital development picture. It is generated on a regular basis and includes the most relevant information on the changes occurring in the innovation sphere of the economies of the RF constituent entities. A feature of the ranking is the presence of quality indicators, in the future, when the annual characteristics of the ranking are updated, it may have a negative effect due to the lack of data. Factor X7 is similar in content to factor X6. Therefore, using these two parameters in the sample is redundant.

In the comparative analysis of the qualitative indicators presented in the sample of the second group of factors, which characterise the level of readiness of the Russian regions to digitalise the construction complex, a number of repetitive ones factors can be highlighted: X5.1.2=X6.2.2.2; X5.2.2=X6.3.1.1=X7.2.1; X6.3.2.1=X7.2.3; X5.2.6=X6.3.3.1=X7.2.9; X5.4.1=X6.3.4.1=X7.2.4; X5.4.2=X7.3.4; X5.4.3=X6.2.3.2=X7.1.5; X7.1.1=X6.1.2.2; X7.1.3=X6.1.2.1; X7.1.6=X6.2.3.1; X7.1.8=X6.2.1.1; X7.1.9=X6.2.1.3; X7.2.5=X6.3.4.2; X7.2.7=X6.4.2.2; X7.2.8=X6.2.3.3; X7.3.1=X6.1.1.2; X7.3.2=X6.1.1.1; X7.3.3=X6.1.1.3; X7.4.1=X6.5.4.3; and X7.4.2=X6.5.4.1. As you can see, the indicators in the three groups have intersections by the same parameters. Consequently, the previously selected quantitative factors X5, X6, and X7 cannot be used in the aggregate. In addition, the factor 'Ranking of innovative development of the RF regions' contains indicator X6.1.3.1, which is identical to the indicator from the first group of factors – 'Specific weight of organisations using broadband Internet (%)'. The group of factors 'Development of digital technology in regions' has to be supplemented with the quantitative indicator 'Specific weight of organisations using design software (%)', which reflects the information support of construction complex enterprises with software products necessary for carrying out design processes in accordance with BIM technologies.

[7] Ranking of innovative regions of Russia: version 2017. http://i-regions.org/images/files/airr17.pdf

Table 4. Indicators of the Ranking of Innovative Russian Regions (X7)

Indicator designation	Indicator	Factor is considered in evaluation (yes/no)
1st indicator group 'Research and Development'		
X7.1.1	Number of students studying in higher professional education institutions per total population	Yes
X7.1.2	Number of researchers per total population	No
X7.1.3	Specific weight of working age employees with higher education in total working age population (%)	Yes
X7.1.4	Number of international PCT applications filed per total economically active population	No
X7.1.5	Number of patent applications for inventions submitted to Rospatent by national applicants per total economically active population	Yes
X7.1.6	Number of papers published in journals indexed in the Web of Science per total researchers	Yes
X7.1.7	Number of papers published in peer-reviewed journals indexed in the RSCI per total researchers	No
X7.1.8	Internal R&D expenditures as percentage of GRP (%)	No
X7.1.9	Specific weight of funds of organisations in the entrepreneurial sector in total internal R&D expenditures (%)	No
2nd indicator group 'Innovative Activity'		
X7.2.1	Specific weight of organisations engaged in technological innovations in the total organisations (%)	Yes
X7.2.2	Specific weight of organisations engaged in non-technological innovations in the total organisations (%)	No
X7.2.3	Specific weight of small enterprises engaged in technological innovations in the total small enterprises (%)	No
X7.2.4	Specific weight of innovative goods, work, services in the total of good shipped, work executed and services rendered	Yes
X7.2.5	Specific weight of newly launched or significantly technologically modified innovative goods, work and services for the market in the total goods shipped, work executed and services rendered (%)	No
X7.2.6	Number of inventions used per total population	No
X7.2.7	Technology export earnings in relation to GRP	No
X7.2.8	Number of created advanced production technologies per total economically active population members	No
X7.2.9	Intensity of expenditure on technology innovations (%)	Yes
3rd indicator group 'Socio-Economic Conditions for Innovative Activity'		
X7.3.1	Fixed assets renovation coefficient (%)	No
X7.3.2	GRP per one person employed in the region's economy (excluding extractive industries)	Yes
X7.3.3	Specific weight of the employed in high-tech and medium-intensive (high-level) types of activity per total employed in the region's economy (%)	No
X7.3.4	Share of products of high-tech and science-intensive industries of GRP (%)	Yes
X7.3.5	Specific weight of organisations using Internet with a data transfer rate 2 Mbit/sec as a minimum in the total organisations investigated* (%)	No
4th indicator group 'Innovative Activity of the Region'		
X7.4.1	Attracting investments from federal sources into the innovative sphere of the region's economy in relation to GRP	No
X7.4.2	Support of innovative projects by federal development institutes	No
X7.4.3	Innovative activity of regional government bodies (score indicator)	No
X7.4.4	Winning competitions held by federal executive government bodies and federal development institutions (score indicator)	No
X7.4.5	Involving companies in interaction within clusters and technology parks	No
X7.4.6	Publicly held innovative events (score indicator)	No

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Let us form the necessary and sufficient sample of factors for the subgroups in order to assess the level of readiness of the Russian regions to digitalise the construction complex. The key requirement for the factors is their availability and annual update (Table 5). The factors for the group ‘Development of Science and Innovation in the Regions’ are revised based on a detailed analysis of the indicators included in the index and rankings. Thus, we can form the necessary sample of available quantitative indicators, which are divided into subgroups within the group. We keep the index of scientific and technological development, as it is updated annually, is minimally sufficient for measuring the potential of the constituent entities and the data it contains are freely accessed from the Rosstat state statistics base. It is worth

Table 5. Adjusted sample of factors for assessing the digital potential of the construction complex of the region

Group	Indicator	
1. Socio-economic conditions for sectoral digitalisation of the regions	X1	Human Development Index by RF region
	X2	GRP by type of economic activity ‘Construction’ (%)
	X3	Indicator subgroup ‘Business Digitalisation’ includes: X3.1 Specific weight of organisations using broadband Internet (%); X3.2 Specific weight of organisations using CRM, ERP, SCM – systems (%); X3.3 Specific weight of organisations using electronic document management systems (%); X3.4 Specific weight of organisations using cloud services (%); X3.5 Specific weight of organisations using local area networks (%)
	X4	Ranking of the socio-economic position of the RF constituent entities
	X5	Indicator subgroup ‘Educational Potential of Population’ includes: X5.1 Specific weight of employed population by level of education (higher) (%); X5.2 Specific weight of employed population by level of education (secondary vocational) (%); X5.3 Number of students enrolled in higher educational programmes – Bachelor’s, Master’s, specialist’s programmes, per 10,000 people, persons; X5.4 Number of students enrolled in secondary vocational education programmes – programmes training medium specialists, per 10,000 people, persons; X5.5 Specific weight of organisations engaged in training their personnel in digital skills (%)
2. Development of science and innovation in regions	X6	Science and Technology Development Index
	X7	Number of papers published in journals indexed in the Web of Science per total researchers, units
3. Development of the construction complex of regions	X8	Commissioning residential and non-residential buildings, m^2
	X9	Investments by type of economic activity ‘Construction’ (excluding small business enterprises), million rubles
	X10	Number of enterprises and organisations by type of economic activity ‘Construction’, units at the end of year according to the state registration data
	X11	Distribution of the average annual number of employed people by type of economic activity ‘Construction’ (%) of the total employed
4. Development of digital technology in regions	X12	Digital Literacy Index
	X13	Number of Building Information Modelling (BIM) technology users
	X14	Experience in BIM projects (from three to five years)
	X15	Specific weight of organisations using design software (%)

introducing the assessment of publication activity in the Web of Science as an additional parameter. The educational potential of the population, previously included in the ranking of innovative development of the RF regions, is also revised. Given the implications of the factors characterising the educational potential, the sample of quantitative indicators within the subgroup 'Educational potential of the population' is assigned to the first group of factors.

In order to rank the selected factors and then correctly assess the level of readiness of the regions to digitalise the building complex, the authors conducted a surveywith 49 specialists . The interviewees are experts in the field of construction and are engaged in management, pedagogical or administrative activities. In terms of their geographical distribution, all the respondents belong to St. Petersburg, Leningrad Region, Moscow and Moscow Region. The survey was conducted for the following groups: 1) Socio-economic conditions for sectoral digitalisation; 2) Development of science and innovation in the regions; 3) Development of the construction complex of the regions; and 4) Development of digital technology in the regions. Within each block, the respondents assessed the characteristics that affect the development of a particular block in the context of the construction complex digitalisation. Blocks were assessed using a ten-point scale, where 1 indicates a low level of significance, and 10 indicates a high level of significance. The groups of factors, subgroups and/or factors included in the groups were ranked based on the total distribution of assessments in accordance with the arithmetic mean parameter. The arithmetic mean value for the groups was adopted as a calculation method. For example, to perform calculations for the first group consisting of factors X1–X5, expert assessments on a 10-point scale were considered. Then, the arithmetic mean value was considered for each factor (X1 is 7.367; X2 is 6.041; X3 is 7.694; X4 is 7.735; X5 is 9.000), and in accordance with it the weight was determined using some parameter within the group (X1 is 0.195; X2 is 0.160; X3 is 0.203; X4 is 0.204; X5 is 0.238). The parameters for each group of factors were calculated in a similar way. Then, the weight was calculated for each group in accordance with the arithmetic mean of the factors in this group. For example, for group 1 the total arithmetic mean is 7.567, for group 2 it is 7.827, for group 3 it is 6.827 and for group 4 it is 8.106.

Table 6 contains the weights calculated by group and by indicator. In addition, a significance rank was assigned to each factor, where 1 indicates the greatest significance. The rank was determined both between the groups of factors and within the indicators/subgroups of indicators.

Table 6. Ranking the factors for assessing the digital potential of the construction complex in the region according to the survey

Group	Weight	Rank	Subgroup/Indicator	Weight	Rank in the group
1. Socio-economic conditions for sectoral digitalisation of regions	0.250	3	X1	0.195	4
			X2	0.160	5
			X3	0.203	3
			X4	0.204	2
			X5	0.238	1
2. Development of science and innovation in regions	0.258	2	X6	0.732	1
			X7	0.268	2
3. Development of the construction complex of regions	0.225	4	X8	0.244	2
			X9	0.288	1
			X10	0.241	3
			X11	0.226	4
4. Development of digital technology in regions	0.267	1	X12	0.262	1
			X13	0.256	2
			X14	0.242	3
			X15	0.240	4

In future research, a correlation and regression analysis of the indicator sample has to be carried out to determine how the indicators affect the development of the region. We also plan to study the efficient frontiers of the formed ranking indicator using the DEA shell analysis method to develop more accurate ranking indicators in the future. The ranking itself will further be used to form a mechanism for strategic development of the digital potential of the construction complex in Russian regions in conjunction with the regional innovation system.

5. Conclusion

This study validates the factors that were previously identified as important for assessing the readiness of regions to digitalise the construction complex in order to avoid: 1) duplicating the indicators within qualitative factors – rankings and indices; and 2) using data inaccessible through Rosstat (i.e. those that are no longer collected or published in the open government statistical database). In addition, a necessary and sufficient sample of factors was constructed. An updated ranking for measuring the digital potential of the construction complex of Russian regions using the fuzzy sets method could be considered in the future. Additionally, the identified group ranks of factors and indicators included in these groups will be used to form the ranking, and the calculated parameters will be adjusted considering the weighted average values and priority ranks. Therefore, the study is unique for Russian territories and contributes significantly to the methodological assessment of the digital development of the construction complex of these territories. Research of this kind is rudimental so far. The study suggests the data that could be used for assessing the readiness of regions to digitalise the construction complex. Moreover, these data can be used to track the development at different levels of management.

It should be noted that the research results are of international interest. The proposed selection of factors for measuring the digital potential of the construction complex of a territory can be translated from the micro to the macro level to make comparisons between various countries. Consequently, in the near future an international ranking based on the formed sample of factors could be compiled to measure the degree to which countries are ready to digitalise their construction complexes.

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SUSTAINABLE BUSINESS MODELS AND SMALL- AND MEDIUM-SIZED ENTERPRISES – A LITERATURE REVIEW

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Abstract

Recent developments show that an increasing number of organisations, regardless of type and size, understand that there is a need for them to make an active contribution to society, both socially and environmentally, while maintaining their financial profitability. It is no longer possible to waste resources and ignore the expectations of both internal and external stakeholders. To address these developments, all organisations are required to adapt their business models. Against this background, this paper provides a systematic review of the extant research on sustainable business models (SBMs) in small- and medium-sized enterprises (SMEs) to establish the current body of knowledge and, on this basis, to suggest some promising avenues for future research. Given the impact of SMEs on the majority of economies and their consequent role in addressing present and future societal challenges, there is a clear justification for this study. The review of 85 refereed articles shows that, although a good body of knowledge about the topic has been developed during the period covered in this study, there is still a need for further rigorous research. It appears that certain shortcomings, stressed by some researchers in the past, still prevail. The study's findings advance the current understanding of SBMs in SMEs and highlight several promising research avenues that scholars who are interested in the study of SBMs, in general, and SBMs in SMEs, in particular, might address.

Keywords: sustainable business models, business models, sustainable development, small firms, SMEs, systematic literature review

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УСТОЙЧИВЫЕ БИЗНЕС-МОДЕЛИ И МАЛЫЕ И СРЕДНИЕ ПРЕДПРИЯТИЯ – ОБЗОР ЛИТЕРАТУРЫ

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Аннотация

Последние события показывают, что все большее число организаций, независимо от их типа и размера, понимают, что необходимо вносить активный вклад в жизнь общества, как в социальном, так и в экологическом плане, сохраняя при этом свою финансовую рентабельность. Больше невозможно растрачивать ресурсы и игнорировать ожидания как внутренних, так и внешних заинтересованных сторон. Для решения этих проблем все организации должны адаптировать свои бизнес-модели. На этом фоне в данной работе представлен систематический обзор сохранившихся исследований по устойчивым бизнес-моделям малых и средних предприятий (МСП) с целью создания современного массива знаний и, исходя из этого, предложения некоторых перспективных направлений для будущих исследований. Учитывая влияние МСП на экономику большинства стран и, следовательно, их роль в решении нынешних и будущих проблем общества, существует четкое обоснование для проведения исследования. Обзор 85 рецензируемых статей показывает, что, несмотря на то, что за период, охватываемый настоящим исследованием, был накоплен большой объем знаний по данной теме, все еще существует необходимость в более тщательных исследованиях. На самом деле, как представляется, некоторые недостатки, отмеченные некоторыми исследователями в прошлом, все еще преобладают. Выводы исследования способствуют углублению нынешнего понимания устойчивых моделей предпринимательской деятельности в МСП и указывают на ряд перспективных направлений исследований, которые могут быть изучены учеными, заинтересованными в изучении устойчивых моделей предпринимательской деятельности в целом и устойчивых моделей предпринимательской деятельности в МСП в частности.

Ключевые слова: устойчивые бизнес-модели, бизнес-модели, устойчивое развитие, малые фирмы, МСП, систематический обзор литературы
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1. Introduction

Recent developments show that an increasing number of organisations, regardless of type and size, understand that there is a need for them to make an active contribution to society, both socially and environmentally, while maintaining their financial profitability. It is no longer possible for them to waste resources and ignore the expectations of both internal and external stakeholders. At the same time, market demands for more sustainable goods and services have increased, which has led to a growing interest amongst companies to put a stronger focus on sustainability (Schönborn et al., 2019). To address recent developments, organisations are also required to adapt their business models and transform them into sustainable business models (SBMs) (Hacklin et al., 2018). An SBM can be understood as 'a business model that incorporates pro-active multi-stakeholder management, the creation of monetary and non-monetary value for a broad range of stakeholders, and which holds a long-term perspective' (Geissdoerfer et al., 2018). In comparison to the study of business models (Zott et al., 2011), the study of SBMs is still an emergent one (Foss and Saebi, 2016).

According to Evans et al. (2017), the concept of 'value' has been perceived as an important and substantiating building block of business models. As the world changed, so did the perception of value – and today the understanding of value also includes the aspects of ecology and sociology. Consequently, companies should consider incorporating environmental and social goals into their value logic (Evans et al., 2017). Hence, business model innovation or adaptation towards more sustainability needs to include environmental and social actions as well and not to solely focus on economic actions.

Both topics – namely, business models and sustainability – tend to be studied in large, often multi-national, organisations. Small- and medium-sized enterprises (SMEs) have received little attention in comparison even though they form the backbone of economies all over the world (Johnson and Schaltegger, 2015; Miller et al., 2020; Tsvetkova et al., 2020).

Against this background, this paper aims to review research on SMBs in SMEs in order to establish the current body of knowledge and, on the basis of this foundation, identify gaps in our understanding. In turn, this identification can subsequently form the basis for future research. To reach that aim, the following research questions were formulated:

RQ1: What topics are researched in conjunction with SBMs in SMEs?
RQ2: What were the main findings of these studies?
RQ3: What methods were used?
RQ4: What theories have been applied in these studies?

The paper is structured as follows. The next section provides more detailed insight into the procedure of the methodology chosen for identifying the extant research on SBMs in SMEs. Subsequently, the results are presented. This is followed by a provision of possible future research opportunities. The paper concludes with implications for both theory and practice.

2. Methodology of the literature review

Our systematic literature review (SLR) followed a combined approach of Jesson et al. (2011) and McNulty et al. (2012). Jesson (2011) proposed six principles for systematic reviews, which are: 1) Mapping the field through a scoping review, 2) Comprehensive search, 3) Quality assessment via reading and selecting qualified papers, 4) Data extraction via collecting needed data from reviewed papers and storing them in an excel sheet with predetermined fields for all papers, 5) Synthesis of the extracted data to show the known and to provide the basis for establishing the unknown and 6) Write-up. McNulty et al. (2012) proposed a list of criteria that can be used to establish the basis for a descriptive and analytical overview of research on SBMs in SMEs, which formed the basis for our data extraction. Although McNulty et al.'s (2012) study investigated corporate governance, their list of criteria can be transferred to other fields because it allows us to obtain quantitative and qualitative insights into the subject under investigation, which is necessary in order to establish the current body of knowledge as this study intends.

We conducted our systematic literature review through the following steps. First, we agreed on a research plan based on the research questions we were interested in answering. The plan included the search keywords as well as the inclusion and exclusion criteria. Since we were interested in developing an understanding of the current body of research on SBMs in SMEs, we decided to use multiple keywords to identify relevant studies, such as sustainable, sustainability, eco, environment, triple bottom line and circular together with business model. In addition, we used keywords to define our target business size: small- and medium-sized enterprises (SMEs), small businesses, small companies, small firms, entrepreneurships or start-ups. The inclusion criteria were empirical research papers, peer-reviewed, English language and indexed in one of the following databases: Scopus, Web of Science, EBSCO and Wiley Online Library. We excluded grey literature, such as reports and non-academic research, and languages other than English. Furthermore, we produced an excel data sheet consisting of criteria relevant for establishing our understanding of SBMs in SMEs.

Second, one of us accessed the above-mentioned databases and searched using the combinations of the agreed keywords in the titles, keywords or abstracts of selected papers. The literature review included papers published up until December 2020. Depending on the search keyword combinations used, different numbers of hits were generated, totalling 286 articles distributed amongst databases as follows: Scopus (114 articles), Web of Science (75 articles), EBSCO (72 articles) and Wiley Online Library (25 articles). There was minimal overlap amongst the four databases (11 articles). Third, each of us went through the abstracts of these papers and, if required, more parts of the articles in order to qualify them on the basis of our research questions as well as out inclusion and exclusion criteria. This reduced the number of articles without duplications to a final tally of 153 articles that fulfilled our criteria, which were then analysed. Fourth, we distributed the papers amongst the authors, with each reviewing and analysing nearly 40 papers, then coding them according to the criteria specified below. Fifth, individual data were synthesised into one. Subsequently, each author individually worked through the merged sheet to check for coding consistency, specifically in the cases in which we could not take advantage of McNulty et al. (2012), e.g. codes for the criterion topic. Our different views were shared and discussed during discussion rounds, which led to a further reduction in the number of papers. Ultimately, a total of 85 empirical papers formed the basis for our analysis. Sixth, the final stage of our SLR was reserved for writing up our findings.

2.1 Specification of criteria

In the following subsections, each criterion used in the present paper is briefly outlined.

2.1.1 Year of publication

To determine when the current body of knowledge was made available to research communities, we captured the year of publication for every paper covered in the study.

2.1.2 Journal of publication

To obtain data regarding the fields from which the existing body of knowledge emerged, we classified the journals according to the following five broad categories: sustainable innovation, sustainable development, business model, business strategy and other journals.

2.1.3. Theoretical/research aim

To understand the authors' orientation (perception) towards the study of SBMs in SMEs, we were interested in gaining insights into the papers' theoretical aims. Consequently, a paper's aim could have been to explore, to develop (elaborate) or to test (validate) SBMs in SMEs. This understanding would indicate the level of maturity of the research field – i.e. a focus on exploration indicates that the research field is relatively at its beginning. Additionally, it provides information about the boundaries of the topic – i.e. a greater focus on empirical research helps to better define the boundaries of the topic.

2.1.4 Theories and theoretical perspectives

We were also interested in learning about the theories or theoretical perspectives applied by the authors covered in the review to study business models in SMEs because a lack of theoretical groundings in research on business models has been highlighted (e.g. Boons and Lüdeke-Freund, 2013).

2.1.5 Research setting

In relation to this criterion, we investigated where—i.e. the geographical location — the research on SBMs in SMEs had been conducted (in order to identify focal points in the world) and which sectors were represented in the literature (in order to detect missing and underrepresented industries to help guide future research).

2.1.6 Research methods

To understand what the existing body of knowledge is based upon, we examined the instruments/techniques used to collect data. This information also helped us determine the preferred research approaches found in the area under investigation.

2.2.7 Unit of analysis

To better understand the extant research on business models in SMEs and, thus, its complexity, we also considered the unit of analysis being studied in the reviewed papers—that is, an individual, an organisation or even groups of individuals, organisations, etc. The articles examined may have used multiple units of analysis as well.

2.1.8 Theme

As the study of SBMs is still a relatively recent field, one would assume that the study topics/themes are rather fragmented and are mainly driven by individual scholars and their preferences. Consequently, we decided not to specify any themes in advance but to derive them as an outcome of each author's individual analysis and the authors' joint discussions. More precisely, based on the analysis, corresponding theme for each paper were deduced, which were then grouped into broader categories and subcategories.

3. Results

In the following subsections, the results we obtained are presented, covering both quantitative and qualitative insights into the study of SBMs in SMEs.

3.1 Year of publication

Amongst the 85 papers that formed the basis for the analysis, the oldest publication was published in 2014, while the most recent ones were published in 2020. Reviewing the papers involved in the present study points to a growing interest in the topic starting in the year 2017 (with 12 articles in 2017, 21 in 2018, 23 in 2019 and 19 in 2020). This increased interest might have been driven and supported by the rising need for sustainable business development and SBMs. The more recent research activities might have been amplified by both the growing market for sustainable goods and the increasing number of companies that are convinced that becoming more sustainable does not only benefit them but also the society at large.

3.2 Journal of publication

The journals that published research on SBMs in SMEs can primarily be assigned to the challenging areas relating to sustainability, sustainable development, socioeconomics, corporate social responsibility, business strategy, entrepreneurship and innovation in business sustainability. It is not surprising that the majority of publications were found in the areas of sustainable business and strategy in corporations. As shown in Table 1, most of the papers were published in the journals *Cleaner Production*, *Sustainability*, and *Business Strategy and the Environment.*

Table 1. Overview of journals that published papers on SBMs in SMEs

Name of journal	**Number of Published Articles**
Cleaner Production	25
Sustainability	23
Business Strategy and the Environment	6
Corporate Social Responsibility and Environmental Management	2
Renewable Energy	2
Acta Commercii	1
Agriculture	1
British Food	1
Business Ethics	1
Business Horizons	1
Economics and Management (JEM)	1
Energies	1
Engineering and Environment	1
Entrepreneurship and Innovation	1
Entrepreneurship, Management and Innovation	1
European Countryside	1
Fashion Practice	1
Forest Policy and Economics	1
Global Business and Organizational Excellence	1
Integrative Environmental Sciences	1
Precision Engineering and Manufacturing-Green Technology	1
Production Economics	1
Knowledge Management	1
Management & Marketing. Challenges for the Knowledge Society	1
Management Decision	1
Research Policy	1
Resources, Conservation and Recycling	1
Small Business Management	1
Social Business	1
Sustainable Tourism	1
Technology Analysis and Strategic Management	1
TEM JOURNAL – Technology, Education, Management, Informatics	1
Total	**85**

Source: The authors

3.3 Research aims/objectives

Throughout the reviewed articles, the authors of the present paper approached the field of SBMs in SMEs with different aims in mind. Some papers had multiple objectives as well. Although the majority of articles were of exploratory nature (83 articles), some papers aimed at developing hypotheses and archetypes (9 articles). The proposition of tools and frameworks for developing a better understanding of SBMs in SMEs also formed a considerable proportion of the papers covered (9 articles). Articles aimed at testing certain areas related to SBMs in SMEs were a rare occurrence (3 articles). The organisation of research aims across articles is illustrated in Table 2.

3.4 Exploratory articles

The articles of exploratory nature were further grouped based on the driving topics they were trying to examine.

3.4.1 The antecedents and influencers of SBMs

(a) Challenges and barriers to the development, adoption and implementation of SBMs, such as articles on barriers when transitioning to sustainable product-service systems (de Jesus Pacheco et al., 2019), linking path dependencies to cognitive barriers (Brozovic, 2019) or exploring barriers to implementing sharing economy business models (Govindan et al., 2020).

(b) Enablers, influencing and success factors of SBMs, such as papers highlighting environmental management practices (EMPs) as a supportive factor (Buffa et al., 2018), identifying market conditions influencing SBMs (Bolesnikov et al., 2019) or exploring consumer needs and demands, thus shaping business models towards sustainability (Bonadonna et al., 2019).

3.4.2 The activation and operationalisation of SBMs

(a) The evolution, lifecycle and path dependencies of SBMs, such as articles exploring business model evolution and path dependencies in the electric vehicle industry (Bohnsack et al., 2014), identifying the development stages of business models for sustainable tourism (Szromek, 2019) or following the innovation journey in the business model of a Scandinavian social enterprise (Olofsson et al., 2018).

(b) The role of SBMs in value creation and delivery, such as exploring how sustainable value is created through bicycle sharing schemes in Barcelona (Winslow and Mont, 2019) or closely investigating the full cycle of value creation, delivery and capture in circular bioeconomy business models amongst Finnish SMEs (D'Amato et al., 2020).

(c) The practices and characteristics of SBMs, such as looking at circular economy implementation practices by Italian SMEs (Mura et al., 2020), exploring business model innovation practices to overcome hybridity tensions in sustainable entrepreneurship (Matzembacher et al., 2020) or characterising B Corps as sustainable enterprises in Australia (Stubbs, 2017).

(d) The relations and interdependencies of SBMs with: management research and theories (e.g. García-Álvarez de Perea et al., 2019) looking at internationalisation Business Models (BMs) for sustainable agri-food SMEs and Multinational Enterprises (MNEs); organisational factors (e.g. Hahn et al., 2018) correlating the commercial orientation within organisations with the development of hybrid business models; and the ecosystem (e.g. Neumeyer and Santos, 2018) exploring SBM in relation with entrepreneurial ecosystems from a social network perspective.

3.4.3 Effects and impacts of SBMs and sustainability practices

The benefits of SBMs, such as those in articles identifying the value created by SBMs in the tourism industry (Kruczek and Szromek, 2020), exploring the impact of CSR training and practices on business outcomes (López-Pérez et al., 2017), studying their investment attractiveness (de Lange, 2017) or exploring SBMs impact on regional policy and investment planning (Robinson et al., 2017).

3.5 Developmental articles

A lesser share of articles aimed at developing or elaborating on certain archetypes and hypotheses related to sustainability and business models, including Bocken et al.'s (2014) literature review to develop SBMs archetypes and Tate and Bals' (2016) study proposing a social resource-based view (social RBV). Daou et al. (2020) devised a tool using the Eco canvas for developing circular economy business models and Minatogawa, Franco, Rampasso et al. (2019) developed a tool for business model innovation in sustainable SMEs. Additionally, frameworks were proposed with contextual practical utilisation, such as Townsend et al. (2019) who identified and developed SBM for the fashion industry or Ünal et al. (2019) who created a circular business model for SMEs in the construction/building sector.

3.6 Testing articles

The smallest proportion of the literature reviewed aimed at testing the readiness of SMEs for sustainability and eco-innovation (Pigosso et al., 2018) or at assessing the financial viability of SBMs (Hamid and Blanchard, 2018) and their financial models (Elmustapha and Hoppe, 2020).

3.7 Research setting

The sectors that were represented in the articles reviewed are illustrated in Figure 1. There was a wide representation of multiple sectors in the reviewed articles. It was found that over one-third of the articles (29) were sector agnostic, such as those accounting for the relation between firm size and SBM innovation (Aguilar-Fernández and Otegi-Olaso, 2018); those reviewing and developing SBM archetypes (Bocken et al., 2014); those studying the SBMs' impact on attractiveness (de Lange, 2017); or those exploring how digital technologies can enable the adoption and activation of SBMs (Gregori and Holzmann, 2020).

The most represented sectors in our systematic literature review were manufacturing (7 articles), e.g. investigating the barriers for product-service systems transformation into sustainable models (de Jesus Pacheco et al., 2019), and food and beverage (7 articles), such as the work of Long et al. (2018) identifying critical success factors for food SMEs transforming into SBMs in the Netherlands. These sectors were followed by hospitality (6 articles), e.g. Buffa et al. (2018) who reviewed environmental management practices for SBMs in small- and medium-sized hotels in the Italian Alpes. Next was agriculture (5 articles), with Cederholm Björklund (2018) identifying barriers to SBM innovation in this sector. The fashion industry was investigated in 5 articles, with one developing an SBM for the fashion industry (Townsend et al., 2019). The study of social enterprises was the focus of 5 articles, e.g. developing a roadmap for transforming an non-governmental organization (NGO) into a sustainable social enterprise (Dumalanède and Payaud, 2018). Renewable energy was addressed in 5 articles with one assessing workable financial models for solar energy SMEs (Elmustapha and Hoppe, 2020).

Other sectors covered included construction (3 articles), electricity (2), automotive (2), forestry (2), sharing economy (2), ecological start-ups (1), industry 4.0 (1), business services (1), pharmaceuticals (1) and NGOs (1).

Table 2. Overview of the research aims found in the papers reviewed

Research aim	Topic	Authors
Explore	Challenges and barriers to SBMs adoption	de Jesus Pacheco et al., 2019; Brozovic, 2019; Govindan et al., 2020; Caldera et al., 2019; Rizos et al., 2016; Cederholm Björklund, 2018; Linder and Williander, 2015; Staicu and Pop, 2018; Long et al., 2018; Baldassarre et al., 2020; Ahlgren Ode and Lagerstedt Wadin, 2019; Battistella et al., 2018; Soltysova and Modrak, 2020
	Enablers, influencers, and success factors	Buffa et al., 2018; Bolesnikov et al., 2019; Bonadonna et al., 2019; Caldera et al., 2019; Rizos et al., 2016; Staicu and Pop, 2018; Long et al., 2018; Battistella et al., 2018; Dyck and Silvestre, 2018; Ievoli et al., 2019; González-Varona et al., 2020; Gregori and Holzmann, 2020; Voinea et al., 2019; Peralta et al., 2019; Belyaeva et al., 2020; Vongchan, 2020; Real et al., 2020; Veleva and Bodkin, 2018; Halme and Korpela, 2013; Karlsson et al., 2017; Filser et al., 2019; Bocken, 2015
	SBM evolution, life cycle and path dependencies	Brozovic, 2019; Bohnsack et al., 2014; Szromek, 2019; Olofsson et al., 2018; Byerly, 2014
	Benefits of SBMs	(Kruczek and Szromek, 2020; Matinaro et al., 2019
	Impact on financial performance and shareholders/ firm value	López-Pérez et al., 2017, 2018; Broccardo and Zicari, 2020; Okanga and Groenewald, 2017
	Impact on investment attractiveness and policy planning	de Lange, 2017; Robinson et al., 2017
	Role in value creation and delivery	Winslow and Mont, 2019; D'Amato et al., 2020; Tate and Bals, 2016; Ünal, et al., 2019; Dyck and Silvestre, 2018; Müller and Voigt, 2018; Cannas et al., 2018; Gregori et al., 2019; Henriques and Catarino, 2015; Kuckertz et al., 2019
	SBMs characteristics and practices	Mura et al., 2020; Matzembacher et al., 2020; Stubbs, 2017; Jolink and Niesten, 2013; Sedlmeier et al., 2019; Nigri and Del Baldo, 2018; Plank et al., 2016; Dumalanède and Payaud, 2018; Hahn and Ince, 2016
	Relations with other areas of management research	García-Álvarez de Perea et al., 2019; Filser et al., 2019; Müller and Voigt, 2018; Gregori et al., 2019; Rosca et al., 2017; Chaurasia et al., 2020; Davies and Chambers, 2018; Lüdeke-Freund, 2019
	Interdependence on organisational factors	Hahn et al., 2018; Aguilar-Fernández and Otegi-Olaso, 2018
	Ecosystem and network relationships	(Neumeyer and Santos, 2018; Bocken, 2015; Cannas et al., 2018; Valdez-Juárez et al., 2018
Develop	Archetypes and hypotheses	Bocken et al., 2014; Tate and Bals, 2016; Hamid and Blanchard, 2018; Soltysova and Modrak, 2020; Byerly, 2014; Safar et al., 2018; Lee and Chang, 2019; Svobodová and Urbancová, 2016; Pattinson, 2019)
	Tools	(Daou et al., 2020; Minatogawa, Franco, Rampasso et al., 2019; Henriques and Catarino, 2015; Ulvenblad et al., 2018; Minatogawa, Franco, Durán et al., 2020
	Frameworks	Townsend et al., 2019; Ünal, et al., 2019; Lüdeke-Freund, 2019; Todeschini et al., 2017
Test	Readiness for implementation	Pigosso et al., 2018
	Financial viability	(Hamid and Blanchard, 2018; Elmustapha and Hoppe, 2020)

Source: The authors

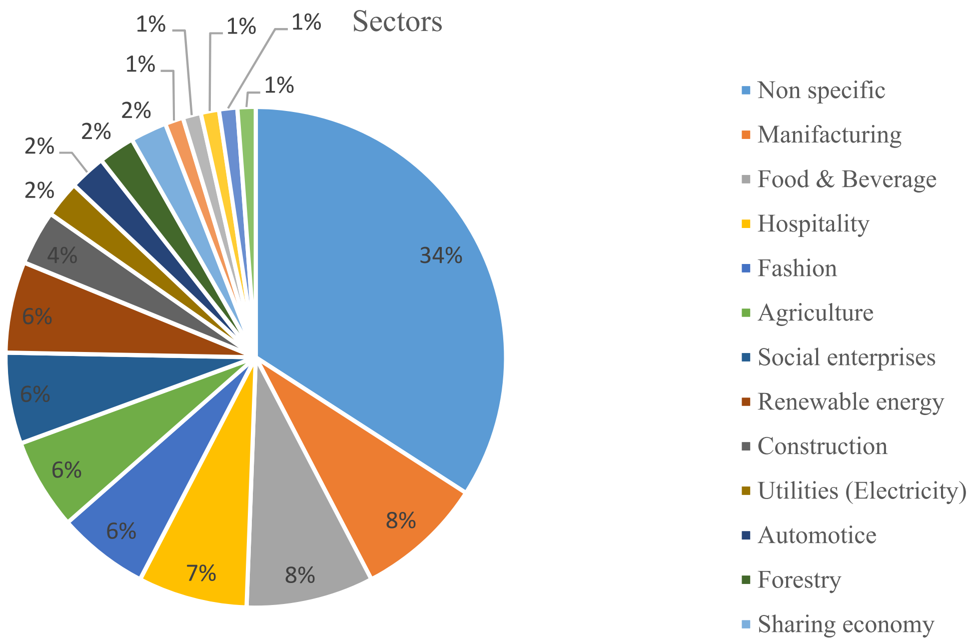

Figure 1. Paper distribution by sector
Source: The authors

The geographical distribution of the reviewed papers is summarised in Figure 2. The majority of papers were conducted in Europe, with 52 articles, followed by the US and Latin America with 7 papers each. There were 6 research papers studied in Asia, followed by Africa with 2 papers. Only 2 studies were conducted in Australia and 1 in the Middle East, while 8 papers covered more than one continent (e.g. Matzembacher et al., 2020).

Of the 52 studies conducted in Europe, those conducted in Sweden predominated with 8 articles, such as Brozovic's (2019) research on business models related to strong sustainability and Ulvenblad et al.'s (2018) study focusing on SBMs role in innovating business activities. Studies conducted in Spain came second, such as the study by Peralta et al. (2019) addressing SBM development. With respect to studies that covered multiple locations, some investigated SBMs for start-ups across different continents (e.g. North America, Europe and Asia: de Lange, 2017), while others had a regional focus (e.g. Nordic countries: Halme and Korpela, 2013).

Outside Europe, research on SBMs in SMEs was conducted in the US (e.g. Neumeyer and Santos, 2018; Kuckertz et al., 2019), while 6 studies were conducted in Brazil (e.g. Barbieri and Santos, 2020; Minatogawa, Franco, Rampasso et al., 2019) and 1 in Mexico (Valdez-Juárez et al., 2018), representing contributions from Latin America.

The 6 articles from Asian countries were conducted in China (Müller and Voigt, 2018), India (Chaurasia et al., 2020; Govindan et al., 2020), Taiwan (Lee and Chang, 2019; Matinaro et al., 2019) and Thailand (Vongchan, 2020). Some studies were conducted in Africa, such as those by Gregori et al. (2019) in Uganda and Hamid and Blanchard (2018) in Kenya. Finally, Elmustapha and Hoppe (2020) studied the topic of SBMs in Lebanon in the Middle East.

From the above information, it can be concluded that the study of SBMs in SMEs is dominated by contributions from Europe.

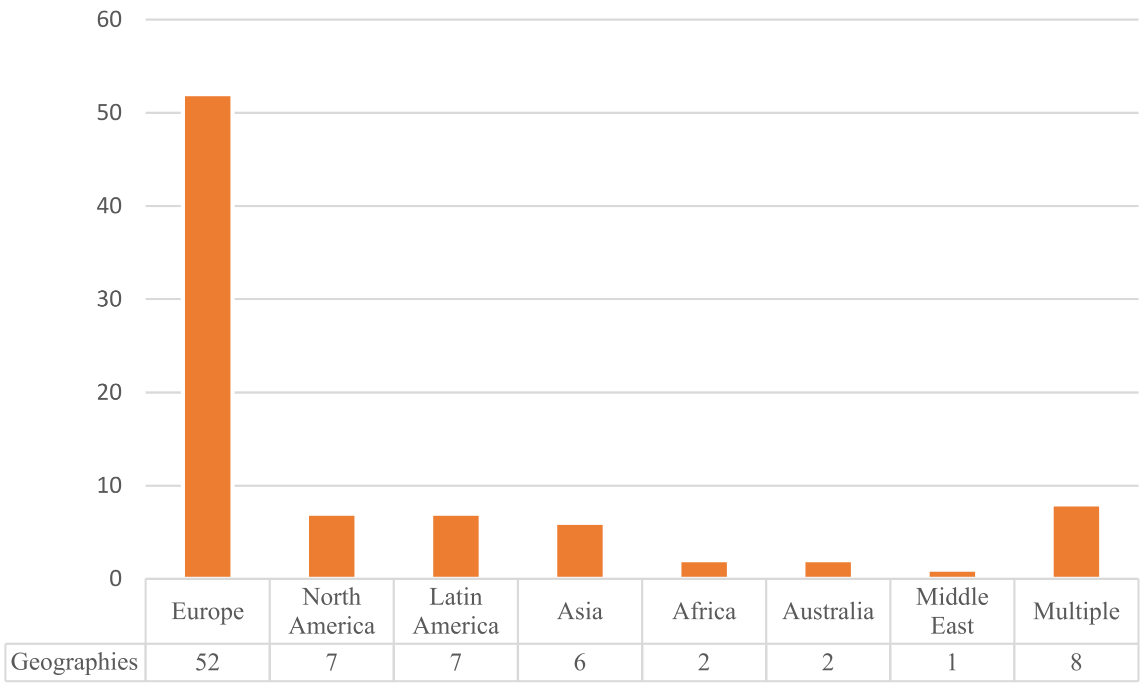

Figure 2. Paper distribution by geography

Source: The authors

3.8 Theories and theoretical perspectives

The theories and perspectives applied in the reviewed papers are summarised in Table 3. The table clarifies that researchers in the field of SBMs in SMEs applied several different theories to study the topic under investigation, such as the resource-based view (RBV), institutional theory and stakeholder theory. Even though the use of the Business Model Canvas as a tool for approaching business models is still used, findings suggest that an increasing number of authors is using alternative theories to develop a more scientific and grounded understanding of business models in order to increase the research field's legitimacy. Our findings also show that several authors used more than one theory/theoretical perspective. The table below highlights the theories and theoretical perspectives applied by the authors to study the field of SBMs in SMEs.

3.9 Research methods

Figure 3 provides an overview of the research methods used in the reviewed articles and Table 4 provides a further breakdown of each method. In addition, the table provides some additional details about the concrete techniques used in the different articles. One can see that the papers primarily utilised mono methods or case study methods (31 papers each). Case study papers can be further divided into case studies in general—as the authors remained silent about their actual case study approach—single case study approaches and multiple case study approaches.

A total of 9 articles were assigned to the category of theoretical/conceptual papers. This is followed by multi-method papers (i.e. the ones that used more than one research method: 7 papers) and mixed methods papers (i.e. the ones that mixed qualitative and quantitative methods/data: 3 papers). There were 5 articles based on rarer approaches in this research field – namely, design science research method (4 articles) and action research (1 paper).

Table 3. Theories and theoretical perspectives

Theories and theoretical perspectives	Authors
Triple Bottom Line	Tate and Bals, 2016; Battistella et al., 2018; Dyck and Silvestre, 2018; Bocken, 2015
Business Model Canvas	(Bonadonna et al. 2019; , Robinson et al., 2017; Daou et al., 2020; Okanga and Groenewald, 2017; Müller and Voigt, 2018; Dumalanède and Payaud, 2018; Aguilar-Fernández and Otegi-Olaso, 2018
Social Contract Theory	Byerly, 2014
Institutional Theory Perspective/ Institutional Logics Perspective	Winslow and Mont, 2019; Caldera et al., 2019; Gregori and Holzmann, 2020; Gregori et al., 2019
S-D logic	Cannas et al., 2018
Hybrid Organisational Theory	Matzembacher et al., 2020; Davies and Chambers, 2018
Corporate Social Responsibility	(de Lange, 2017
Internationalisation Theories	García-Álvarez de Perea et al., 2019)
Resource-based View	(López-Pérez et al., 2017a; Tate and Bals, 2016; Townsend et al., 2019; Dyck and Silvestre, 2018; Halme and Korpela, 2013; López-Pérez et al., 2017b
Socio-echnical Transition Theories	Elmustapha and Hoppe, 2020
Value Analysis Methodology	Henriques and Catarino, 2015
Social Capital Theory	López-Pérez et al., 2017b; Voinea et al., 2019
Stewardship Theory	López-Pérez et al., 2018
Socioemotional Wealth Theory	López-Pérez et al., 2018
Agency Perspective	Lüdeke-Freund, 2019
Systems Perspective	Lüdeke-Freund, 2019
Stakeholder	Vongchan, 2020; Matinaro et al., 2019; Valdez-Juárez et al., 2018
Organisational Ambidexterity	Minatogawa, Franco, Durán et al., 2020
Network Theory	Neumeyer and Santos, 2018
Technological Innovation Systems	Planko et al., 2016

Source: The authors

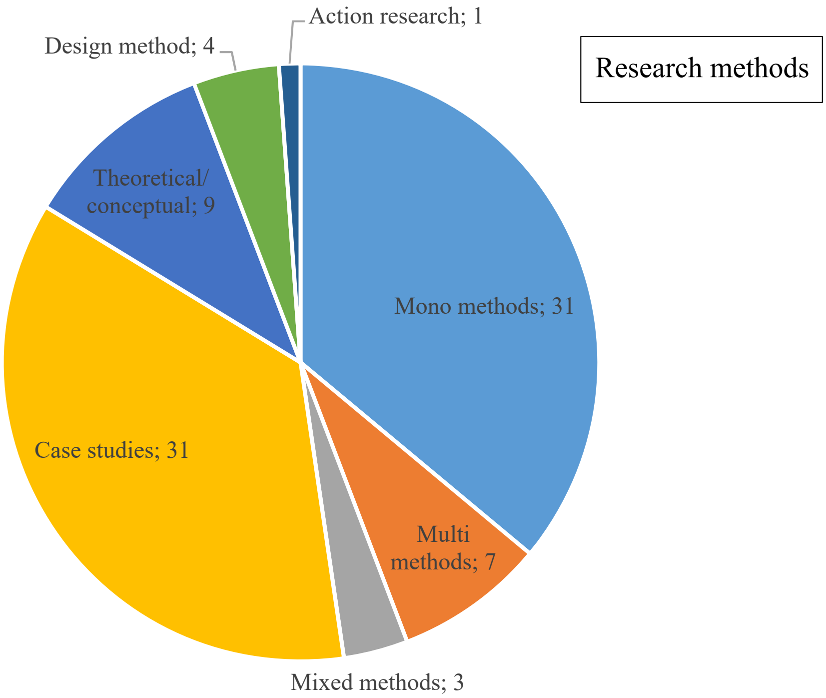

Figure 3. Overview of research methods

Source: The authors

Table 4. Overviews of research methods covered in the papers analysed

Research methods	Number of papers
Mono methods	*31*
- Interview studies	10
- Questionnaires	11
- Use of secondary data/creation of own database	
◦ Decision-making trial and evaluation laboratory (DEMATEL)	1
◦ Sensitivity analysis	1
◦ Different types of regressions	1
◦ PCA and cluster analysis	1
◦ Logistic function	1
- Mystery shoppers	1
- Content analysis	2
- Workshops	1
- Participative observations	1
Multi methods	*7*
- Open interviews followed by semi-structured interviews	1
- Semi-structured interviews conducted with individuals and groups	1
- Observation, interviews plus secondary data	1
- Semi-structured interviews, homepages, blog posts, social media, newspaper articles, videos	1
- Expert interviews, specialised press, number of start-ups	1
- Interpretative phenomenology analysis and action research	1
- Secondary data (media, research works) and semi-structured interviews	1
Mixed methods	*3*
- Interviews, surveys & focus groups	1
- Semi-structured interviews, Business Model comparisons, GIS landscape analysis, value potential and ROI scenarios	1
- Structured survey and case studies	1
Case studies	*31*
- Case study approach	3
- Development of a conceptual tool that was then tested in firms	1
- Interviews, process analysis, company records	1
- Site visits, talks	1
- Semi-structured interviews, online publications, newsletters, professional publications	1
- Semi-structured interviews, open interviews, archival data	1
- Qualitative case study; in-depth/semi-structured interviews	2
- In-depth personal interviews, documents, field visits	1
- Exploratory; corporate documents, websites, press releases	1
- Interviews and questionnaire	1
- Publicly available information: websites, annual/sustainability reports, in-depth semi-structured interviews	1
- Instrumental design; interviews, field notes, photos, and printed marketing material	1
Single case study approach	
- Interviews, official and internal documents	1
- Semi-structured interviews, secondary data	1
- Longitudinal action research; observation, semi-structured interviews, decision-making meetings, structured interviews, market segment survey, customer interviews and follow-up interviews	1
- Semi-structured interviews, focus groups and archival data	1
- Single embedded, semi-structured interviews	1
- Quantitative and qualitative information	1
- Exploratory; semi-structured interviews, website, company blogs, magazines, documents	1
Multiple case study approach	
- Semi-structured interviews, press reviews, websites and archival documents	1
- Interviews, websites, news databases, internal documents	1
- Semi-structure interviews	3
- Deductive case study logic, one-year period, interviews, websites, social media, blogs	1
- Interviews, websites, product specifications, news media	1
- Exploratory; use of publicly available documents	1
- Exploratory; semi-structured interviews	1

Table 4 (continued)

Theoretical/conceptual papers	*9*
(Systematic) literature reviews	3
Conceptual papers	4
Bibliometric technique	1
Theoretical paper	1
Design science research method	4
Action research method	1

Source: The authors

3.10 Unit of analysis

The majority of studies reviewed in this paper used the individual as the unit of analysis, including business owners (e.g. Cannas et al., 2018), entrepreneurs (e.g. Davies and Chambers, 2018) and managers (e.g. López-Pérez et al., 2017).

Some studies were also interested in studying SBMs from a group perspective. For instance, Barbieri and Santos (2020) investigated a group of managers and employees in the veterinary homeopathy pharmaceutical industry, while Lee and Chang (2019) involved a group of department heads, managers and workers in their research on SBMs in forestry firms.

We also found studies that had groups of enterprises as their unit of analysis, e.g. SME food chains (Bonadonna et al., 2019) and a mixed group of SMEs and start-ups in the food and beverages sector (Long et al., 2018).

3.11 Themes of interest

The articles that were analysed explored SBMs from different perspectives, trying to identify their characteristics, how they are affected and impacted by other ecosystem components and how theories about their development and evolution can be synthesised. We identified five broad themes running through them in relation to SBMs in SMEs (see Table 5).

As indicted in Table 5, articles studying the antecedents of SBMs and their activation/realisation had the most representation, with 24 and 21 articles, respectively. This is understandable because the concepts of sustainability, SBMs and business model innovation are relatively new to research and have had exponential growth in interest in recent years across both policymaking and industry.

The extant literature has explored several challenges and barriers such as: lack of financial resources and knowledge (Caldera et al., 2019); internal practices related to the lack of competence and follower mentality (de Jesus Pacheco et al., 2019); and mental models and obsolete paradigms (Brozovic, 2019). Others have considered the prerequisites and requirements affecting SBM adoption and implementation – e.g. Rizos et al. (2016) focus on company culture and networks; Dyck and Silvestre (2018) on organisational capabilities and Caldera et al. (2019) on highlighting integrated strategy and stakeholder engagement. Papers examining possible methods for the successful integration and

Table 5. Classification of themes

Theme	Number of articles
Antecedents	24
Activation	21
Relational	15
Theoretical	14
Effects	11
Total	85

Source: The authors

operationalisation of SBMs within organisations included Jolink and Niesten's (2013) suggestions for leveraging network partners and Elmustapha and Hoppe's (2020) identification of financial models for sustainable SMEs.

Following from there, several articles explored the relations between SBMs, sustainability and other variables. One group of articles explored relations with other fields of management research, such as frugal innovation (Rosca et al., 2017), hybridity and BM theory (Davies and Chambers, 2018) and open innovation (Chaurasia et al., 2020). Another group of researchers explored the relationship with organisational factors, such as business size (Aguilar-Fernández and Otegi-Olaso, 2018) or commercial orientation (Hahn et al., 2018). A third group looked at how SBMs interact with ecosystem forces, such as the availability of venture capital (Bocken, 2015), social networks influence (Neumeyer and Santos, 2018), supply chain innovation (Valdez-Juárez et al., 2018) or the intersections of sustainable entrepreneurship, sustainability innovation and business models (Lüdeke-Freund, 2019).

As expected with a nascent field of research, there were articles of theoretical nature trying to develop our understanding of SBMs in SMEs. These papers suggested SBM archetypes (Bocken et al., 2014), addressed the evolution of various forms of SBMs (Byerly, 2014), proposed a sustainable value methodology (Henriques and Catarino, 2015), investigated SBM characteristics such as culture and orientation (Hahn and Ince, 2016) and proposed an extension of the RBV) to a social RBV (Tate and Bals, 2016). Other papers provided a classification for sharing economy business models (Soltysova and Modrak, 2020) as well as tools for business model innovation (Minatogawa, Franco, Rampasso et al., 2019; Minatogawa, Franco, Durán et al., 2020). Additional articles developed frameworks to support SBM development and implementation in multiple contexts – e.g. in fashion (Todeschini et al., 2017; Townsend et al., 2019), construction (Ünal et al., 2019) and others.

Finally, there were empirical papers that assessed the effects/impacts of SBMs on investment attractiveness (de Lange, 2017), shareholder value (López-Pérez et al., 2017), market performance (Okanga and Groenewald, 2017), policy and regional investment planning (Robinson et al., 2017) and business outcomes (López-Pérez et al., 2018). Only a few papers investigated the benefits of SBMs (Kruczek and Szromek, 2020; Matinaro et al., 2019).

5. Avenues for further development

Conducting this literature review helped us identify several limitations in the existing literature, which can serve as the basis for future research. First, our findings are in line with Miller et al.'s (2020) observation that the heterogeneity found in SMEs has not been addressed in the papers analysed for this systematic literature review. One may argue that researchers either underestimated this aspect or did not take it into account at all. Given the fact that a micro company cannot be compared with a medium-sized company, we follow Miller et al. (2020) and call for future research that takes into consideration the differences found amongst SMEs and tries to understand their implications for SBMs, its development and continued adaption. These activities may also lead to the identification of dominant business models that take into consideration size and industry differences.

Our findings have also clarified that the study of failure regarding SBM activities – e.g. failed business model innovation – is missing/underdeveloped. Thus, one can conclude that the call by Geissdoerfer et al. (2018) still prevails. Given the higher failure rate of small firms, particularly new ones, in comparison to their larger counterparts (Mayr and Lixl, 2019), there is a clear need for research to turn towards failed activities as well to advance our understanding of SBMs in SMEs.

From a geographical coverage perspective, it appears that most literature had thus far focused on Europe, with scarce amounts of research performed in Latin America outside of Brazil or in Africa and the Middle East. Hence, we call for more research to focus on exploring the topic of SBMs in SMEs in developing countries from these regions in particular.

With regards to the sectors in which the SMEs in the reviewed articles operated, it seems that the current literature only covers a narrow spectrum of industries – i.e. manufacturing, agriculture and fishing; renewable energy; fashion; tourism; and, to a limited extent, renewable manufacturing; forestry; sharing economy; and construction. These are commonly the sectors that are closely connected with sustainability and social enterprise themes. However, research is missing on SBMs in SMEs representing other crucial industries, such as advanced and heavy manufacturing, pharmaceuticals, fossil fuel and energy and traditional automotive, or service sectors, such as information technology and communications, healthcare, education and learning and retail. SMEs operating in those sectors were not studied in the reviewed articles, neither empirically nor theoretically.

Papers exploring the effects of SBMs focused on traditional measures for assessing business outcomes – those related to finances, such as the financial performance of a company, shareholders and firm value as well as the investment attractiveness of SBMs and companies adopting them. Even when exploring policy implications, the reviewed papers primarily focused on the investment planning aspect. We suggest that future research should investigate the impact of SBMs, with their practices and innovations, using other business metrics, including employee satisfaction and retention, brand reputation and customer engagement as well as knowledge generation and innovation ability of the company. Additionally, we advise future research to look beyond business outcomes into sustainability-related indicators—those related to the adoption of SBMs by SMEs. We also advise studying the links with regional and national policy planning and implementation while using different lenses than the financial one. As the majority of studies investigating the impact of SMEs' adoption of SBMs on firm performance and the local economy followed a qualitative exploratory approach, we suggest that future research on this link could adopt/include quantitative methods.

The scarcity of papers aimed at testing devised theories or theoretical frameworks can be attributed to the relative nascency of this research area. Most researchers are thus far mainly inclined towards adopting an exploratory approach. Acknowledging recent developments that show an increasing production of multiple theoretical frameworks, we suggest that more researchers should follow this promising path and turn towards the testing of the knowledge developed.

With regard to the methods used, the reviewed studies suggest that the case study methodology—often based on different types of interviews, i.e. semi-structured interviews, in particular – has been overused. Future research should consider using different research methods and paradigms, going beyond the typical ones. With respect to the latter, inclusive research approaches may prove useful to advance research on SBMs in SMEs. Moreover, there is also room for more longitudinal research projects to further our understanding of the activities and efforts undertaken in SMEs with regards to the SBM development and thus the hampering and supporting factors encountered.

6. Conclusion

In view of the increasing relevance and wider acknowledgement of SBMs, a better understanding of this topic is essential and can contribute to greater development and improvement in the awareness related to this specific type of business model. Accordingly, the purpose of this paper was to systematically review research on SBMs in SMEs in order to establish the current body of knowledge regarding this topic. The focus on SMEs is logical given their impact on European economies and, consequently, on their further sustainable development (European Central Bank, 2021).

Based on a total of 85 reviewed papers, the current frame of knowledge regarding SBMs in SMEs was determined and specified. This has helped us develop a more comprehensive view of the topic and, in turn, has formed a basis for upcoming research activities.

The study has practical implications that could be helpful to SME managers and entrepreneurs who are considering the adoption and promotion of SBMs in their organisations. As was determined in this study, there is already a good understanding of both the supporting and hampering factors that practitioners should be aware of.

The authors are aware that the present study is not without limitations. Due to the chosen research procedures, this study may not have enabled complete coverage of all scientific articles in the field of SBMs in SMEs. Nevertheless, it seems reasonable to assume that the review process covered a large portion of available studies.

The future research avenues proposed here, although perhaps not exhaustive, are viewed as possible further steps for the advancement of research on SBMs in SMEs.

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SECTION 3.
SUSTAINABLE DEVELOPMENT OF REGIONAL INFRASTRUCTURE

РАЗДЕЛ 3.
УСТОЙЧИВОЕ РАЗВИТИЕ РЕГИОНАЛЬНОЙ ИНФРАСТРУКТУРЫ

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BALANCE SCOREBOARD FOR SUSTAINABLE DEVELOPMENT IN THE RUSSIAN ARCTIC ZONE

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Abstract

This article carries out a comparative analysis of the modified structures of the classical system of balanced scorecards of domestic and foreign authors. The necessity of using the tool of balanced scorecards to manage the development strategy of socio-economic systems (SES) has been substantiated. This tool was the methodological basis of the research in the development of a system of indicators for assessing the sustainable development of socio-economic systems of the Arctic zone of the Russian Federation (shipbuilding cluster, Arkhangelsk region). Strategic maps have been developed for the Arkhangelsk region and the Cluster of Shipbuilding and Production of Marine Equipment of the Arkhangelsk region association, reflecting the main strategic objectives for the four perspectives (components). At the first stage of the process of forming a strategic map of the shipbuilding cluster, four adapted components were proposed: the financial component, the environmental component, the domestic and external market, and development and modernisation. Four additional adapted components for the Arkhangelsk region were proposed: the region's well-being, the ecological component, the economic component, learning and development. For each strategic goal, indicators were developed to assess the progress of achievement, based on which a balanced scorecard system was developed for the cluster and the region. This system reflects an interconnected set of indices of sustainable development for each level. These indices can be used to evaluate and monitor the results of the implementation of relevant strategies and to study the relationship between the sustainable development of the Arkhangelsk region and the activities of the Cluster of Shipbuilding and Production of Marine Equipment of the Arkhangelsk region association.

Keywords: balanced scorecard (BSC), modified BSC models, sustainable development, shipbuilding cluster, Arkhangelsk region, strategic map.

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ФОРМИРОВАНИЯ ИНДИКАТОРОВ УСТОЙЧИВОГО РАЗВИТИЯ СОЦИАЛЬНО-ЭКОНОМИЧЕСКИХ СИСТЕМ АРКТИЧЕСКОЙ ЗОНЫ РФ НА ОСНОВЕ СИСТЕМЫ СБАЛАНСИРОВАННЫХ ПОКАЗАТЕЛЕЙ

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Аннотация

В данной статье рассмотрены модифицированные структуры классической системы сбалансированных показателей отечественных и зарубежных авторов. Проведен сравнительный анализ данных концепций и моделей сбалансированных систем. Обоснована необходимость использования такого инструмента, как система сбалансированных показателей для управления стратегией развития социально-экономических систем. Данный инструмент явился методологической основной исследования при разработке системы индикаторов оценки устойчивого развития социально-экономических систем Арктической зоны РФ (судостроительного кластера, Архангельской области). Для Архангельской области и ассоциации «Кластер судостроения и производства морской техники Архангельской области» были разработаны стратегические карты, отражающие основные стратегические цели по четырем перспективам (составляющим). На первом этапе процесса формирования стратегической карты судостроительного кластера были предложены четыре адаптированные составляющие: финансовая составляющая, экологическая составляющая, внутренний и внешний рынок, развитие и модернизация. Также были предложены четыре адаптированные составляющие для Архангельской области: благосостояние региона, экологическая составляющая, эконмическая составляющая, обучение и развитие. Для каждой стратегической цели были разработаны индикаторы оценки прогресса в их достижении, на основе которых была разработана система сбалансированных показателей (ССП) для кластера и региона. ССП отражает взаимоувязанный набор показателей (индикаторов) устойчивого развития для каждого из уровней. Данные показатели (индикаторы) могут быть использованы для оценки и мониторинга результатов реализации соответствующих стратегий и исследования взаимосвязи устойчивого развития региона (Архангельская область) и деятельности ассоциации «Кластер судостроения и производства морской техники Архангельской области».

Ключевые слова: сбалансированная система показателей (ССП), модифицированные модели ССП, устойчивое развитие, судостроительный кластер, Архангельская область, стратегическая карта.

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Introduction

The world economy is characterised by a long and ongoing process of globalisation. Globalisation can be seen as both positive and negative. The need for global social, economic and environmental solutions has led to the development of the concept of sustainable development.[1]

In the Russian Federation, the state policy of regional development currently aims at ensuring the sustainable socio-economic development of federal subjects of Russia.[2] Developed strategies for the socio-economic development of different regions of the Russian Federation include tasks such as ensuring sustainable economic growth, development of human capital, improving the quality of the urban environment, ensuring the efficiency of governance and development of civil society. In many regions of the Russian Federation, attempts are being made to integrate environmental and social aspects into the strategic management system. The sustainable development is the major prioritized line for the regional development government policy for the Arctic zone of the Russian Federation due to geopolitical and geoeconomic regional characteristics. At the same time, in the face of the permanent growth of global economic competition, states – especially those with emerging economies – have to develop more innovative, cost-effective, competitive forms of cooperation among economic agents with the active involvement of the research sector. As successful international practice shows, this kind of cooperation can be the unification of several stakeholders in the form of an industrial (or any other, depending on the objectives of the participants) cluster. The form of cluster cooperation as cooperation of several parties (industrial enterprises, suppliers, banks, investors, government bodies, scientific organisations) into one general formation achieves a cumulative synergistic effect through, among other things, savings on costs, as well as through mutual diffusion of unique knowledge, which, in turn, contributes to the differentiation of manufactured products and increase of the overall competitiveness.

Despite the positive effects of cluster creation, there is no universal procedure to assess and analyse the impact of cluster results on the sustainable development of a region. In order to carry out this analysis, it is necessary to identify the relationship between the main indicators of the cluster's performance and the level of sustainable development of the region. To identify this relationship, it is necessary to determine the indicators that could assess the effectiveness of the cluster and the level of sustainable development of the region. Typically, these figures are contained in relevant strategic documents, strategies or development programmes.[3,4,5,6,7,8,9,10]

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[4] RF Presidential Decree of 01.04.1996 N 440 "On the Concept of the Transition of the Russian Federation to Sustainable Development". Available at: http://www.consultant.ru/cons/cgi/online.cgi?req=doc&base=EXP&n= 233558 # 04747149941947586

[5] Federal Law of June 28, 2014 N 172-FZ (as amended on December 31, 2017) "On strategic planning in the Russian Federation" Available at: http://www.consultant.ru/document/cons_doc_LAW_164841/

[6] Order of the Government of the Russian Federation of November 17, 2008 N 1662-r (as amended on September 28, 2018) "On the Concept of long-term socio-economic development of the Russian Federation for the period until 2020." Available at: http://www.consultant.ru/document/cons_doc_LAW_82134

[7] RF Presidential Decree of 07.05.2018 N 204 (as amended on 19.07.2018) "On the national goals and strategic objectives of development of the Russian Federation for the period until 2024". Available at: http://kremlin.ru/acts/bank/43027

[8] Decree of the Russian Federation Government dated 21.04.2014 N 366 (as amended on 05.06.2019) "On the approval of the state programme "Socioeconomic development of the Arctic Zone of the Russian Federation". Available at: http://www.consultant.ru/document/cons_doc_LAW_162195/

At the heart of any strategy is strategic analysis and planning. Strategic planning and management are based on the principle of interconnectedness, the complexity of goals and objectives for sustainable socio-economic development. In other world, there is a need for consistency in the actions of government agencies at the regional and federal level, considering the characteristics and capabilities of individual territories.

In order to assess the quality of governance and effectiveness of the ongoing strategy for sustainable development of the Arctic zone of the Russian Federation, specific indicators should be formed, serving as the basis for representatives of different levels of state authorities to assess and monitor the economic, social and environmental situation in any SES (country, region, city, cluster, etc.). In the development and implementation of the cluster strategy, it is necessary to consider the relationship between key indicators of the cluster's performance and indicators of sustainable development of a particular territory of the Russian Federation. Thus, the relevance of the problem, its theoretical and practical significance determined the topic of the study, its purpose and objectives.

The goal of the work is to develop interconnected systems of indicators of sustainable development of the region and the industrial cluster based on the concept of balanced scorecards (BSC). To achieve the set goal, the following tasks were completed: the analysis of BSC as a tool for implementing the sustainable development strategy; the investigation of various BSC modifications; the selection of the best variant of possible prospects of BSC; the proposal of a system of indicators of sustainable development of the region and industrial cluster under investigation.

Literature review

To date, there is no single universal system of indicators of sustainable development assessment. Modern studies highlight two main approaches to constructing indicators and indices of sustainable development:

An indicator system evaluating three areas of sustainable development: environmental, economic, social[11,12] (World Bank, 1997; Hassan, 2008).

A system of integral indices that assess the development of the territories comprehensively. These are divided into the following groups: A) socio-economic; B) environmental and economic; C) social and environmental; D) eco-socio-economic[13,14,15] (Hassan, 2008; Ozkan and Schott, 2013; van Zeijl-Rozema et al., 2011)

[9] Decree of the Russian Federation Government dated 21.04.2014 N 366 (as amended on 05.06.2019) "On the approval of the state programme "Socioeconomic development of the Arctic Zone of the Russian Federation". Available at: http://www.consultant.ru/document/cons_doc_LAW_162195/

[10] President of Russia. Strategy for the development of the Arctic zone of the Russian Federation and ensuring national security for the period until 2020. Available at: http://www.minregion.ru/uploads/attachment/documents/2013/03/200313/200313_2.doc

[11] Indicators for Sustainable Development: guidelines and methodologies. Available at: https://sustainable development.un.org

[12] Sustainable Development Solutions Network. 2014. Why Sustainable Development Goals are Important. Framing Sustainable Development Goals, Targets, and Indicators. Prepared by the SDSN secretariat Issue Brief. Available at: https://irp-cdn.multiscreensite.com/be6d1d56/files/uploaded/141120-Framing-Goals-Targets-and-Indicators.pdf

[13] Recommendations of the Conference of European Statisticians for Measuring Sustainable Development // United Nations Economic Commission for Europe: http://www.cisstat.com14

[14] World development Indicators. 2017. World Bank. Washington DC. Available at: http://data.worldbank.org

[15] SDG Index & Dashboards. A global report (full version). Available at: http://www.sdgindex.org/

Analysis of domestic and foreign literature has shown that, to date, there is no single theoretical-methodological approach for the management and evaluation of sustainable development of the territories, despite a large number of studies on sustainable development [16] (Bell and Morse, 2008; Cornel L. and Mirela L., 2008; World Bank, 1997; Köppen et al., 2008; Loiseau et al., 2012; Mori and Christodoulou, 2012; Ozkan and Schott, 2013; Pope et al., 2004; Uskova, 2019; van Zeijl-Rozema et al., 2011). For example, Hassan (2008) proposed a method to assess sustainable development, based on an adapted multifactorial theory of usefulness. According to the author, this method explores the potential for improving the sustainable development of the region in the short and the long term (Hassan, 2008). Tarasova and Kruchina (2006) consider the close dependence of social well-being and the environment in the problems of human development in the Arctic. Skawińska and Zalewski (2009) proved by research that sustainable development is influenced by economic systems like clusters, which help regions to economically and socially develop. Papa et al. (2017) compared several development indices and conclude that the lack of reliable and structured statistics at the city or region levels creates problems in the development of indices needed to manage territories. Singh et al. (2009) note that the most developed indices do not use a comprehensive approach that would consider environmental, economic and social aspects. According to Kuosmanen et al. (2013), no studies reflect the relationship between the level of sustainable development of the company and the region.

This study will attempt to develop a system of indicators to assess the sustainability of the region and the industrial cluster based on BSC. The classical structure of BSC was proposed by Kaplan and Norton and became widely known around the world (Kaplan et al., 2004). The proposed classical structure of the BSC system indicates that an effective system of measurement of the activities of a modern company should include at least four perspectives: financial perspective, customer perspective, internal perspective, innovation and learning perspective.

The resulting interest in the strategy implementation system contributed to the formation of various domestic modifications of the classical BSC model (Akao, 2020; Andersen, 2007; Cornel L. and Mirela L., 2008; Derek et al., 2015; Gibson, 2015; Hassan, 2008; Kaplan et al., 2004; Mitskievich, 2004; Niven, 2015; Porter, 2000; Rampersad, 2003; van Zeijl-Rozema et al., 2011). Some BSC modifications and their features proposed by domestic economists are presented in Table 1.

As we can see in the matrix, the modified models consist of different components but some of them are repeated. Each model has distinctive features compared to the classical BSC. The “natural replacement” model does not specify the “learning and development” component, which is replaced by the “personnel” component. In the same system, the “marketing” component is more extensive compared to the classical BSC “customers” perspective. The model of the “Russian trinity” is convenient for the BSC owners, because finance forms its entire basis, and the company’s activities are divided into internal and external. A distinctive feature of the “innovation concentration” model is that the staff indicators are scattered across all four perspectives. In the “natural expansion”, the “external world” component considers a set of macroeconomic indicators (currency rates, inflation, consumer income, GDP growth, etc.), the social sphere, the environment and others. A feature of the domestic BSC version “extended classics” is that the section “marketing” includes information about consumers and competitors.

[16] Department of Economic and Social Affairs Commission on Sustainable Development Ninth Session Division for Sustainable Development. 2011. Indicators of sustainable development: framework and methodologies – background paper no. 3. Available at: https://www.un.org/esa/sustdev/csd/csd9_indi_bp3.pdf

Table 1. Matrix of domestic BSC modified structures

№	Components	Names of modified models					
		Classic SSP model	Natural replacement	Russian Trinity	Innovative concentration	Natural expansion	Extended classics
1	finance	+	+	+	+	+	+
2	customers	+					
3	internal business processes	+	+	+	+	+	+
4	learning and development	+				+	
5	marketing		+		+	+	+
6	personnel		+			+	+
7	external world			+		+	+
8	innovation				+		+
9	products						+
10	suppliers						+

Source: Compiled works published by: Akao, 2020; Andersen, 2007; Cornel L. and Mirela L., 2008; Derek et al., 2015; Gibson, 2015; Hassan, 2008; Kaplan et al., 2004; Miscavige, 2004; Niven, 2015; Porter, 2000; Rampersad, 2003; van Zeijl-Rozema et al., 2011.

Most existing foreign models of balanced systems are modifications of the classical approach and differ in the methods or tools applied to achieve the main goals (Akao, 2020). These models include Lorenz Meisel's model, K. McNair's efficiency pyramid, the "control panel", Adams and Roberts' model (EP2M), the stakeholder model, the economic value added management system (Economic Value Added – EVA), the universal Hubert Rampersad performance system, the European Foundation for Quality Management (EFQM) model (Adams and Roberts, 1993; Akao, 2020; Andersen, 2007; Derek et al., 2015; Maisel, 1992; McNair et al., 1990; Mitskievich, 2004; Niven, 2015; Porter, 2000; Rampersad, 2003). All models share common ground with the classical BSC model, but at the same time differ in some components (Table 2).

As we can see in Table 2, the modified models proposed by both foreign and domestic economists have a number of distinctive features compared to the classical BSC model. Meisel's model uses the "human resources" component instead of "learning and development projection". The reason is that the management of the company should pay more attention to its staff and evaluate the effectiveness of employees. In the "efficiency pyramid", instead of the accepted four components, four levels representing the structure of the enterprise and the overall vision of the organisation are proposed. Within these levels, goals and directions of development and actions are highlighted. Unlike classical BSC, where key performance indicators cannot exceed the number fifteen, the "control panel" does not have there are no restrictions on indicators and objectives. Also, this model addresses only two of the components: "financial" and "internal business processes". The EP2M model includes four different components, but the purpose of this system is in line with the goals of BSC, namely, to ensure the implementation of the company's strategy and culture formation. The stakeholder model focuses on creating maximum added value for all stakeholder groups. Such a model does not represent integrated development and maintenance of the organisation's activities, nor does it have a clear structure and links between indicators. The EVA model can lead to short-term benefit-oriented decisions. The universal Hubert Rampersad performance system consists of five components, including a universal set of related indicators. Lastly, the EFQM model consists of nine criteria belonging to the opportunities and results (input criteria – leadership, policy & strategy, people, partnership & resources and processes; result criteria – customer results, employee results, society results and key performance results).

Table 2. Matrix of foreign BSC modified structures

№	Components	Names of modified models							
		Meisel's model	Efficiency pyramid	Control panel	Adams and Roberts' model (EP2M)	Stakeholder model	Economic value-added management system (EVA)	Universal Hubert Rampersad performance system	European Foundation for Quality Management (EFQM) model
1	human resources / people	+							+
2	financial	+	+	+		+	+		+
3	internal business processes	+		+					+
4	customer and market service		+		+				+
5	improving internal processes				+				
6	policy & strategy				+				+
7	property and freedom of action				+				
8	personal BSC							+	
9	organisational BSC							+	
10	universal quality management							+	
11	management / leadership							+	+
12	Kolb's learning cycle							+	
13	personnel training and development	+							+
14	society								+
15	partnership / internal resources								+

Source: Compiled works published by: Adams and Roberts, 1993; Akao, 2020; Andersen, 2008; Derek et al., 2015; Maisel, 1992; McNair et al., 1990; Mitskievich, 2004; Niven, 2015; Porter, 2000; Rampersad, 2003.

As a result of the research, we can say that most of the existing BSC modifications are inferior to the classical BSC, in different ways. Some of these (e.g., EVA, Stakeholder model, "control panel") propose a divergence from the four original BSC projections (Adams and Roberts, 1993; Akao, 2020; Andersen, 2007; Derek et al., 2015; Maisel, 1992; McNair et al., 1990; Mitskievich, 2004; Niven, 2015; Porter, 2000; Rampersad, 2003). The Meisel model and the EP2M model include four projections like the BSC ones, but using other names (Adams and Roberts, 1993; Maisel, 1992). However, the EP2M model is focused not only on the development and implementation of the company's strategy but also on the formation of culture. The Meisel model uses a separate perspective of "human resources" as the management evaluates the effectiveness of not only processes but also people. The universal Hubert Rampersad performance system was developed on the basis of Kaplan and Norton's BSC; however, it is quite large-scale and costly in terms of implementation. Consequently, not all organisations are ready to use the system in its current form. The EFQM model includes two types of criteria: "opportunities" and "results". The "opportunities" reflect how organisations operate as pathways and means or potential factors. The "results" include the achievements of the organisation. Each criterion is divided into components, including a number of issues that need to be discussed to assess performance. The introduction of such a model leads to the expansion of classical BSC through additional criteria (Adams and Roberts, 1993; Maisel, 1992; McNair et al., 1990; Mitskievich, 2004).

Materials and methods

The methodological basis of this study is the BSC model proposed by Kaplan and Norton (Kaplan et al., 2004). The classical structure of BSC, if adapted, allows exploring the issues related to the development and implementation at different levels, including aligning the indicator system with the company's or other structures' (e.g., cluster, region) goals and strategy which contributes to the sustainable development of the latter.

A cascading method was used to build a model of causality. The cascading method is based on the principle of harmonizing the objectives of all levels of economic systems and the successful implementation of the sustainable development strategy (Kaplan et al., 2004). Based on this method and by defining strategic goals and indicators, the systems of indicators of the lower and upper levels are aligned. In this study, the BSC adapted for regional specifics was the tool for the formation of indicators that assess the sustainable development of the territories for each of the four projections: the well-being of the region, environmental, economic, learning and development, innovation (Table 4). Similarly, the classical BSC adapted to the characteristics of cluster formations was the tool for the formation of indicators to assess the sustainable development of a cluster in four projections: financial, environmental, domestic and external markets, development and modernisation (Table 3).

Table 3 Adaptation of BSC components to the cluster

Components of classical BSC	Components of the cluster-adapted BSC
Financial component	Financial component
Customer component	Environmental component
Internal business processes	Domestic and external markets
Learning and development	Development and modernisation

Source: Compiled by the author of the present study.

Table 4 Adaptation of the company's components to the region

Components of classical BSC	Components of the region-adapted BSC
Financial component	The well-being of the region
Customer component	Environmental component
Internal business processes	Economic component
Learning and development	Learning and development, innovation

Source: Compiled by the author of the present study.

The main advantage of the proposed approach is that it links the sustainable development strategies of individual enterprises or other socio-economic subsystems in the region to the overall strategy for sustainable development of the region and, then, translates each strategy into a specific bottom-up action sequence aimed at achieving the goals at all management levels.

In this way, BSC allows for the formation of an interconnected set of sustainable development indicators for each level to assess the results of an overall sustainable development strategy. The indicators highlighted in the process of the formation of BSC allow not only to assess the achievement of the results of the strategy but also to further model the various relationships within the region, including the impact of the cluster's activities on the regional development.

Results

In order to propose a tool that assesses the impact of the industrial cluster on the development of the region, the classical BSC model was adapted following existing regional development programmes.[9,10] The Arkhangelsk Region and Cluster of Shipbuilding and Production of Marine Equipment of the Arkhangelsk region association (hereinafter, the shipbuilding cluster) were selected as the subjects of this study. At the first stage of forming a strategic map of the shipbuilding cluster, four adapted components were proposed: financial component, environmental component, internal and external market, development and modernisation (Table 3).

Four adapted components for the Arkhangelsk region were also proposed: the well-being of the region, environmental, economic, learning and development, innovation. (Table 4).

Further, strategic maps were developed for the Shipbuilding cluster and the Arkhangelsk region, followed by the determination of strategic development goals and key indicators for their assessment (Figures 1 and 2).

Strategic maps are interconnected with the objectives of the shipbuilding cluster and the Arkhangelsk region. This is a condition that is mandatory to benefit from the implementation of BSC. The interconnection between the cluster and the region is implemented using the cascading method (Kaplan et al., 2004). The proposed strategic maps allow to link the strategic goals of economic systems of different levels (cluster and region) and illustrate the causal relationship between them, as well as assess the degree of achievement of the goals, based on a set of developed indicators. For example, consider one of the projections of the shipbuilding cluster and the region: "domestic and external market" and "economic component" respectively. For example, consider one of the projections of the shipbuilding cluster and the region: "Internal and external markets" and "Economic component", respectively. These two goals are linked by key assessment indicators. For example, the indicator "number of foreign companies involved in the cluster" can influence the "investment in fixed capital" of the region and contribute to achieving one of the goals of the development of the region, by increasing the investment attractiveness.

Depending on the indicators in the proposed system change, it will be possible to assess the trends in the Arkhangelsk region and identify factors contributing to or hindering the sustainable development of the region.

[9] On the approval of the programme for the development of the shipbuilding innovative territorial cluster of the Arkhangelsk region for 2014-2017 (with changes from July 28, 2015). The resolution of the Government of the Arkhangelsk Region of October 7, 2014 N 390-pp "Electronic resource." Available at: http://docs.cntd.ru

[10] On the approval of the Russian Federation's Innovation Development Strategy for the period up to 2020. Order of the Government of the Russian Federation dated 08.12.2011 N 2227-p // RLS Consultant Plus.

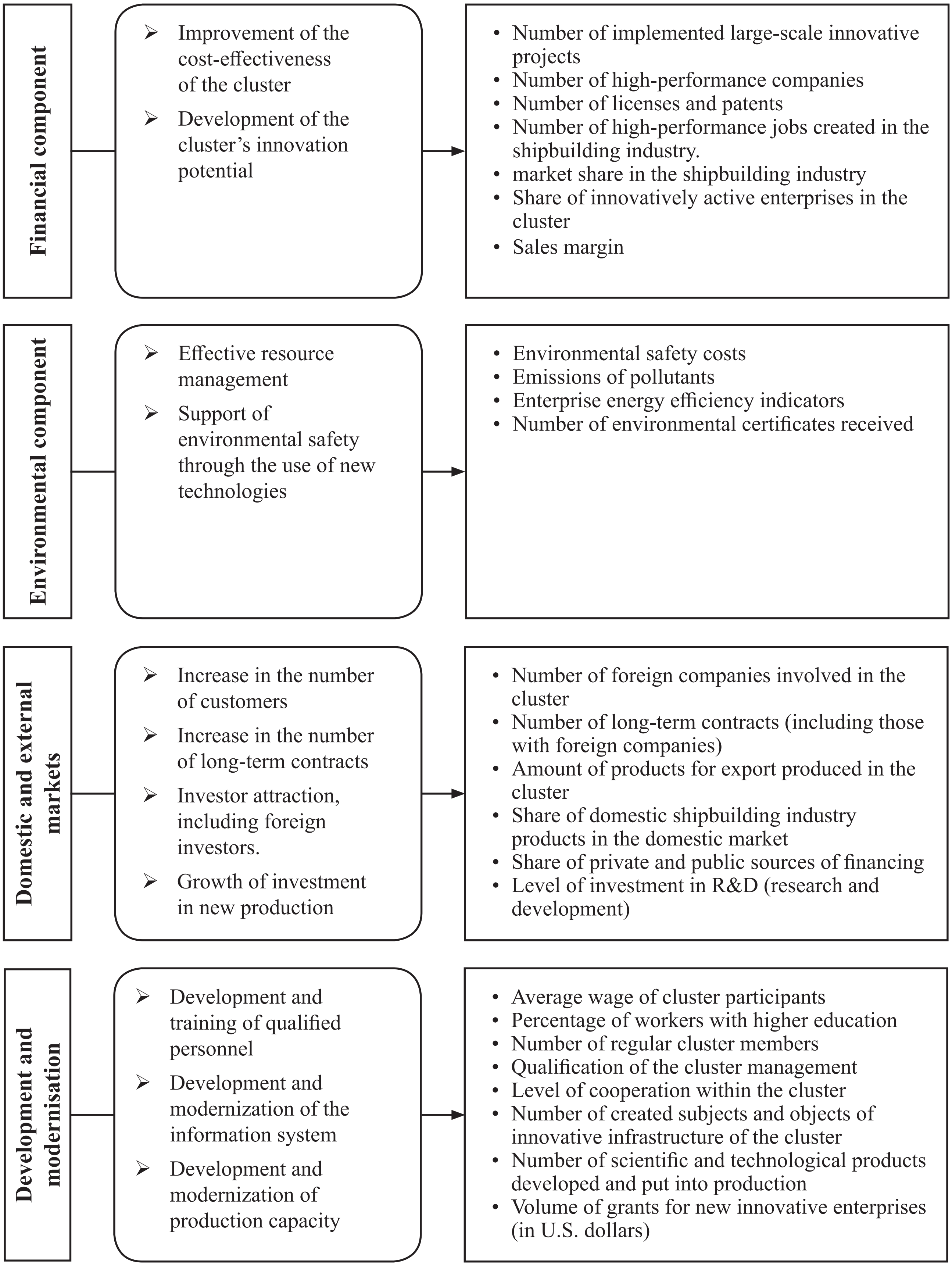

Figure 1. Strategic map of sustainable development of the cluster.
Source: Compiled by the author of the present study.

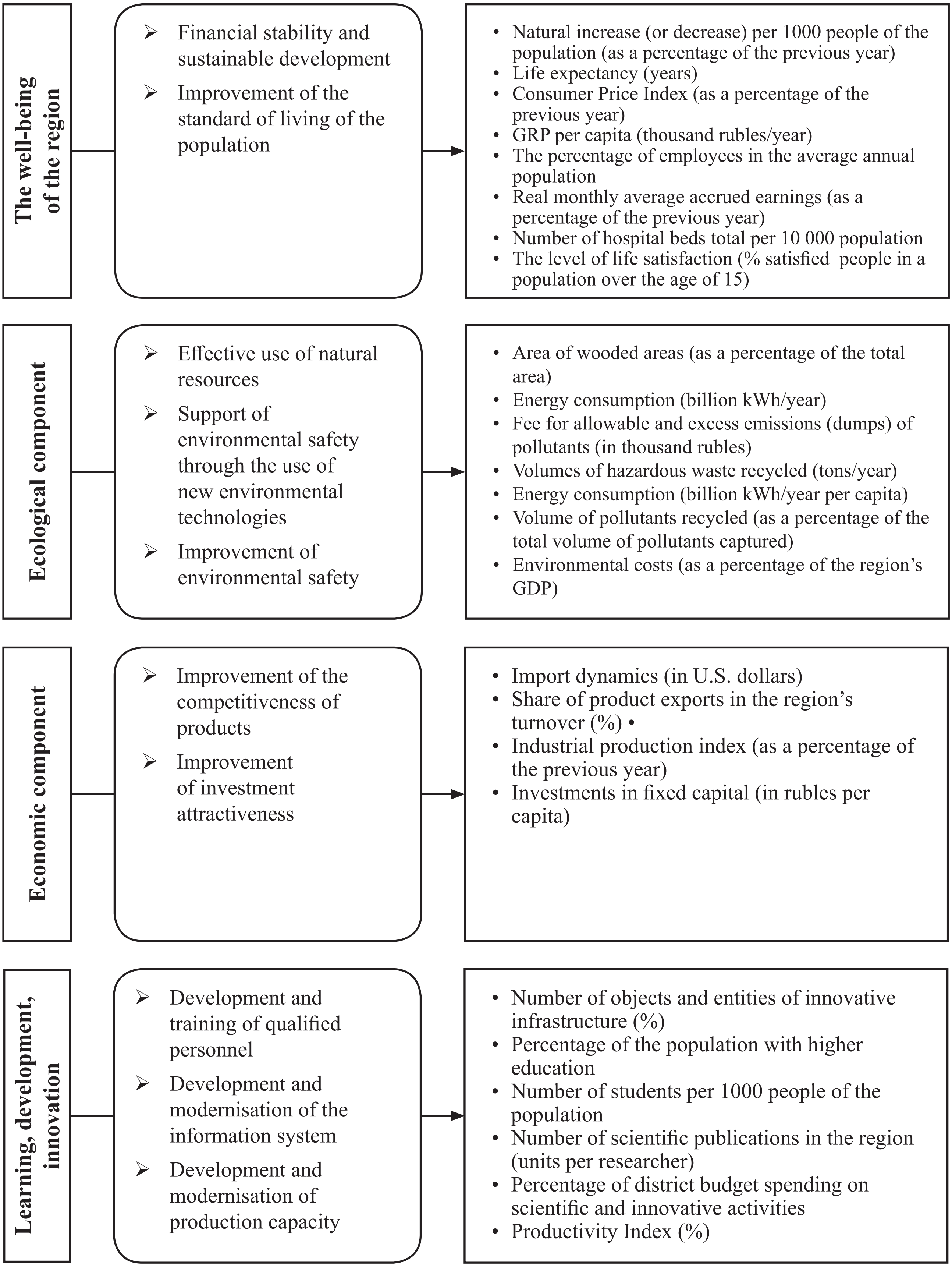

Figure 2. Strategic map of sustainable development of the Arkhangelsk region.
Source: Compiled by the author of the present study.

Conclusion

As a result of the study of the concept of sustainable development, analysis of literature and reports of international organizations, the author concludes that sustainable development includes the triunity of social, economic and environmental development of territorial socio-economic systems. At the current stage of development of the world community, it is necessary to ensure the comprehensive development of all management levels. This study focuses on industry (cluster) and regional level, their relationship and the main indicators that will reflect the impact of the shipbuilding cluster on the development of the Arkhangelsk region where it operates.

As part of this study, BSC was adapted to build an indicator system that reflects the relationship between cluster activity and sustainable development in the region. As a result, indicators of the assessment of the sustainable development of the actors in question were identified. Specifically, the components of BSC were adapted and strategic development maps were formed for the shipbuilding cluster of the Arkhangelsk region, within which indicators of the region's development assessment and cluster were proposed for each strategic goal. Based on the developed indices, it is possible to regularly monitor the implemented strategic alternatives and to exert regulatory influences for the sustainable development of both the shipbuilding cluster and the Arkhangelsk region. Depending on how the indicators in the system change, it will be possible to assess the trends in the territories and identify factors contributing to or hindering sustainable development. This will contribute to the identification of priorities and the most suitable tools for the sustainable development of both the cluster and region. The indicators will not only allow to assess the achievement of the strategy but also model the relationships within the region, including the impact of the cluster's activities on regional development.

The approach discussed in this article opens up opportunities for further discussions on managing the sustainable development of the region. The limitations of the present article and the lack of the necessary empirical data from open sources make the proposed indicator system a theoretical basis for future research. To implement this approach and to effectively use the adapted BSC model, these indices must be introduced into the statistical accounting system in practice, making it possible to continue the study and confirmation or rejection of the projected relationship between the region's development and the cluster based on empirical data.

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ANALYSIS OF TERRITORY ENERGY SECURITY IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT (CASE OF GEORGIA)

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Abstract

The topicality of energy security (*EnS*) issues is confirmed by the unstable energy situation in the macroeconomic space. Countries with low energy potential risk losing autonomy. The development of methods for conducting EnS analysis will become an effective tool for reducing such negative threats. The goal of this research is to build a toolkit for the analysis of *EnS* for territories. To do this, it is proposed to consider the Energy Trilemma Index (*ETI*), to work out a methodology for assessing the level of EnS and to build a regression model of dependence of the obtained values on the selected economic parameters. The scientific novelty of the proposed toolkit lies in development of a methodology that allows the comparison of the EnS level of different territories and the identification of "influence-factors". The developed tools were tested on the case of Georgia, for which *EnS* issues are a national priority. As a result of the test, the trend of reduction in Georgia's level of EnS (from 0.772 in 2008 to 0.705 in 2018) was revealed, and Georgia's dependence on the state of import-exports was substantiated. The findings show the viability of the model and the possibility of adapting it to other territories. The importance of the problem of maintaining *EnS* is growing today due to the need to ensure the sustainable development of territories at different levels. In this context, the expansion of scientific and applied knowledge in this area is aligning with the interests of regional economies and the world community.

Keywords: energy security, energy economics, innovative energy, sustainable development, energy sustainability, regional economy.

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АНАЛИЗ ЭНЕРГЕТИЧЕСКОЙ БЕЗОПАСНОСТИ ТЕРРИТОРИИ В КОНТЕКСТЕ УСТОЙЧИВОГО РАЗВИТИИ (НА ПРИМЕРЕ ГРУЗИИ)

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Аннотация

Актуальность вопросов энергетической безопасности подтверждается нестабильной энергетической обстановкой в макроэкономическом пространстве. Страны со слабым энергетическим потенциалом рискуют потерять свою самостоятельность. Развитие способов проведения анализа энергетической безопасности станет действенным инструментом для сокращения таких негативных угроз. Цель исследования заключается в построении инструментария для проведения анализа энергетической безопасности территорий. Для этого предлагается рассмотреть Индекс энергетической трилеммы, проработать методику оценки уровня энергетической безопасности и построить регрессионную модель зависимости полученных значений от отобранных экономических параметров. Научная новизна предложенного инструментария заключается в разработке методики, позволяющей сопоставить уровень энергетической безопасности различных территорий и выявить «факторы-влияния». Выработанный инструментарий был апробирован на примере Грузии, для которой вопросы энергетической безопасности являются приоритетными на национальном уровне. В результате апробации выявлен тренд на снижение уровня энергетической безопасности страны (с 0.772 в 2008 году до 0.705 в 2018 году) и обоснована его зависимость от состояния импорта-экспорта. Полученные данные свидетельствуют о жизнеспособности данной модели и возможности ее адаптации к другим странам и территориальным структурам. С авторской позиции отмечено, что высокая значимость проблемы поддержания энергетической безопасности приобретается на сегодняшний день в связи с необходимостью обеспечения устойчивого развития регионов и территорий на разных уровнях. В таком контексте расширение научных и прикладных знаний данного направления соответствует интересам региональной экономики и мирового сообщества.

Ключевые слова: энергетическая безопасность, экономика энергетики, инновационная энергетика, устойчивое развитие, устойчивость энергетики, региональная экономика.

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1. Introduction

The complex apparatus of *EnS* does not allow the formation of a unified system of energy process management. The macroeconomic space is constantly becoming more complex, having a direct or indirect impact on the energy situation of countries, regions, territories. For example, there is serious energy instability in many areas of the planet because of ever-increasing energy consumption. Many countries lack sufficient energy capacity, which leads to the risk of loss of independence in the event of excessive dependence on energy resources and their irrational use. The energy crisis of 2008 proved the emergence of global problems due to the insolvency of energy systems (Li and Liu, 2013), (Öztürk et al., 2013).

The current scientific thought on *EnS* is incomplete and highly fragmented, and its further formation expands the apparatus of search for energy efficiency strategies with certain alternatives and compromises. In particular, a number of studies (Böhringer and Bortolamedi, 2015; Cherp and Jewell, 2014), note the need to develop a multi-purpose energy policy. The strategy for *EnS* support facilitates detailed exploration of vulnerabilities for a combination of potential risks and sustainability parameters. Energy systems should be considered a vital element of the regional economy, hence the need to expand the existing apparatus to identify synergies between *EnS* and sustainability. As Axon and Darton (2021) have demonstrated, the methodological analysis of risks in energy systems remains barely studied; however, the further development of knowledge would be practically impossible without deepening the theoretical and methodological basis.

Thus, it becomes much more urgent to explore the possibilities of rational implementation of *EnS* measures, which will result in the resolution of methodological difficulties. Despite the existence of approaches to energy resource research in international practice, there exist limitations in the theoretical and practical consideration of the *EnS* category (Jakstas, 2020). This article proposes to develop a toolkit for *EnS* analysis based on the need to decrease current negative threats influencing the energy sector.

The scientific novelty of the study lies in the development of a toolkit that facilitates not only the determination of the level of *EnS* of various territories (country, region, etc.) but also the identification of “influence-factors” by which it is proposed to understand the determining factors contributing to the change at this level. The study importance is confirmed by the fact that based on the proposed methodology, it becomes possible to form *EnS* management mechanisms by changing the influence of certain factors.

The purpose of the study is to build a toolkit for analysing the *EnS* of territories. Achieving this goal requires addressing the following objectives: consideration of methods for estimating *EnS* based on the *ETI* analysis; working out a methodology for assessing *EnS* at the territorial level; building a re-gression model of the dependence of the obtained values on the selected economic parameters. In the context of the study, the national level is considered, and the indicators are adapted to analyse the country. The practical testing of the analytical toolkit was carried out using Georgia as an example.

2. Literature review

2.1. Common energy security issues

Energy security issues have been under consideration for a long time, so there is a sufficient body of research exploring the conditions for building energy potential and reducing the negative impact of systemic constraints. It is necessary to mention the research on the economic aspects of energy functioning and opportunities for diversification of the energy balance, in particular the studies of Bahgat (2008), Biggar and Hesamzadeh (2014) and Pillay et al. (2015). Öztürk et al. (2013) provide a comparative analysis of the energy independence of countries based on statistical analysis. All researchers note that the problem of energy independence and *EnS* will only gain importance in the scientific and practical sense every year in association with the inevitable increase in energy consumption.

The innovative component of sustainable development plays a massive role in the construction of rational energy policies. Continuous work in the area of innovation development allows us to build the innovative potential of enterprises and industries, as discussed by Mamrayeva et al. (2018). This practice is also common in the energy sector, without innovative renewal of production assets, it is impossible to ensure the *EnS* of fuel and energy enterprises and industries. The importance of integrated innovation development reflects the possibility of creating additional value for the energy complex because of their innovative transformation. Innovative value, discussed by Zaytsev et al. (2020a, 2020c), should become an incentive to transform energy enterprises, and the focus of innovation in *EnS* can be an effective tool of public energy policy.

It should be noted that *EnS* gains key importance for regional development as the creation of favourable interactions between corporate structures in the energy sector and local governments ensures the improvement not only of energy but also of economic security of territory (Kichigin et al., 2018). The energy policy of the territories should be aimed at the rational import of primary energy sources and maintaining the stability of the energy balance (Vosta and Musiyenko, 2015). The imperfection of regional economic policy does not ensure the maximum level of *EnS* of a territory. These imperfections should include the ratio of economic, environmental, energy, social and other interests. Maintaining sustainable development causes a reduction in the negative impact on the environment, which can lead to a decrease in the *EnS* level and industrial production, which is analysed by Tvaronavičienė et al. (2015). This practice negatively influences the territories functioning and necessitates the search for new energy policy instruments.

The transformation of the ecological and economic space of territorial formations determines the development and transformation of various segments of the national economy, including the energy sector, which should take into account the mechanisms for regulating innovation on the basis of green economy principles (Shabunina et al., 2017). Now, energy resources are a key source of economic development, and their lack can lead to a decline in economic growth, up to the complete stagnation or degradation of economic relations. At the same time, energy must be environmentally friendly and aimed at maintaining the sustainability of the territories. This practice necessitates implementation of eco-innovations in the energy sector and ways to provide environmentally sustainable energy resources, the essence of which is reflected in the work of Blum and Legey (2012). To support this approach, it is necessary to attract investments in complex projects and implement new methods of strategic management of economic complexes; for example, it is possible to introduce lean manufacturing tools into the energy sector (Zaytsev et al., 2020b).

After analysing the scientific literature, it becomes clear that *EnS* faces a number of economic problems that prevent the development of policies aimed at purposefully reducing costs, as noted by Labandeira and Manzano (2012). However, the importance of *EnS* remains undeniable as this indicator characterises the degree of significant vulnerability of the economy in the global energy market. The crisis state of energy systems in various regions prevents long-term forecasts and high-quality results for maintaining the energy balance of territories. The development and adaptation of methodological approaches to the analysed problem will facilitate solutions to some pressing issues and improvements to the existing *EnS* policy.

2.2. Energy security methodological issues

EnS is one of the key elements of national security, which increases the importance of forming a methodological apparatus for its practical analysis. Thus, many approaches and techniques for practical calculations have been implemented in the scientific community. At the same time, many methods require the use of a significant amount of information, which makes them difficult to implement. Thus, the researcher is primarily interested in finding ways to assess energy security with a minimum number of indicators. For example, the research analyses and expands the requested assessment of *EnS* based on widely available information as proposed by Vasikov et al. (2010).

An overview of methods for assessing *EnS* for the comparison of different territories, for example, was presented by Berezhnaya and Yegorchenko (2012) and Mazur (2014). Modern approaches to assessing the *EnS* of a territory allow researchers to calculate general and specific indicators of energy resource use efficiency. The obtained results can be used to determine the reserves for boosting energy potential and forming economically sound ways for making management decisions aimed at preventing and neutralising energy threats. Meanwhile, for specific countries and regions, different methods and approaches can be applied, considering specific conditions of functioning for these territories. Specific practical methods for evaluating and analysing *EnS* have been studied. Augutis et al. (2012) proposed a dynamic model for assessing the level of *EnS* for Lithuanian conditions; Kisel et al. (2016) described approaches and reflected the *EnS* matrix based on Estonian data; Sovacool (2013) examined *EnS* indices in Japan, Laos and Myanmar; Smagulova et al. (2018) and Amirov et al. (2018) considered Kazakhstan's *EnS*; and Myzin et al. (2012) described a developed software complex for calculating the state of *EnS* in the Russia.

If sufficient information is available, it is possible to use expert methods, such as those discussed by the Karapetyan (2009). The extended method of expert assessments allows the determination of the *EnS* level for certain types of energy resources. In the scientific literature, in most cases, an indicative method is used, which implies the use of many indicators that can be combined into blocks, such as electricity supply, heat supply, fuel supply, structural-mode blocks and reproduction of energy reserves. The data obtained after structuring allow us not only to determine the value of indicators but also to highlight their threshold values to prevent the onset of crisis situations (Biggar and Hesamzadeh, 2014; Dyer and Trombetta, 2013; Reddy and Ulgiati, 2015).

Despite the effectiveness of statistical methods, such calculations are extensive and time consuming and require greater accessibility of the information base. However, less precise methods are permissible for highlighting key factors and obtaining comparative results for different territories. In this study, of interest was the economic and mathematical modelling used to highlight key parameters. Specifically, Dmitriev et al. (2021) and Lebedev et al. (2014) considered the possibility of constructing optimisation models in the electricity industry based on correlation-regression analysis. So, it is fair to say that the use of mathematical modelling makes it possible to identify the key factors that influence the change in each parameter of the regression model.

3. Materials and Methods

At the first stage, it is proposed to analyse the concept of the ETI. According to this concept, a balance must be maintained between the three pillars of the trilemma. There is no single indicator of *EnS* in international practice, and the use of a global index based on statistics allows the construction of a model of *EnS* based on balanced indicators. ETI, ensuring balance through the integration of energy systems, allows the assessment of a country's ability to facilitate sustainable energy. The first assessment of the *ETI* was carried out in 2010. This index allows to track the country's progress in the energy sector and look for weaknesses in its energy policy to eliminate them as soon as possible.[1]

In the 2020 ranking, 108 countries were selected to construct a balance assessment (AAA – highest score and DDD – lowest). The first letter represents *EnS*, the second letter represents energy equity and the last letter represents the environmental sustainability of energy systems. Trilemma scores are weighted indicators (0 to 100 points, with lower scores indicating more effective energy policy) for each measure (so-called national results) (Fu et al., 2021; Tovar-Facio et al., 2021). The key indicators (lower indicators indicate a higher Trilemma Index):

1. Energy security: the country's ability to reliably meet current and future energy demand and to withstand and recover swiftly from systemic shocks with minimal supply disruptions.

2. Energy equity: the country's ability to provide universal access to reliable, affordable and abundant energy for domestic and commercial use.

3. Environmental sustainability: the transition of the country's energy system to mitigating and preventing potential environmental damage and the effects of climate change.

It can be concluded that this interactive index is an effective way to assess the sustainability of national energy policy. It should be used as a tool to construct energy policy analysis and forecast its transformation in order to improve quality returns (Song et al., 2017). In the research, this index is used to reveal economic indicators, controlling which can ensure the growth of *EnS*.

It should be noted that the status of *ETI* is determined based on factors that include the following indicators: the concentration of primary energy reserves in the territory, dependence on energy imports, the price of energy for industry actors, the intensity of carbon dioxide emissions, the state of the environment and the impact on it and the concentration of electricity generation. At the same time, the use of this method in the context of *EnS* assessment is not universal as the lack of relevant data and the confidentiality of information make it impossible to make calculations for many countries, as well as for the period up to 2010.

In order to achieve high-quality *EnS* at the national level, monitoring and timely assessment of *EnS* should be ensured on the basis of the definition of a given set of parametric indices (Reddy and Ulgiati, 2015). Indices should reflect the development of mechanisms for ensuring the *EnS* of a territory, making it possible to identify problem areas in the functioning of an energy system. In this manner, at the research stage, it is proposed to assess the level of *EnS* of a territory, which can be further used to identify the main factors and threats that impede its provision. The toolkit was based on a simplified assessment of the level of *EnS* based on widely available information (Vasikov et al., 2010), in which the following indicators were selected to calculate the *EnS* index: the human development index, the solvency index and the efficiency index. The final formula for assessing *EnS* is calculated according to Formula 1.

$$I_{es} = ½ \times (I_{hr} + I_s) \times I_{ef}, \quad (1)$$

I_{es} – energy security index;
I_{hr} – human development index;
I_s – solvency index;
I_{ef} – efficiency index.

[1] WES, World Energy Trilemma Index, 2020. https://trilemma.worldenergy.org/.

At the same time, methods and step-by-step toolkits were proposed to calculate each index. However, the proposed methodologies are subject to revision to improve the quality of the calculation values. It is possible to use weight coefficients of the integral index (Karapetyan, 2009) to increase the effective part of the resulting score. The weight coefficients are in the range between 0 and 1. The classic version of the integral index calculation is shown in Formula 2.

$$LI_{es} = \sum (k_i \times N_i), \quad (2)$$

LI_{es} – energy security index;
k_i – weight at the stage i ($\sum i=1$);
N_i – value of an indicator at the stage i.

The presence of secondary and irrelevant data based on expert assessments in this formula distorts the results, making it impossible to base practical recommendations solely on this approach. In the toolkit, it is proposed to set weights only to index values, which will help form an apparatus of identification of factors and risks that determine the functioning of the energy sector. In this manner, the assessment of *EnS* in the toolkit for the analysis of the *EnS* of a territorial association is calculated in three stages:

1. Self-sufficiency index calculation (Formulas 3 and 4). This index differs by calculations from the previously mentioned solvency index. Data on the consumption and production of primary energy are used to calculate it. Formula 3 is extended and is used in the case of combinatory models for a certain period exceeding 20 years. Formula 4 is standardised and suitable for a quick assessment that is part of the integrated *EnS* index.

$$I_{\Delta ss} = ((P_{pe\ j} / C_{pe\ j}) - (P_{pe\ min} / C_{pe\ max})) / ((P_{pe\ max} / C_{pe\ min}) - (P_{pe\ min} / C_{pe\ max})), \quad (3)$$

$I_{\Delta ss}$ – combinatory index of a territory's energy self-sufficiency.;
$P_{pe\ j}$ – value of primary energy production at stage j;
$P_{pe\ min}$ – minimum value of primary energy production;
$P_{pe\ max}$ – maximum value of primary energy production;
$C_{pe\ j}$ – value of primary energy consumption at stage j;
$C_{pe\ min}$ – minimum value of primary energy consumption;
$C_{pe\ max}$ – maximum value of primary energy consumption.

$$I_{\Delta(st)ss} = P_{pe\ j} / C_{pe\ j}, \quad (4)$$

$I_{\Delta(st)ss}$ – standardised index of a territory's energy self-sufficiency;
$P_{pe\ j}$ – value of primary energy production at stage j;
$C_{pe\ j}$ – value of primary energy consumption at stage j.

2. Efficiency index calculation (Formulas 5 and 6). It uses data on net consumption and electricity generation. Formula 5 is extended and is used in the case of combinatory models for a certain period exceeding 20 years. Formula 6 is standardised and suitable for a quick assessment that is part of the integral *EnS* index.

$$I_{\Delta ef} = ((G_{ne\ j} / D_{ne\ j}) - (G_{ne\ min} / D_{ne\ max})) / ((G_{ne\ max} / D_{ne\ min}) - (G_{ne\ min} / D_{ne\ max})), \quad (5)$$

$I_{\Delta ef}$ – combinatory index of energy efficiency of the territory;
$G_{ne\ j}$ – net power generation at stage j;

$G_{ne\ min}$ – minimum value of net electricity generation;
$G_{ne\ max}$ – maximum value of net electricity generation;
$D_{ne\ j}$ – net electricity consumption at stage j;
$D_{ne\ min}$ – minimum value of net electricity consumption;
$D_{ne\ max}$ – maximum value of net electricity consumption.

$$I_{\Delta(st)ef} = G_{ne\ j} / D_{ne\ j}, \quad (6)$$

$I_{\Delta(st)ef}$ – standardised index of a territory's energy efficiency;
$G_{ne\ j}$ – net power generation at stage j;
$D_{ne\ j}$ – net electricity consumption at stage j.

3. Energy security index calculation (Formula 7). This index differs in calculations from the previously mentioned *EnS* formula. It is based on an integral assessment and the introduction of weight coefficients. These coefficients are based on expert assessments and fair distribution of indices.

$$I_{\Delta(st)es} = 0.2 \times I_{hr} + 0,4 \times I_{\Delta(st)ss} + 0.4 \times I_{\Delta(st)ef}, \quad (7)$$

The third step proposes to use the *EnS* assessment to identify the threats that have a direct impact on the energy supply of a territory due to external and internal factors. To do this, it is proposed to use the apparatus of economic and mathematical analysis and, more specifically, a regression model based on the least squares method (Dmitriev et al., 2021; Lebedev et al., 2014). Over 20 parameters were selected for the analysis, of which it is recommended to keep only the most significant, considering the presence of multicollinearity and the conformity of parameters to the specified values of the model. Formula 8 presents the model of the least square's method of the optimisation problem, allowing the selection of indicators that have the strongest or most insignificant impact on the dynamics of the model indicators. For the resulting indicator, it is possible to choose the *ETI* or Energy Security Index. Formula 8 demonstrates the classic approach to calculating the regression model.

$$Y_{es} = a_i \times X_i + const, \quad (8)$$

Based on the data, it is possible to obtain the mathematical values of dependent and independent variables, reflecting the quantitative indicators of the factors analysed. After selecting statistically significant results with minimal standard deviations, it is possible to identify parameters that can be used to manage the *EnS* of the territory. If the energy base is divided into separate components, it is possible to identify ways to diversify the sources of energy imports and create a system of optimal energy supplies to maintain energy independence. However, the proposed toolkit is one of many in economic science, and now there is no generally accepted method of assessing *EnS* due to the inability to accurately evaluate the various territries based on an identical apparatus.

4. Results

4.1. Georgia's energy situation: Trilemma Index and key economic parameters

Adaptation of the *EnS* analysis toolkit to Georgia facilitates discourse about the situation of the country in the energy space. To begin with, the *ETI* (Table 1) was analysed. Georgia is ranked 53rd, and its *EnS* leaves much to be desired. It should be noted that the energy sector is dominated

Table 1. Place of Georgia and other post-Soviet countries in the ETI

Index rank	Country name	Balance grade	Trilemma score	Energy security rank	Energy equity rank	Enviromental sustainability rank
16	Lithuania	BAA	77.6	43	18	16
22	Latvia	ABB	76.4	5	54	31
26	Estonia	BAB	75.3	38	23	52
29	Russia	AAC	73.8	16	12	73
36	Azerbaijan	ABB	72.1	17	44	54
42	Kazakhstan	ABD	70.3	15	38	83
43	Albania	DBA	69.9	83	53	4
50	Ukraine	ACB	68.9	12	74	49
53	Georgia	CBB	67.6	66	70	34
54	Armenia	CBB	67.4	66	65	34
83	Tajikistan	DCC	57.1	86	82	69
84	Moldova	CCD	56.9	81	81	88

by hydropower, which can fluctuate depending on weather and climatic conditions. Additionally, a dependence on fossil fuels remains. However, the country's small population (3.7 million people) has high access to electricity, and prices remain at an affordable level. In many ways, the ranking is improved by reducing CO2 emissions and maintaining sustainable energy. Now, there is an increase in the consumption of energy resources, primarily in the industrial sector, which leads to an increase in the country's energy dependence and may negatively affect *EnS*.

Forecasts for 2020 showed that among the countries in the post-Soviet space there are no states with secure energy sectors, and Georgia is at risk. In the following 10 years, the onset of an energy shortage is possible due to the expansion of energy consumption. Such forecasts necessitate the search for ways to improve *EnS*, the development of which should begin with the construction of high-quality analytical models.

It is possible to use *EnS* assessment methods based on rating comparisons, indicative parameters, expert modelling; however, their use will not provide objective information, as there are insufficient data for comprehensive analysisй. Table 2 and Figure 1 show data on the ETI, which displays gaps and insufficient information. The lack of statistics for the area does not allow the formation of models of *EnS* analysis through this indicator.

It is worth noting that the rapid growth of energy consumption with insufficient power generation is not conducive to talking about ensuring *EnS*. Alternative energy, which the state relies on, does not provide for all the needs of the country, and hydropower capacity hardly covers domestic needs.[2] It is necessary to establish measures to revise the energy policy, considering the methodological approaches to the transformation of regional relations in the way of sustainable development since the formation of economic parameters within *EnS* is impossible to imagine without taking into account socio-environmental factorsв.[3]

Table 2. Change in the *ETI* (Georgia)

	2014	2015	2016	2018	2019	2020
Trilemma score	55	51	51	69	63.1	67.6
Change	–	–7.27%	–	35.29%	–8.55%	7.13%

[2] WES, World Energy Trilemma Index, 2020. https://trilemma.worldenergy.org/

[3] ESCO, Energy Balance, 2021. https://esco.ge/en/energobalansi

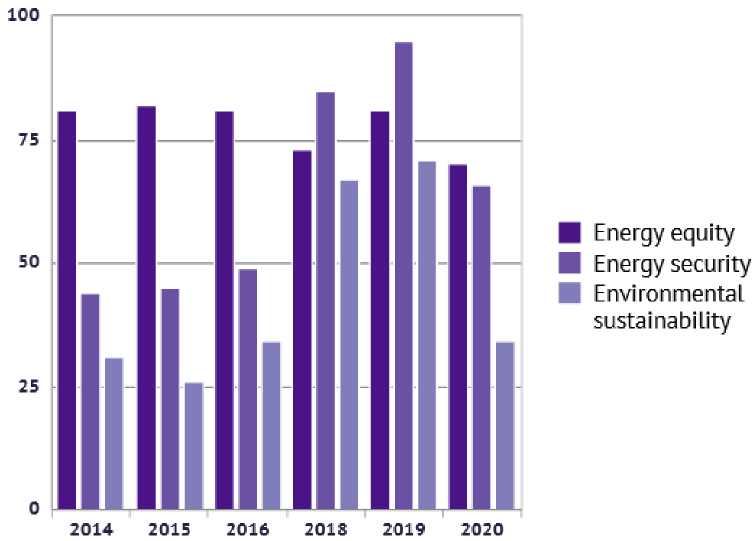

Figure 1. *ETI* components (Georgia)

4.2. Assessment of Georgia's energy security

To assess the *EnS* of the territory, a system and practice of mathematical calculations should be formed, allowing further identification of threats and assessments of the state of the country's energy potential. In the context of Georgia, there is a problem with statistical data on many indicators, but the available list of indicators is presented in Table 3:

X1 – Electricity imports (billion kilowatt-hours – blh).
X2 – Electricity exports (blh).
X3 – Net production of traditional thermal electricity (blh).
X4 – Net power generation (blh).
X5 – Net hydropower generation (blh).
X6 – GDP (billions of USD).
X7 – Human Development Index (points).
X8 – Primary energy consumption (quadrillion BTU).
X9 – Primary energy production (quadrillion BTU).

Table 3. Key indicators for *EnS* assessment (Georgia)

Year	X1	X2	X3	X4	X5	X6	X7	X8	X9
2008	0.56	0.68	1.21	8.3	7.09	12.795	0.74	0.18	0.07
2009	0.26	0.74	1.08	8.42	7.34	10.767	0.75	0.18	0.08
2010	0.23	1.49	0.71	9.98	9.27	12.244	0.75	0.19	0.09
2011	0.48	0.93	2.17	9.98	7.81	15.107	0.76	0.18	0.08
2012	0.62	0.53	2.32	9.47	7.15	16.488	0.77	0.19	0.07
2013	0.48	0.45	1.68	9.87	8.19	17.190	0.78	0.21	0.09
2014	0.85	0.6	1.91	10.17	8.25	17.627	0.78	0.22	0.09
2015	0.7	0.66	2.24	10.61	8.37	14.954	0.79	0.23	0.09
2016	1.33	1.41	2.1	11.35	9.24	15.142	0.79	0.25	0.09
2017	1.75	0.94	2.1	11.31	9.12	16.243	0.8	0.24	0.09
2018	1.52	0.6	1.99	11.92	9.85	17.600	0.81	0.25	0.09
2019	1.76	0.38	2.68	11.61	8.84	17.477	0.81	–	–

The dynamics of the indicators are available since 2008, and some of the data are limited to 2018, which allows an assessment for 10 years. *EnS* assessment calculations based on Formulas 4, 6 and 7 are presented in Table 4. Graphic dynamics are shown in Figure 2. The figure shows that there is a clear downward trend in *EnS* (linear trend: $y=-0.0117x+24.308$). The range of the study is from 2008-2018, which makes it possible to build a regression model to identify the threats and opportunities for the growth of energy potential.

Table 4. *EnS* assessment (Georgia)

Year	IΔ(st)ss	IΔ(st)ef	Ihr	IΔ(st)es
2008	0.389	1.171	0.7400	0.77182
2009	0.444	1.229	0.7500	0.81946
2010	0.474	1.310	0.7500	0.86336
2011	0.444	1.191	0.7600	0.80615
2012	0.368	1.118	0.7700	0.74859
2013	0.429	1.085	0.7800	0.76127
2014	0.409	1.037	0.7800	0.73432
2015	0.391	1.068	0.7900	0.74191
2016	0.360	1.083	0.7900	0.73521
2017	0.375	1.009	0.8000	0.71357
2018	0.389	1.171	0.8100	0.70466

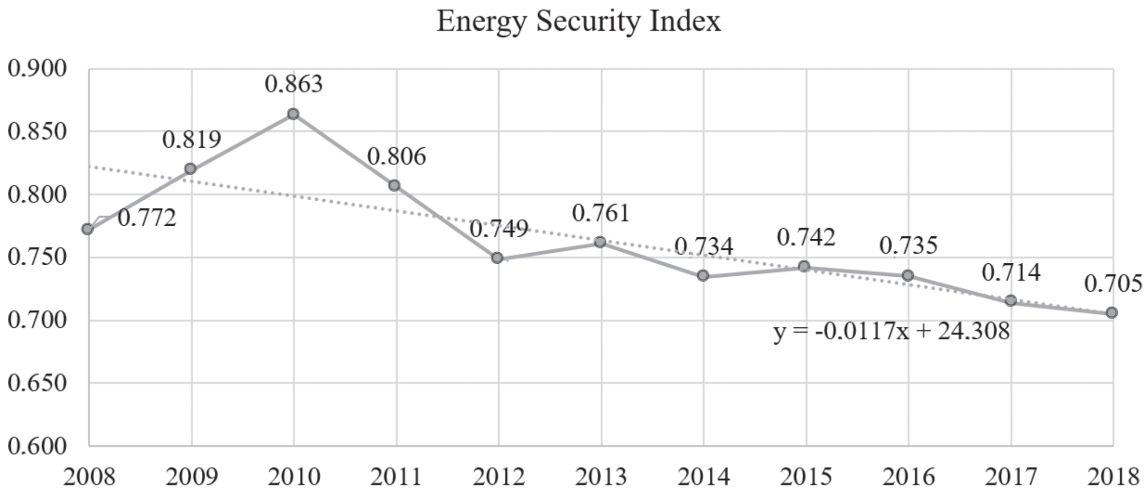

Figure 2. *EnS* assessment (Georgia)

4.3. Regression model of dependency of selected indicators

Since data on the *ETI* are not available for the model due to the lack of statistical data on the country being analysed, the dependence of the assessment of Georgia's *EnS* (Y_{es}) on a few indicators was built. After the selection, X1, X2, X3, X4 and X5 remained the most significant indicators. The rest of the indicators are not statistically significant within this model.

cators are not statistically significant within this model.

As a result of the regression model, the following data were obtained:

1. R-square: 0.993201; Adjusted R-square: 0.986402.
2. Coefficient: const = 0.83202; X1= – 0.125637; X2 = 0.0810529; X3 = – 0.912016; X4 = 0.912256; X5 = 0.918351.

3. P-value: const < 0.00001***; X1 = 0.00006***; X2 = 0.00011***; X3 = 0.00099***; X4 = 0.00109***; X5 = 0.00109***.

$$Y_{es} = 0.83202 - 0.125637 \times X1 + 0.0810529 \times X2 - 0.912016 \times X3 + 0.912256 \times X4 - 0.91835 \times X5$$

Thus, it is possible to draw the following conclusions:

– Increasing electricity imports (X1) leads to a reduction in *EnS*.

– Increasing electricity exports (X2) results in a slight increase in *EnS*.

– Increasing the net generation of traditional thermal electricity (X3) leads to a significant reduction in *EnS*.

– Increasing net power generation (X4) leads to a significant increase in *EnS*.

– Increasing net hydropower generation (X5) leads to a significant reduction in *EnS*.

It can be concluded that now it is in Georgia's interest to maintain a low import of energy resources, as well as to facilitate net power generation. At the same time, hydroelectric and thermal power capacity are insufficient to maintain *EnS* growth. However, these indicators are not enough to build a comprehensive study, and access to statistics is needed.

It is proposed to consider a regression model with indicators of energy imports and exports. For example, the following data were obtained:

1. R-square: 0.903946; Adjusted R-square: 0.879932.
2. Coefficient: const = 0.772889; X1 = – 0.0801297; X2 = 0.066675.
3. P-value: const < 0.00001***; X1 = 0.00005***; X2 = 0.00245***.
4. Variance inflation factor method: X1 = 1.003; X2 = 1.003 (no multicollinearity).

$$Y_{es} = 0.772889 - 0.0801297 \times X1 + 0.066675 \times X2$$

There is also an increase in *EnS* with increased electricity exports and a reduction in *EnS* while importing electricity. It should be noted that in this case, a complete lack of multicollinearity between the factors is observed.

In general, it should be noted that the obtained data show the viability of the author's toolkit and the possibility of adapting it to other territory.

5. Discussion

The use of the toolkit allows the assessment of the *EnS* level based on the methodical monitoring. It is possible to expand the proposed tools based on the development of indicative analysis, but this direction requires a more in-depth discussion of the scientific community on energy issues (Dyer and Trombetta, 2013). The position of the state on *EnS* should be more integrated, since without the implementation of a functional apparatus of regulation it is impossible to ensure the execution of the targeted plans to achieve security of energy supply. Identifying trends in *EnS* changes allows for the development of mechanisms of influence, primarily financial, on the energy sector (Blum and Legey, 2012; Labandeira and Manzano, 2012).

The quantitative measurement of the *EnS* territory is not calculated in international practice; however, from the author's point of view, this issue will be revised in the near future as ratings, indices and *EnS* indicators are closely related to sustainable development (Jakstas, 2020; Tvaronavičienė et al., 2015). In theoretical and methodological terms, previous studies are based on obtaining results without specific quantitative estimates, which prevents the acquisition of objective information for predicting

EnS based on economic and mathematical methods. The indices of organisations and research companies are of particular interest in the research environment; however, their calculation requires the use of specific information, which is not always available to researchers. Additionally, available studies do not allow the determination of the universal assessment of *EnS*, instead only giving an idea of the analysed phenomenon (Cherp and Jewell, 2014).

Since empirical research requires more data and access to private information, the use of the proposed toolkit based on publicly available information leads to a fair conclusion about its advantages. The analysis also showed the possibility of forming a methodological toolkit in the context of maintaining *EnS* in connection with the need to ensure the sustainable development of territories at different levels (Reddy and Ulgiati, 2015). The development of sets of indicators, indices and structures to assess the *EnS* of countries becomes a key parameter in determining the sustainability of the territory under the influence of geopolitical uncertainty (Axon and Darton, 2021). Therefore, the expansion of scientific and applied knowledge in this area is in the interests of the global community. The result of the development of the instrumental apparatus will be the formation of algorithms for determining problem areas, and the regression analysis will provide a few opportunities to identify the impact of factors on the *EnS*.

As a result of the testing of the toolkit using Georgia as an example, the data on the dynamics of the assessment of the country's *EnS* were obtained, which allowed the building of a regression model of dependencies. Despite the lack of statistical data on the analysed region, the trend between electricity imports and exports was revealed. To strengthen Georgia's position in the global energy market, measures should be taken, such as balancing energy imports and exports, primarily by focussing efforts on reducing imports and meeting domestic needs through net electricity generation. At the same time, the impact of traditional thermal electricity, the growth of which has a negative impact on *EnS*, should be reduced. Of course, these indicators may not reflect a complete functional picture, but the results show the effectiveness of the instrumental approach and the possibilities for its further development. Unfortunately, the results obtained during testing of the proposed methodology are difficult to compare with the results of other studies as there are no objective scientific studies on the region in the context of *EnS*. However, when compared with the ETI, there is a clear correlation with the energy equity indicator;[4] a complete comparison of the proposed methodology and the *ETI* is not required. They are complementary and allow for the assessment of different aspects of energy development in the territory.

6. Conclusions

The article considered: the theoretical aspects of the *EnS* concept, which allowed us to expand the contribution to the study of the problem of sustainable development; methodological approaches and methods of evaluating *EnS* are analysed; the issues of the ETI, which is poorly developed in the scientific literature and is practically unused in the context of the formation of instrumental approaches of optimisation and rationalisation, have been considered.

The author's method of assessing the level of *EnS* at the territorial level has been also constructed, allowing the determination of the *EnS* index and a regression model of the dependence of *EnS* on various factors has been built.

The proposed approach was tested using Georgia as an example. An assessment of the country's *EnS* was calculated, and the downward trend in the level of *EnS* was revealed (from 0.772

[4] WES, World Energy Trilemma Index, 2020. trilemma.worldenergy.org

in 2008 to 0.705 in 2018). An example of a regression model was provided, in which a strong correlation between Georgia's *EnS* and import-export indicators was revealed.

Limitations of the study include the following:

– statistical imbalance: the difficulty of finding statistics by region and the lack of long-term observations of a few indicators.

– structural incompleteness: selected indices are not final, and they are planned to be expanded and complicated.

– innovative insufficiency: the innovative context and state of the territory's energy funds are not sufficiently accounted for in assessing *EnS*.

However, these restrictions are not serious, and they open the way to resolve the problems in further research. The overall result was the construction of a toolkit for the analysis of the *EnS* of a territory. In the future, it is planned to build expanded models of dependency by country and region, highlighting the key parameters for creating energy efficiency for different territories.

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SECTION 4.

MANAGEMENT OF KNOWLEDGE AND INNOVATION FOR SUSTAINABLE DEVELOPMENT

РАЗДЕЛ 4.

УПРАВЛЕНИЕ ЗНАНИЯМИ И ИННОВАЦИЯМИ В ИНТЕРЕСАХ УСТОЙЧИВОГО РАЗВИТИЯ

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CLUSTERING OF TERRITORIAL OBJECTS IN THE MANAGEMENT OF THEIR SUSTAINABLE DEVELOPMENT

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Abstract

It is necessary to understand the nature of spatial territorial socio-economic objects in order for them to have an effective influence on the implementation of measures intended to increase the living standards of the population that resides there. To achieve this, they must be correctly identified amongst a general set of objects. In this regard, the purpose of this work is to develop a tool for territorial clustering. Science is one of the engines of socio-economic progress through which innovations are implemented. Hence, we test the clustering of territorial objects (regions of Russia) in relation to statistical financial cost data for science in terms of their relationship with wages and incomes of the population, the GRP (Gross Regional Product) and innovation activity. The main tool used for cluster analysis is the perceptron mathematical model, the features of which we describe in detail in this work. It follows from its characteristic features that it divides a studied population in a manner that allows for the possibility to simulate the increasing or decreasing dynamics of one quantity's dependence on another. The study develops a universal algorithm for the purpose of territorial cluster analysis, which is proven in the construction of the final models of dependence (paired linear regression) of the indicators identified in the work, whose coefficient of determination is primarily 0.8. In our conclusion, we indicate possible options for the further development of this study, both with respect to the technical aspects of refining and improving the algorithm as well as within the framework of a more detailed analysis of the identified regression patterns using the example of statistical data of Russian reality in relation to science and the level of life quality.

Keywords: Clustering, perceptron, spatial economics, modelling of economic processes, econometric analysis, science and innovation.

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КЛАСТЕРИЗАЦИЯ ТЕРРИТОРИАЛЬНЫХ ОБЪЕКТОВ В УПРАВЛЕНИИ ИХ УСТОЙЧИВЫМ РАЗВИТИЕМ

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Аннотация

Понимание природы пространственных территориальных социально-экономических объектов необходимо для эффективного воздействия внутри них для реализации мер по увеличению качества жизни населения, которое там проживает. Для этого среди общей совокупности объектов их необходимо правильно идентифицировать. В этой связи цель данной работы заключается в разработке инструментария кластеризации территорий. Одним из двигателей социально-экономического прогресса выступает наука, посредством которой воплощаются в жизнь инновации. На основании этого кластеризация территориальных объектов (регионов России) будет апробирована на статистических данных финансовых затрат на науку в их взаимосвязи с оплатой труда и доходами населения, ВРП, и инновационной активностью. Основным инструментом кластерного анализа определена математическая модель персептрона, особенности которой детально описаны в работе. Из ее характерных черт следует выделить то, что она делит исследуемую совокупность таким образом, что сохраняется возможность моделирования возрастающей или снижающейся динамики зависимости одной величины от другой. Итоговым результатом исследования стала разработка универсального алгоритма кластерного анализа территорий, который подтвердил себя при построении конечных моделей зависимости (парная линейная регрессия) обозначенных в работе показателей, коэффициент детерминации которых у большинства равен 0.8. В заключении обозначены возможные варианты дальнейшего развития исследования как в направлении технических аспектов доработки и совершенствования алгоритма, так и в рамках более детального анализа по выявленным регрессионным закономерностям на примере статистических данных российской действительности в отношении науки у уровня качества жизни.

Ключевые слова: кластеризация, персептрон, пространственная экономика, моделирование экономических процессов, эконометрический анализ, наука и инновации.

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Introduction

Advances in science and technology are the driving forces of economic and social development, affecting economic growth, product quality, population living standards and so on. This fundamental idea has been studied in detail in the works of the Austro-American economist Schumpeter (1980). The existence of such patterns is described in detail in the work of Stepanova and Lesnikova 'The Role of Innovations in the Modern Development of Russian Society' (2017) and in the article by Lugovaya 'Innovations as the Basis for the Modernization of Modern Society' (2012). Funding for research and development (R&D) plays an important role in the process of creating innovations. In 2018, the share of R&D funding costs in the gross domestic product (GDP) in the Organisation for Economic Co-operation and Development (OECD) countries was 4.5% (including Sweden: 3.3%, Austria: 3.2%, Germany: 3.1%, the UK: 1.7%, Japan: 3.3%, Korea: 4.5%, China: 2.1%). However, in Russia, the volume of R&D costs remains at an extremely low level. In the 2015–2017 period this indicator was 1.1%, decreasing to 0.98% in 2018, which is comparable to the indicators for South Africa, Brazil and Slovakia (about 1.0% of GDP).[1] One of the ways in which the problem of low R&D costs can be solved is through the creation of funds to support scientific, technical and innovation activities – an important aspect of which is the provision of financial support for R&D.

This study suggests that the creation of funds in order to support scientific, technical and innovation activities can have a significant impact on the socio-economic development of a country. To do so, it is first necessary to determine the relationship between an indicator such as 'R&D costs' and other parameters that characterise a population's living standard, a country's economic development, etc. The formation of such mathematical models of relationships would not only allow us to achieve certain desired results via inertia but would also make it possible for us to create a system of measures for them so that they remain stable over an extended period.

When determining such relationships within seemingly identical territorial objects, a problem arises because similar processes and phenomena occur in these objects in different ways. Consequently, there is a need for the studied objects to correctly be correlated into groups within which it would be possible to apply classical and proven methods of data processing and analysis.[2,3]

Therefore, the purpose of this work is to develop a toolkit for clustering territories. Its approbation is carried out on the data associated with the assessment of the impact of investments in science on the level of the population's well-being, characterised through the prism of various statistical metrics. The need for cluster analysis of territories in this direction is due to the identification of their priority areas of scientific research for the implementation of local administrative measures. These measures, in turn, would more quickly enable faster growth in the population's well-being in areas in which appropriate scientific directions are implemented and specific innovative projects are developed.

2. Literature review

First, we briefly describe what positions on the issue of assessing the impact of investments in science are indicated in modern scientific literature. A literature review reveals that there are different views amongst researchers regarding what indicators affect the R&D cost amounts and, conversely,

[1] Gross domestic spending on R&D, (n.d.). https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm

[2] Ayvazyan, S.A., 2010. Methods of Econometrics: Textbook, Master. INFRA-M, Moscow

[3] Marno, V., 2008. Guide to Modern Econometrics. Scientific Book, Moscow

how R&D financing affects other parameters. The study of the scientific literature has shown that, in general, different authors do not identify indicators but factors that can somehow influence the R&D financing.

For example, according to Yegorenko et al. (2018), R&D financing consists of the following components: federal budget, commercial organisations, non-profit sector and international investment. At the same time, it is important to note that, according to these authors, commercial organisations have a significant impact on the growth of R&D costs. According to OECD data, in most developed countries (China, the Republic of Korea, Japan, the United States, Germany, the United Kingdom, France, etc.), the share of the commercial sector in the country's R&D costs exceeds 40%, while in Russia this indicator is at only 28.1%. In China, for example, the state contributes only a fifth of the total R&D investment, while the business sector directs more than 76% of the funding.[4]

According to Seidl da Fonseca and Pinheiro-Velos (2018), the R&D cost amount can be influenced by such factors as the availability of venture funds that are designed to help companies at different stages of development. In addition, the possibility of obtaining any tax benefits in the field of scientific, technical and innovation activities, as well as the availability of a favourable legislative environment, can be important parameters that affect R&D financing. According to a team of authors led by Seidl de Fonseca (2018), taxes can have a serious impact along with the risks that always accompany all innovative projects.

It is important to note that many authors (Rodina, 2014; Yurchenko, 2013; etc.) emphasise tax incentives and a favourable legislative environment as some of the factors affecting the growth of R&D costs. According to Pashintseva (2018), there is a relationship not only between such indicators as R&D costs, federal budget and availability of venture funds but also between R&D funding and the net profit of organisations.

In addition, as Zhukovskaya et al. (2021) emphasise, the increase in R&D costs does not result from an increase in funding, an increase in the interest of both the state and private investors in the renewal of equipment and technologies or the involvement of R&D results in commercial turnover but from indexation to the level of inflation.

At the same time, when analysing the scientific literature, it is also found that there is a relationship between R&D financing and the foreign policy situation (Maslova and Lalaeva, 2018).

Thus, it is important to note that a significant number of authors do not name specific indicators but only highlight the presence of factors that are somehow related to R&D costs. Nevertheless, the analysis of the scientific literature allows us to identify the parameters that characterise the dependence on the amount of R&D funding, which include: federal budget, commercial and non-profit sectors, international investment, foreign policy environment, taxes, availability of tax incentive tools, favourable legislative environment, availability of venture funds, risks, GDP, inflation and so on.

However, it is important to note here that it is difficult to carry out calculations in order to assess the relationship between changes in R&D costs and the other above-mentioned parameters because many authors do not discuss specific indicators, with the exception of GDP, inflation, international investment and federal budget. Factors such as commercial and non-commercial sectors do not provide a clear understanding of what indicators are being referred to by the authors. At the same time, factors such as foreign policy environment and tax incentive instruments are generally difficult to describe statistically, making it difficult to use these parameters. Hence, it is necessary to look for additional indicators in order to find the relationships between R&D costs and other parameters.

[4] Gross domestic expenditure on R&D by sector of performance and source of funds, (n.d.). https://stats.oecd.org/Index.aspx?-DataSetCode=GERD_SOF

As mentioned above, we assume that the change in R&D costs is related to the parameters of socio-economic development. In this regard, based on the data of the Federal State Statistics Service, we propose to use wages, income of the population, GDP and innovation activity as the main indicators that characterise the population's standard of living as well as the economic and innovative development. Accordingly, it is necessary to analyse the dependence of these indicators on changes in the volume of R&D financing and vice versa.

The issue does not end here and rests on the fact that the dynamics of the above-mentioned indicators behave differently. This is due to the different spatial features of the studied territories. In a series of papers by Kudryavtseva and Skhvediani (2020a, 2020b), the authors discuss the relevance of finding solutions to such problems in detail. In the article 'Econometric Analysis of the Industry Specialization of the Region: on the example of the Manufacturing Industry of Russia' (Kudryavtseva and Skhvediani, 2020a), the author team proposes several tools for assessing regional specifics in accordance with the industrial production located on their territories. In the article 'Studying Regional Clusters with the Use of Data Processing Systems: The Case of the Biopharmaceutical Cluster' (Kudryavtseva and Skhvediani, 2020b), the authors managed to distinguish regions into separate groups in accordance with estimates of the 'localisation', 'size' and 'focus' of a biopharmaceutical cluster located in the territorial space of Russia.

The problems with assessing territorial objects, their development and functioning are also presented in a number of other Russian works. Thus, in Kozhevnikov's (2019) 'Spatial and territorial development of the European North of Russia: Trends and priorities of transformation', the author identifies problems of regional management and highlights their features for the northern areas of the Russian Federation. In Alferyev's (2018) talking points, the work of the autoregressive model is demonstrated on the basis of an example of the Republic of Belarus regions cooperation in science and technology. An article by Minakir (2017) covers developments on spatial and territorial topics in general, analysing the main achievements and developments in this area. The article by Fonotov and Bergal' (2020) provides an overview of foreign developments in the implementation of the policies of individual territorial subjects of states and clusters formed on these states.

A number of foreign works are also devoted to the topic of territorial subject clustering and of the resulting administrative impact on them. Ketels' (2017) 'Cluster Mapping as a Tool for Development' demonstrates the structuring of territories in accordance with the clusters that are located on them and reflects the idea of their visual display in the form of interactive graphics. In the article by Falcioglu and Akgüngör (2008), the authors carry out a cluster analysis of regions using data from Turkey and testing it in accordance with the industrial production facilities located on its territory. In their work, Feser and Bergman (2000) justify the concept of grouping regions in accordance with the main industry clusters that appear at the state level. They also highlight key cluster patterns that may be inherent at the federal level.

The review of the above-mentioned works is expressed in a detailed understanding of how certain specific state industry clusters or industrial production mechanisms (as the main tools for creating a material product) function, which are implemented in the country under consideration. As a result, the approaches to the management of territories used in the reviewed works constitute an empirical approximation and are inherently unique, specific and difficult to adapt for other spatial subjects.

In terms of technical analysis, we use different variations of correlation analysis to determine whether there is a relationship between socio-economic metrics. The limitation of their application for most economic samples lies in the lack of data uniformity. Consequently, relationships, as such, cannot be unambiguously detected but, with the appropriate grouping of objects included in the sample, it is possible to model stable patterns within each group.

The use of the perceptron model on the display area of the quantitative data, which, by its very nature, allows us to linearly divide the n-dimensional space into two components in accordance with the manifestation of the concentration of statistical estimates of interest in them, can represent a possible solution to this problem. A feature of this approach is that, unlike the classical versions of cluster analysis, it allows us to form groups by linearly dividing them and not around the point of accumulation of data, which in turn allows for a more correct display of the dynamics of the process.

The implementation of managed territorial object clustering is reflected in the implementation of 'sustainable economic development' concepts. The fundamental work of Uskova (2009), the 'Management of Sustainable Development of the Region' monograph, touches on this topic. In it, she considers these things through the prism of Russian regions and their smaller structural units —municipalities. Another article, written by a team of authors under the leadership of Pozdnyakova (Pozdnyakova et al., 2017), also demonstrates the importance of the proper clustering of territories for the formation of stable signs of development and for the growth of economic processes and phenomena within them. There is also an emphasis on the fact that the grouping of territories should be based on innovations, the importance of which we mentioned earlier in the 'Introduction' section of this article. Furthermore, a scientific work by Rentkova (2019) shows the importance of proper clustering of territorial objects (the manuscript focuses on cities, using the example of the Republic of Slovakia) in implementing the territories' principles of sustainable economic development.

3. Materials and methods

The basic functional unit of artificial neural networks (ANNs) is a formation such as a perceptron (a single-layer artificial neural network) (Shamin, 2019, n.d.). Its discovery occurred around 1950s and is associated with Rosenblatt (1962), where a principal point that should be noted is its 'learning' property, which seemed to be very promising at first. Subsequently, Minsky and Papert (1969) showed the limitations of this object (some of the simplest logical problems cannot be solved with it) in their works, which led to a decline of interest in this tool. Its schematic illustration is shown in Figure 1:

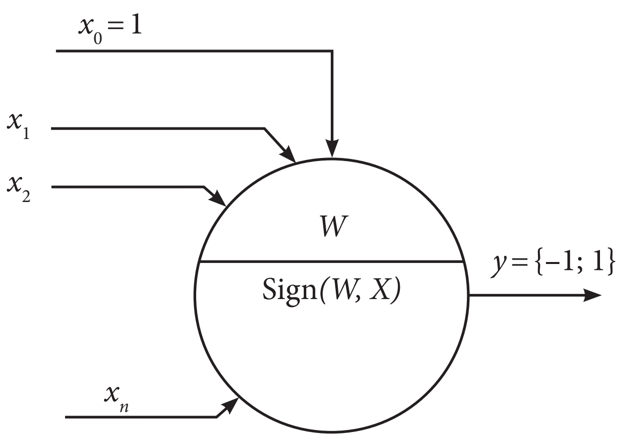
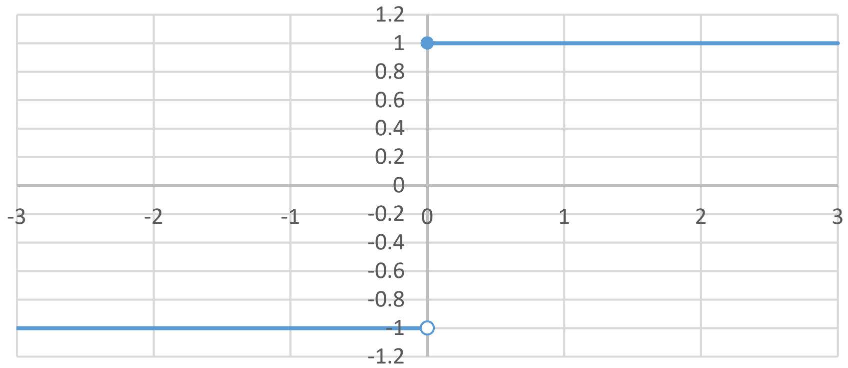


Figure 1. Perceptron circuit *(compiled by the authors)*

Here, $i=\overline{0,n}$; $n\in\mathbb{N}$ is the set of inputs to the perceptron body; $x_i \parallel X=\{x_0,x_1,...,x_n\}$ is the value supplied to the *i*-th input; $x_0=-1\parallel 1$ is the dummy input, the value of which is –1 or 1; $x_i\in\mathbb{R}$ represents user inputs, the estimates of which can take values from a set of real (real) numbers; $w_i \parallel W=\{w_0,w_1,...,w_n\}$ – weight coefficients;

$$\text{Sign}(t)=\begin{cases}-1, t<0,\\ 1, t\geq 0.\end{cases}$$



(1)

Figure 2. Heaviside step function *(compiled by the authors)*

Here, $\text{Sign}(t)$ is the activation function of iteration *t*; $y=\text{Sign}(W,X)$ is the output value of the perceptron, resulting from calculating the Heaviside step function (Figure 1) from the inner product; $(W,X)=w_0x_0+w_1x_1+...+w_nx_n=\sum_{i=0}^{n}w_ix_i$ is the inner product of $\overrightarrow{W}$ and $\overrightarrow{X}$. For $x_0=1$ (Figure 1), the inner product will take the following form – $(W,X)=w_0+w_1x_1+...+w_nx_n=w_0+\sum_{i=1}^{n}w_ix_i$.

In this case $y\in\{-1;1\}$, i.e. the perceptron performs binary classification between vectors. If we do not want the classification to be binary, then Sign does not apply. In this case, we do not determine the class but with what force the considered value belongs to a particular class.

The key thing about the perceptron is that the values of vector *W* can change as we work with it. This process is called learning in the discipline, i.e. we adjust the values of vector *W* in the way that we need (in accordance with the original data).

Learning, in turn, is divided into two main directions: 1) supervised learning (the training set is labelled, i.e. the correct answer is given to the and 2) unsupervised learning. Supervised learning is a typical task statement for ANN. The initial data for it is presented in the following table (Table 1).

Table 1 A priori data set for training a perceptron on labelled data (supervised learning), where *m* is the number of observations in the set (*compiled by the authors*)

x_1^1	x_2^1	…	x_n^1	y^1
x_1^2	x_2^2	…	x_n^2	y^2
…	…	…	…	…
x_1^m	x_2^m	…	x_n^m	y^m

3.1 Detailed perceptron learning algorithm

First, let us set the initial values for vector W. For example, $W = \vec{0}$. The values can also be selected at random. This affects the rate of convergence of the perceptron, provided it is present. Second, we repeat the procedure described below many times (the number of repetitions is selected experimentally):

1) In accordance with $j = \overline{1,m}$; (*j* is a certain number of our observation), we calculate *d:*

$$d = \text{Sign}(W, X) = \begin{cases} -1, \text{if } (W, X) < 0, \\ 1, \text{if } (W, X) \geq 0. \end{cases}$$

How *j* is selected is an open question. There is an option to select it sequentially (if it was previously distributed in an arbitrary order) or stochastically. In accordance with the practice of its own implementation, the random sorting of objects that are divisible by the perceptron should be laid down in the form of a certain iteration. In this case, we randomly sort the trained set until it gives a certain specified result (e.g. splitting the population under study into an acceptable percentage).

2) If $d \cdot y = -1$, then the recognition is performed incorrectly and it is necessary to adjust the values of *W*:

$$w_i = w_i + \alpha \cdot y \cdot x_i, \ \alpha > 0.$$

α is a parameter that sets the rate of our learning, and is determined experimentally. Traditionally, it is positive and small. The smaller it is, the more accurately we learn, but longer and vice versa. If $d \cdot y$ is still –1, then we continue to adjust the weights until we obtain the correct answer. We proceed to the next observation and repeat what we did in steps 1 and 2. The calculation according to the described algorithm is presented below (Table 2).

Thus, the perceptron model under the given conditions will have the following form:

$$\text{Sign}(0.15 - 3.7443x_1).$$

Table 2 Algorithm for calculating weights for the perceptron model *y* from *x* (*compiled by the authors*), where $X = \{x_0, x_1\}$; $x_0 = \{1, 1, 1, 1\}$; $x_1 = \{0.6622, 74.998, 8.9736, 0.0281\}$; $y = \{1, -1, -1, 1\}$; $\alpha = 0.05$

x_0	x_1	y	w_0	w_1	(W, X)	d	$d \cdot y$
1	0.6622	1	0	0	$= w_0 \cdot x_0 + = w_1 \cdot x_1 =$ $= 0 \cdot 1 + 0.06622 = 0$	1	1
1	74.9981	–1	0	0	0	1	–1
1	74.9981	–1	$= w_0 + \alpha \cdot y \cdot x_0 = w_0 + \alpha \cdot y$ $= 0 + 0.05 \cdot (-1) = -0.06$	$= w_0 + \alpha \cdot y \cdot x_1 =$ $= 0 + 0.05 \cdot (-1) \cdot 74.9981 =$ $= 3.7499$	–281.2860	–1	1
1	8.9736	–1	–0.0500	–3.7499	–33.7000	–1	1
1	0.0281	1	–0.0500	–3.7499	–0.1553	–1	–1
1	0.0281	1	0.0000	–3.7485	–0.1053	–1	–1
1	0.0281	1	0.0500	–3.7471	–0.0553	–1	–1
1	0.0281	1	0.1000	–3.7457	–0.0052	–1	–1
1	0.0281	1	0.1500	–3.7443	0.0448	1	1

In conclusion, we want to note two main properties of the perceptron: 1) linear division of the set into two classes and 2) generalisation, expressed in the fact that despite the possibility of incorrect data, its work will be reliable in general. It is also worth noting that the success of using an artificial neural network is ensured by a good learning set. The solution can be the generation of tests (e.g. in a branch of knowledge such as mechanics).

The above algorithm is largely iterative. It can set specific parameters that, due to the simplicity of the pilot simulation, are indicated in the form of constants, taken in accordance with the recommendations of leading scientists in this field. They can also be made dynamic as part of the further development of the study or the initial values can be set in accordance with the actual, current conditions of the problem under consideration.

In the case of the perceptron operation algorithm, the following rules can be set:

– we denoted the vector of weight W as $\vec{0}$. However, if you choose any specific value, then the location of the hyperplane that divides the hyperspace into two parts will be closer to the desired one and, therefore, the learning process will be faster;

– in our case, the learning rate parameter α is taken at the level of 0.05, as a kind of positive practice in applied research related to the perceptron. At the same time, it is constant. However, it is still possible to make it dynamic and to either speed up or slow down the process of finding the acceptable weight. It can also be set separately for each variable included in the modelled structure;

– in accordance with the data included in the training set, the final model of the generated perceptron may be slightly different and divide the studied population without generalisation. In this regard, it is important to set more stringent modelling requirements or to carry out a procedure for mixing observations until the final result meets the specified conditions.

The things mentioned above are the ones primarily considered in two fundamental works: ‘Principles of Neurodynamic’ (Rosenblatt, 1962) and ‘Perceptrons’ (Minsky and Papert, 1969). In the case of working out any complex specific nuances of these algorithms, their use should be carried out manually, modelling each of the possible aspects independently in a computer environment. However, in the case of reproducing experiments that have already been tested or are largely similar to them in terms of the conceptual part, ready-made tools are also suitable – for example, various Python libraries, such as Keras or TensorFlow. An even more narrowly focused option is the neural network toolkit of the Statistica software, maintained by Stata software.[5]

3.2 Perceptron learning algorithm using Python tools

The implementation listing of the perceptron identified above, which divides the labelled training set into two classes (‘1’ or ‘–1’), is provided below (Figure 2).

The parameters w_0, w_1 and α are set by the researcher independently and can be selected under the conditions of the problem. The metric α for each weight can be unique and, for better convergence, is set in terms of acceleration rather than constant rate.

If the data under study is not previously labelled, then the implementation of the perceptron may look like this (Figure 3):

As in the first listing (Figure 2), the parameters w_0, w_1 and α can be set in accordance with the specifics of the data under study. In addition to this, you can apply further normalisation of quantitative estimates to reduce the impact of the response of numerical values supplied to the input of the algorithm during training on the modelling of weight coefficients.

[5] Stata: Software for Statistics and Data Science. https://www.stata.com/

```
for i in range(len(x1)):
    d = -1

    while d == -1:
        b = w0*x0[i] + w1*x1[i]
        if b < 0:
            b = -1
        else: b = 1
        d = b*y[i]
        if d == -1:
            w0 = w0 + a*y[i]*x0[i]
            w1 = w1 + a*y[i]*x1[i]
        else:
            w0 = w0*1
            w1 = w1*1
```

Figure 2. Algorithm for the implementation of the perceptron on labelled data (output value '1' or '–1') *(compiled by the authors)*

Note: Parameters: w_0, w_1 are the weights of the variables; α is the parameter responsible for the rate of change of the simulated weights W. Variables: x_0, x_1 are the vectors of values supplied to the input.

```
for i in range(len(x1)):
    y_prog = w0*x0[i] + w1*x1[i]

    if y_prog > y[i]:
        while y_prog > y[i]:
            w0 = w0 - a*x0[i]
            w1 = w1 - a*x1[i]
            y_prog = w0*x0[i] + w1*x1[i]

    elif y_prog < y[i]:
        while y_prog < y[i]:
            w0 = w0 + a*x0[i]
            w1 = w1 + a*x1[i]
            y_prog = w0*x0[i] + w1*x1[i]

    else:
        w0 = w0*1
        w1 = w1*1
```

Figure 3. Algorithm for the implementation of the perceptron (*compiled by the authors*)

Note: Parameters: w_0, w_1 are the weights of the variables; α is the parameter responsible for the rate of change of the simulated weights W. Variables: x_0, x_1 are the vectors of values supplied to the input.

3.3 Perceptron clustering algorithm on unlabelled data

1. Based on the available data, we construct a model of paired linear regression (Seber, 1977) and calculate its coefficient of determination. In accordance with its ratio and the levels of the Cheddock scale (Koterov et al., 2019, p. 14), we set an acceptable level of model accuracy for us. For example, 0.7 for the Pearson correlation (in the work, when tested on empirical data, the critical level is set at 0.8), described in one of the scientific papers referring to Chaddock as characterising a 'very good relationship'. At this level, the variance of one variable in relation to the other begins to exceed 50%. If this condition is satisfied, no clustering is required. If not, then go to step 2.
2. We sort the training sample randomly.
3. We train the perceptron according to the scheme shown in the listing figures (Figure 3).
4. In accordance with the obtained linear clustering model, we divide the sample population into two parts. In this case, the ratio of the two new aggregates must meet the following specified criteria:
   1) The number of observations in one of the newly formed populations must be greater than or equal to the specified size of the original population (in our example, we set this parameter at the level of 20%);

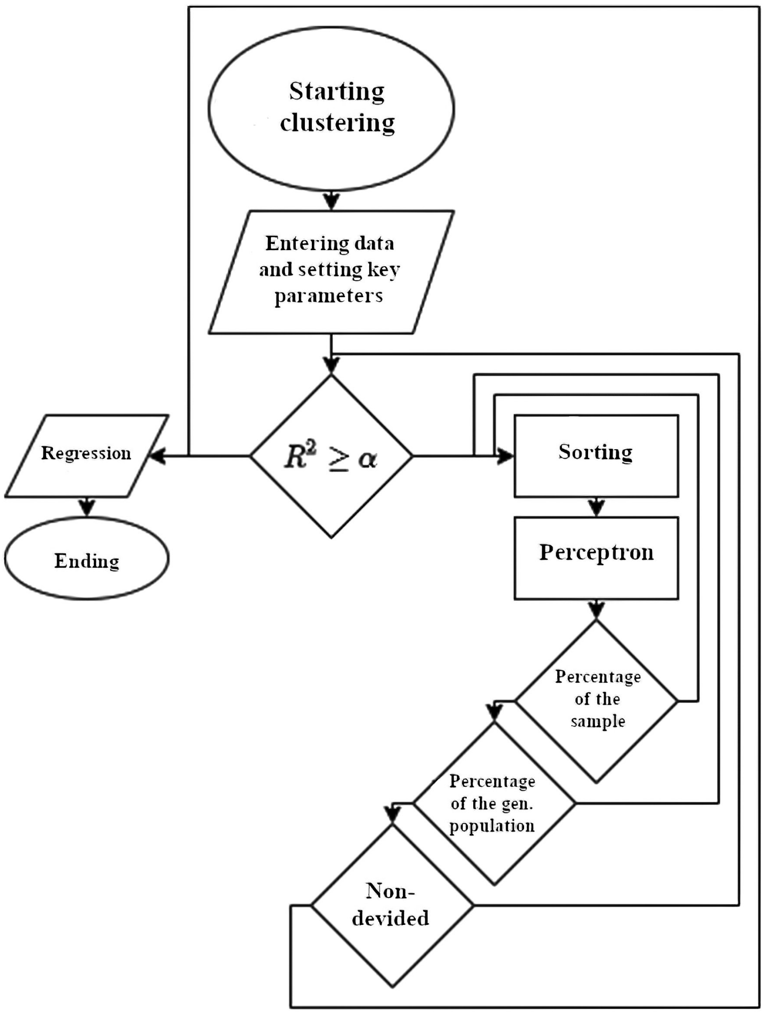


Figure 4. Clustering algorithm (compiled by the authors)

2) The number of observations in one of the newly formed populations must also be simultaneously greater than or equal to the specified size of the general population (in our example, we set this parameter at the level of 5%).

In case of non-compliance with one of the two above-mentioned criteria, we return to step 2. If the conditions are satisfied, we move on.

5. We check the newly formed groups for the possibility of further division in accordance with requirement 2) indicated in step 4. To do this, each of these groups must be divided in half. If the result from the division does not satisfy 2), then the clustering for the original group is completed and the final model of paired linear regression can be built on it through analogy with the one indicated at the first step of the algorithm. If the newly formed group can be divided, then check it for the condition R^2. If the condition is satisfied, no further

Table 3 The ratio of the average monthly salary to the cost of R&D per 10 thousand people, 2015–2019 (comparable prices according to the consumer price index)

Code	Region	R&D costs per 10 thousand people, million rubles	Average monthly salary, rubles
1	Belgorod region (2015)	14.38	29.544
2	Bryansk region (2015)	5.19	25.161
…	…	…	…
400	Sakhalin region (2019)	21.34	84.872

Note: Compiled by Regions of Russia. Socio-economic indicators. 2020: P32 Stat. sat., Moscow, 2020. https://rosstat.gov.ru/folder/210/document/13204

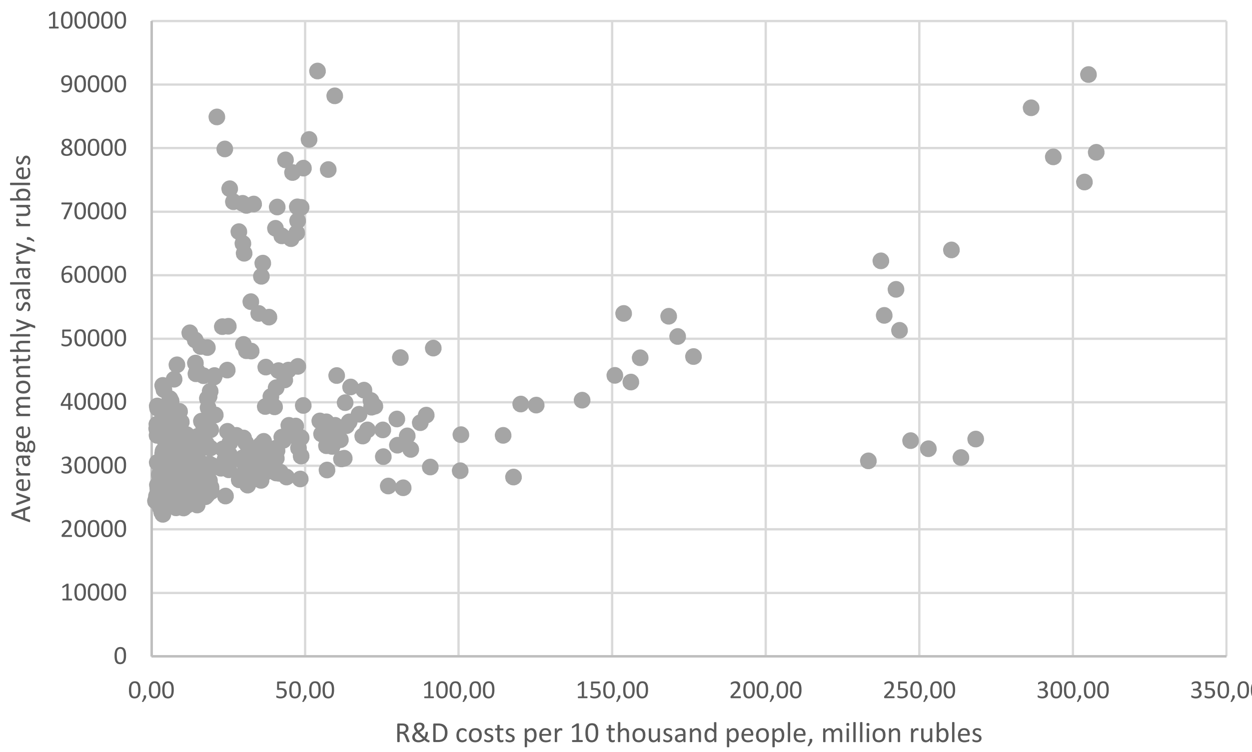


Figure 5. The ratio of the average monthly salary to the cost of R&D per 10 thousand people, 2015–2019 (comparable prices according to the consumer price index)

Note: Compiled by Regions of Russia. Socio-economic indicators. 2020: P32 Stat. sat., Moscow, 2020. https://rosstat.gov.ru/folder/210/document/13204 clustering is required. For this group, we build a model of paired linear regression in accordance with the one indicated in the first step of the algorithm (in fact, it is a return to step 1). If the condition is not satisfied, then we skip the newly formed group in accordance with all the steps of the algorithm and so on, until we get groups that cannot be divided or until the data set that is contained in them does not correspond to the set determination coefficient.

For clarity, the developed scheme of the algorithm is presented in Figure 4 below.

The presented algorithm is a generalisation of the numerical methods indicated before it. It can be detailed in the 'Data entry' part and the 'Regression' part. The initial data for testing the methods indicated in the work are presented in Table 3 below and are fully reflected in Figure 5.

Similarly, as in Table 3 and Figure 5, we make comparisons for 'R&D costs per 10 thousand people of the population' with 'average per capita income per month', 'GRP' and 'innovation activity'. We bring monetary indicators to a single point of reference in time through the consumer price index.

4. Results

Using perceptron clustering, we construct paired linear regression models, showing the linear response of investments and expenditures on science to one of the four indicators identified in the work for each of the groups formed. The visualisation of the performed calculations is presented below (Tables 4–7 and Figures 6–9).

Table 4. Detailed clustering procedure using the example of the statistical dependence of the average monthly salary on R&D costs (*compiled by the authors*)

First iteration (one cluster)		
Number of observations	*Regression*	R^2
400	$y=32\ 177.8834+109.8512x$	0.1996
Perceptron: $y=27\ 348.05+149.36x$		
Second iteration (two clusters)		
1.1. First cluster		
Number of observations	*Regression*	R^2
200	$y=37\ 238.5282+173.9474x$	0.3107
Perceptron: $y=30\ 267.15+193.607x$		
1.2. Second cluster		
Number of observations	*Regression*	R^2
200	$y=26\ 047.2989+87.7247x$	0.6436
Perceptron: $y=23\ 988.9+246.5195x$		
Third iteration (four clusters)		
1.1.1. First cluster		
Number of observations	*Regression*	R^2
122	$y=26\ 047.2989+87.7247x$	0.5911
Perceptron: $y=41\ 336.8574+236,7216x$		
1.1.2. Second cluster		
Number of observations	*Regression*	R^2
78	$y=28\ 701.2019+160.4252x$	0.9836

Table 4 (continued)

1.2.1. Third cluster		
Number of observations	*Regression*	R^2
59	y=25 477.1075+207.1883x	0.7051
Perceptron: y = 20 642+1227.2615x		
1.2.2. Fourth cluster		
Number of observations	*Regression*	R^2
141	y=25 860.0886+88.8163x	0.6175
Perceptron: y=11 826.8+387.581x		
Fourth iteration (seven clusters)		
1.1.1.1. First cluster		
Number of observations	*Regression*	R^2
30	y=31 932.627+1506.5539x	0.8656
1.1.1.2. Third cluster		
Number of observations	*Regression*	R^2
92	y=40 291.616+231.0619x	0.3834
Perceptron: y=27 654.25+1 310.948x		
1.2.1.1. Fourth cluster		
Number of observations	*Regression*	R^2
26	y=24 352.1053+655.074x	0.4881
1.2.1.2. Fifth cluster		
Number of observations	*Regression*	R^2
33	y=25 089.2624+230.0391x	0.8253
1.2.2.1. Sixth cluster		
Number of observations	*Regression*	R^2
96	y=23 059.238+206.0468x	0.8536
1.2.2.2. Seventh cluster		
Number of observations	*Regression*	R^2
45	y=27 790.1666+74.8948x	0.3573
Perceptron: y=11 826.8+387.581x		
Fifth iteration (nine clusters)		
1.1.1.2.1. Third cluster		
Number of observations	*Regression*	R^2
50	y=23 930.1484+1176.487x	0.8633
1.1.1.2.2. Seventh cluster		
Number of observations	*Regression*	R^2
42	y=27 790.1666+74.8948x	0.2525
Perceptron: y=9 197.8+1 575.455x		
1.2.2.2.1. Eighth cluster		
Number of observations	*Regression*	R^2
21	y=23 590.6379+137.5564x	0.3128
1.2.2.2.2. Ninth cluster		
Number of observations	*Regression*	R^2
24	y=27 576.31+75.5219x	0.1987
Sixth iteration (ten clusters)		
1.1.1.2.2.1. Seventh cluster		

Table 4 (finished)

Number of observations	*Regression*	R^2
22	y=9 187.076+1 370.7199x	0.948
1.1.1.2.2.2. Tenth cluster		
Number of observations	*Regression*	R^2
20	y=40 194.7432+165.6774x	0.6153

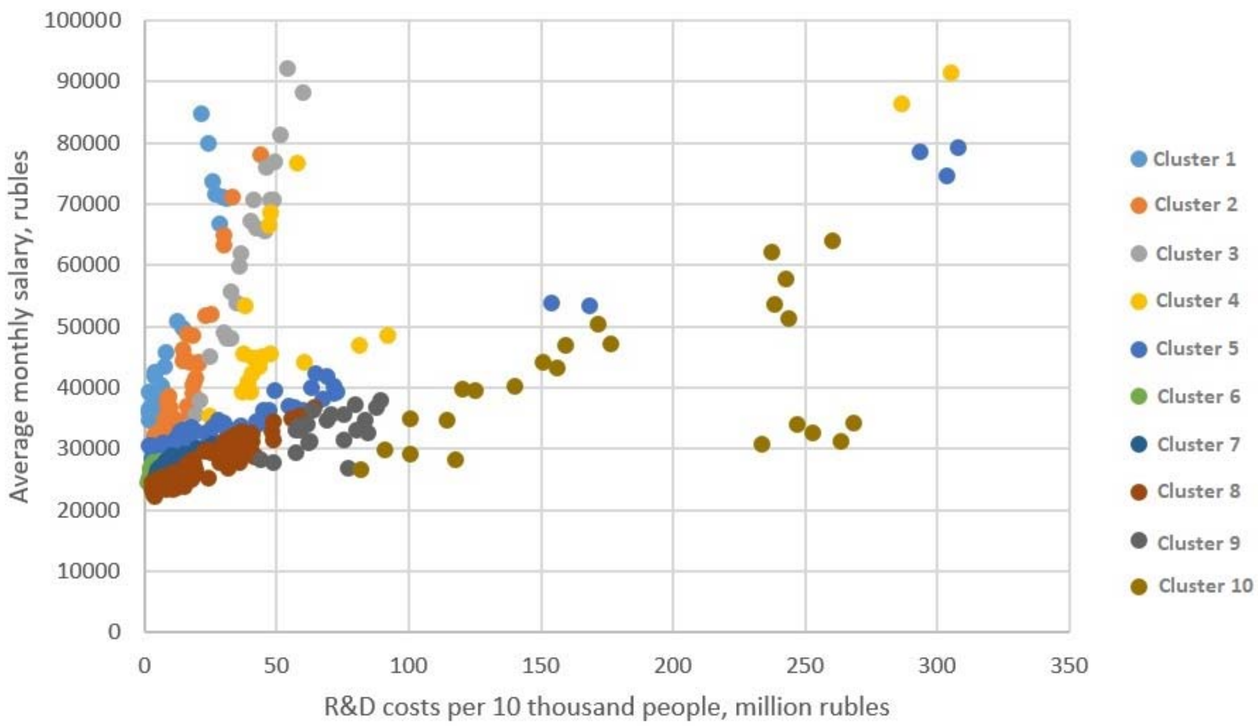


Figure 6 Clustering payroll with R&D costs (*compiled by the authors*)

The main characteristics of the clusters formed with the ratio of wages and R&D costs, as well as their graphical visualisation, are presented in Table 4 and Figure 6 above. With less detail, the results of calculations regarding the relationship between R&D costs and per capita income, GRP and innovation activity are presented below (Tables 5–7 and Figures 7–9).

Table 5. The result of clustering on the example of the statistical dependence of average per capita income on R&D costs (*compiled by the authors*)

First iteration (one cluster)		
1. *Perceptron:* y=22 014.6+391.243x		
Second iteration (two clusters)		
1.1. *Perceptron:* y=19 570,6+636,3575x		
1.2. *Perceptron:* y=17 694.2+574.5665x		
Third iteration (four clusters)		
1.1.1. First cluster		
Number of observations	*Regression*	R^2
123	y=23 965.7267+665.5832x	0.8352
1.1.2. Second cluster		
Number of observations	*Regression*	R^2

Table 5 (continued)

24	$y=-29.7756+0{,}0016x$	0.24
1.2.1. *Perceptron:* $y=13\,248.8+1492.3185x$		
1.2.2. *Perceptron:* $y=14\,230.65+188.6715x$		
Fourth iteration (six clusters)		
1.2.1.1. Third cluster		
Number of observations	*Regression*	R^2
22	$y=20\,174.1019+1483.178x$	0.4043
1.2.1.2. Fourth cluster		
Number of observations	*Regression*	R^2
22	$y=20\,028.4187+470.0996x$	0.7823
1.2.2.1. *Perceptron:* $y=14\,323.85+769.799x$		
1.2.2.2. Fifth cluster		
Number of observations	*Regression*	R^2
35	$y=15\,730.7867+120.8396x$	0.5997
Fifth iteration (seven clusters)		
1.2.2.1.1. Sixth cluster		
Number of observations	*Regression*	R^2
21	$y=15\,869.667+715.4577x$	0.956
1.2.2.1.2. *Perceptron:* $y=1\,567.8+776.533x$		
Sixth iteration (eight clusters)		
1.2.2.1.2.1. Seventh cluster		
Number of observations	*Regression*	R^2
83	$y=14\,312.6826+505.4476x$	0.805
1.2.2.1.2.2. Eighth cluster		
Number of observations	*Regression*	R^2
70	$y=21\,042.7696+164.9877x$	0.8656

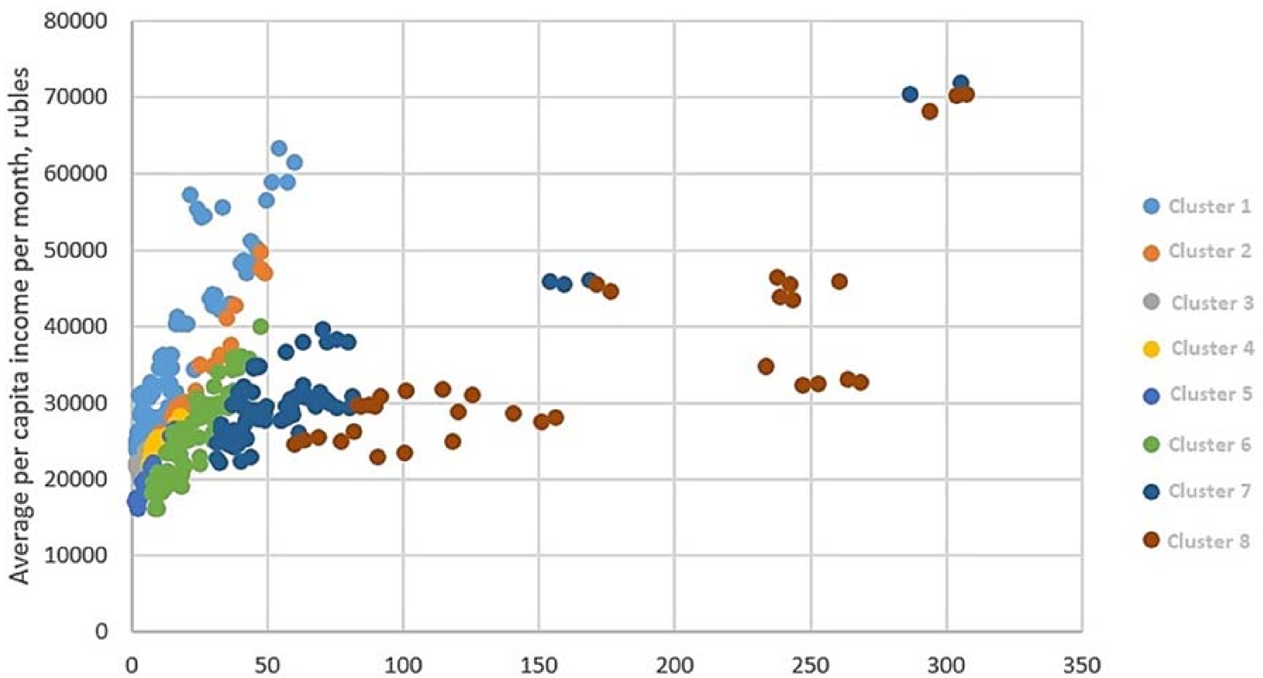


Figure 7 Clustering of average per capita incomes with R&D costs (*compiled by the authors*)

Table 5 and Figure 7 show the results of the modelling cluster analysis of regions with the ratio of their average per capita income and R&D costs. The performed calculations can be considered successful because most of the obtained models of the growth of average per capita income on R&D expenditure dependence have a high coefficient of determination ($R^2 \geq 0.8$).

Table 6. The result of clustering on the example of the statistical dependence of GRP per 10 thousand people population on R&D costs (*compiled by the authors*)

First iteration (one cluster)		
1. *Perceptron*: *y*=2 864.2+18.704x		
Second iteration (two clusters)		
1.1. *Perceptron: y* =3 238.2+337.842*x*		
1.2. *Perceptron: y = 1 962.95+30.5355x*		
Third iteration (four clusters)		
1.1.1. First cluster		
Number of observations	*Regression*	R^2
17	*y*=4 305.258+401.6492*x*	0.833
1.1.2. *Perceptron: y*=2 102.4+156.7485*x*		
1.2.1. *Perceptron: y*=1 472.15+95.059*x*		
1.2.2. *Perceptron: y*=936.15+44.042*x*		
Fourth iteration (seven clusters)		
1.1.2.1. Second cluster		
Number of observations	*Regression*	R^2
51	*y*=3 067.3004+175.3168*x*	0.8594
1.1.2.2. *Perceptron:* y=171.3+74.482x		
1.2.1.1. *Perceptron:* y=1 002.1+257.4945x		
1.2.1.2. Third cluster		
Number of observations	*Regression*	R^2
24	*y*=2 204.2446+29.0543*x*	0.8895
1.2.2.1. *Perceptron:* *y* = 837.25 + 138.5545*x*		
1.2.2.2. Fourth cluster		
Number of observations	*Regression*	R^2
23	*y*=2 810.7234+9.4134*x*	0.2974
Fifth iteration (ten clusters)		
1.1.2.2.1. *Perceptron: y*=136.1+223.9675*x*		
1.1.2.2.2. Fifth cluster		
Number of observations	*Regression*	R^2
21	*y*=2 234.1708+31.7977*x*	0.8511
1.2.1.1.1. Sixth cluster		
Number of observations	*Regression*	R^2
28	*y*=2 846.8172-92.2809*x*	0.1194
1.2.1.1.2. Seventh cluster		
Number of observations	*Regression*	R^2
24	*y*=1 939.6131+72.9646*x*	0.8478
1.2.2.1.1. Eighth cluster		
Number of observations	*Regression*	R^2
19	*y*=1 030.987+137.5103*x*	0.9065

Table 6 (continued)

1.2.2.1.2. Ninth cluster		
Number of observations	*Regression*	R^2
26	$y=1\ 468.6517+38.3244x$	0.8162
Sixth iteration (eleven clusters)		
1.2.2.1.2.1. Tenth cluster		
Number of observations	*Regression*	R^2
17	$y=1\ 825.8237+152.8044x$	0.8634
1.2.2.1.2.2. *Perceptron:* $y=23.4+153.024x$		
Seventh iteration (twelve clusters)		
1.2.2.1.2.2.1. Eleventh cluster		
Number of observations	*Regression*	R^2
22	$y=642.3635+156.6956x$	0.9308
1.2.2.1.2.2.2. *Perceptron*: $y=8.05+109.579x$		
Eight iteration (thirteen clusters)		
1.2.2.1.2.2.2.1. Twelfth cluster		
Number of observations	*Regression*	R^2
27	$y=707.2714+109.6994x$	0.7761
1.2.2.1.2.2.2.2. Thirteenth cluster		
Number of observations	*Regression*	R^2
21	$y=520.8359+85.6223x$	0.831

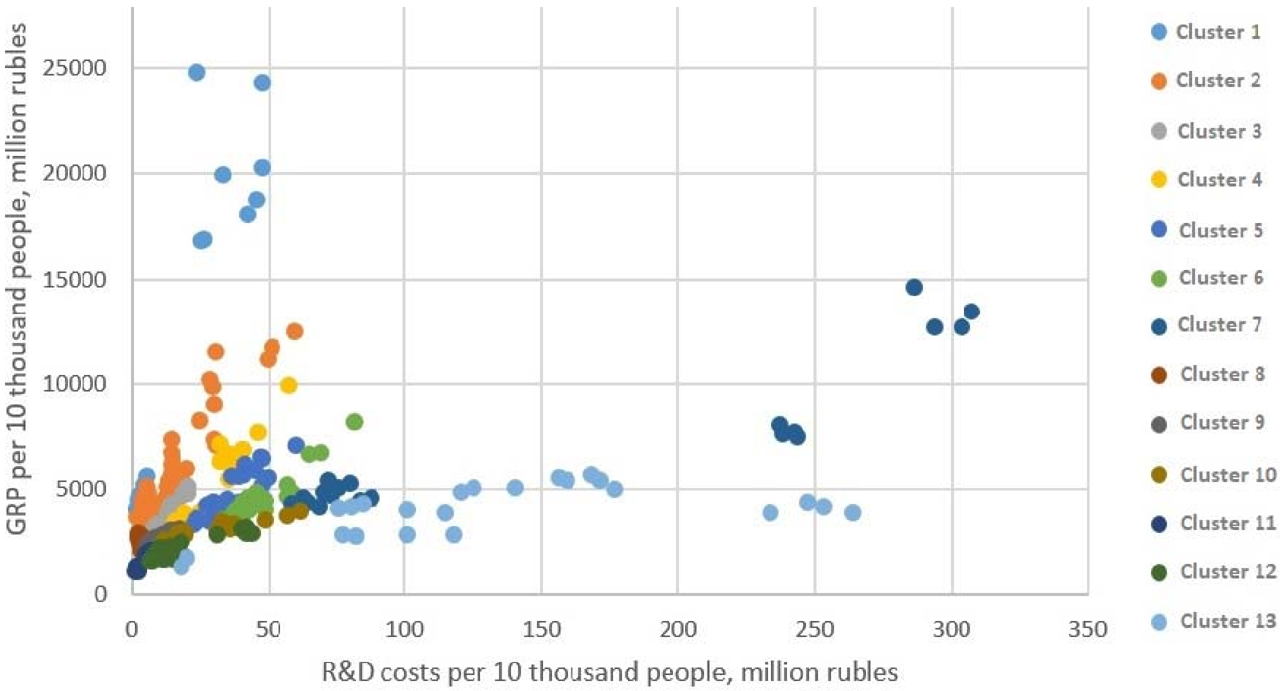


Figure 8. GRP clustering with R&D costs (*compiled by the authors*)

Table 6 and Figure 8 present the results of modelling the clustering of regions in determining the relationship between the simultaneous growth of R&D costs and GRP. As in the previous versions, the algorithm showed a good result, simulating most of the dependencies at the $R^2 \geq 0.8$ level.

Table 7. The result of clustering on the example of statistical innovation activity on R&D costs (*compiled by the authors*)

First iteration (one cluster)		
1. *Perceptron*: y=4.8+0.1818x		
Second iteration (two clusters)		
1.1. *Perceptron:* y=5.9+0.1864x		
1.2. *Perceptron:* y=2.4+0.2573x		
Third iteration (four clusters)		
1.1.1. *Perceptron:* y=5.295+0.3286x		
1.1.2. First cluster		
Number of observations	*Regression*	R^2
41	y=5.3453+0.181x	0.9849
1.2.1. Second cluster		
Number of observations	*Regression*	R^2
41	y=3.4789+0.2323x	0.8712
1.2.2. *Perceptron:* y=1.39+0,156x		
Fourth iteration (six clusters)		
1.1.1.1. *Perceptron:* y=4.925+1.1323x		
1.1.1.2. Third cluster		
Number of observations	*Regression*	R^2
25	y=6.4438+0.2067x	0.8804
1.2.2.1. Fourth cluster		
Number of observations	*Regression*	R^2
102	y=2.2743+0.1801x	0.9046
1.2.2.2. *Perceptron:* y=1.39+0,156x		
Fifth iteration (eight clusters)		
1.1.1.1.1. Fifth cluster		
Number of observations	*Regression*	R^2
20	y=8.4344+1.1673x	0.6182
1.1.1.1.2. *Perceptron:* y=1.615+0.9766x		
1.2.2.2.1. *Perceptron:* y=0.315+0.1352x		
1.2.2.2.2. Sixth cluster		
Number of observations	*Regression*	R^2
21	y=–1.4109+0.0685x	0.3228
Sixth iteration (ten clusters)		
1.1.1.1.2.1. Seventh cluster		
Number of observations	*Regression*	R^2
34	y=3.3653+0.979x	0.8472
1.1.1.1.2.2. Eighth cluster		
Number of observations	*Regression*	R^2
30	y=6.6578+0.3444x	0.892
1.2.2.2.1.1. Ninth cluster		
Number of observations	*Regression*	R^2
25	y=0.7996+0.1498x	0.9717
1.2.2.2.1.2. Tenth cluster		
Number of observations	*Regression*	R^2
51	y=0.4622+0.0991x	0.8776

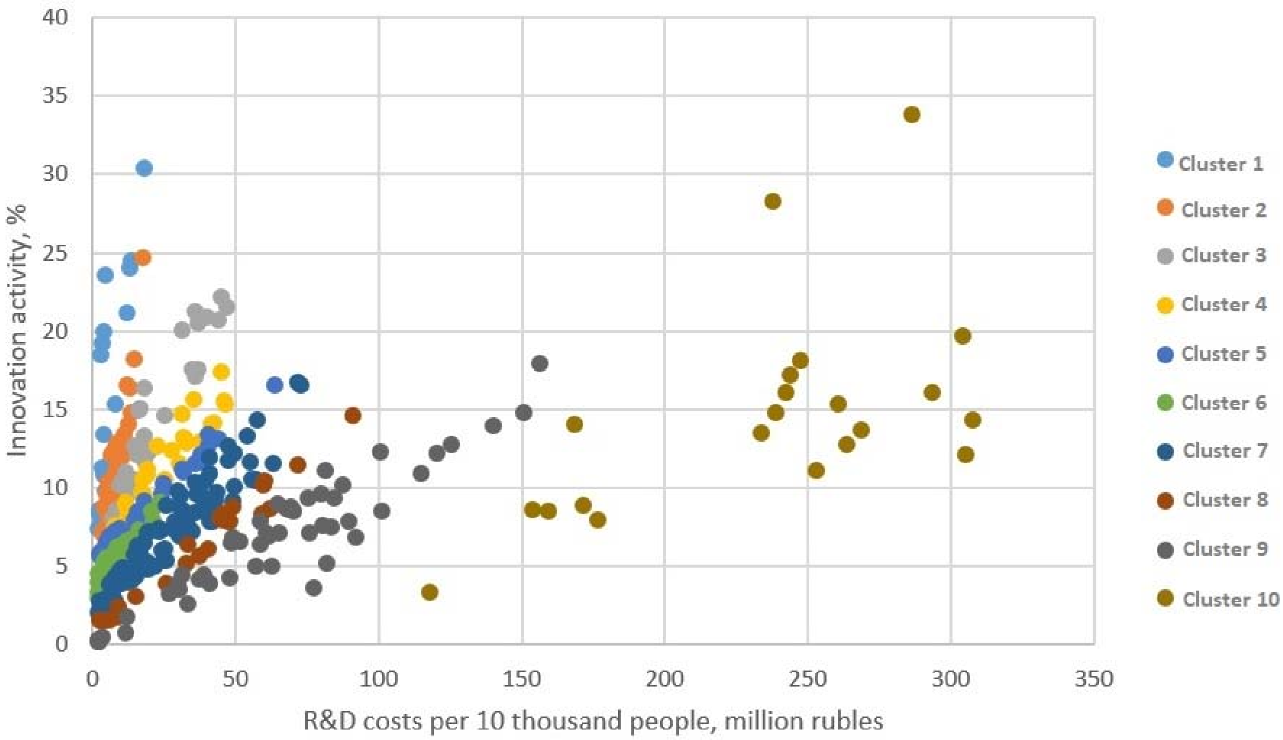


Figure 9. Clustering innovation activity with R&D costs (*compiled by the authors*)

In the last clustering, the learning rate of the weights was reduced by one order of magnitude ($\alpha = 0.05 \rightarrow \alpha = 0.005$). The need for this procedure arises from the fact that the perceptron could not divide the population supplied to it as input into two parts in accordance with the condition of a sufficient share of the sample and the general population. This is due to the size of the indicators involved in the learning for which the weights are modelled on the resulting response. For wages, per capita income and GRP per unit of population, the average dimension is measured in thousands of units, for innovation activity is measured in dozens. A possible universal way to implement the perceptron algorithm is to pre-normalise the data.

5. Discussion

Forecasting estimates for socio-economic systems is a complex and urgent task in view of the disparate behaviour of the relationships between them in the field of their representation. In contrast to natural systems, socio-economic patterns visually often have several variants of development. To some extent, this may be due to the fact that the objects of research that are identical for us are actually not identical. A variant of this can be territorial entities that are nominally designated as regions (municipalities, states, countries and other similar objects can also appear here), although, in fact, they are something different.

It is also worth noting here that socio-economic information is often unstable, even for identical objects, in contrast to natural science data. If we measure the mass of a body or, for example, its mechanical speed of movement, then we can compare it with another object using these same characteristics. In the case of economy, things are more complicated. Not only does the measurement of certain socio-economic characteristics largely depend on the opinion of the person who takes these indicators but the indicators themselves are to some extent dynamic in nature. An example of this is a currency that, when used in a different areas, will have different purchasing power. A possible option for more accurate modelling of such processes can be quantum computing (Kozyrev, 2018). In one of the most recent publications in 2020, a team of authors led by Moreira (Moreira et al., 2020) proposed a universal scheme for modelling the decision-making process that allows us to reflect the irrationality of human behaviour and thinking. The complexity of modelling socio-economic processes and the inefficient use of existing mathematical methods in relation to them is shown in the work of Martínez-Martínez (2014). An alternative solution to them is quantum computing.

The use of the perceptron model in this work allowed us to divide the studied population in a universal manner in accordance with the behaviour of the dynamics of three different indicators of the socio-economic well-being of citizens in response to changes in the R&D cost amount. In general, the trend in all four metrics (salary, per capita income, GRP and innovation activity) with an increase in the amount of spending on science can be described as positive, however, it manifests itself differently in different regions. For some it is faster, for some it is slower.

The final linear regression models have a high coefficient R^2 , greater than 0.8, which, in accordance with established econometric practice, is a good result that can be used in applied management activities. At the same time, in the future, the model proposed in this paper will have the potential for improvement in the form of connecting a variation of the genetic algorithm to it when choosing the best possible clustering option. The linear regression model can also be replaced with a function that more closely approximates the actual data: exponential trend, if there is an acceleration of the dynamics of the process under study; logarithmic, if there is a damping; trigonometric, if there are static fluctuations.

Modelling the impact of investments in science is an important component for planning the qualitative development of human society because science constitutes the ‘spark of ignition’ when creating new technologies or innovations. The forecast of the response and return from it would allow us to invest into various branches of knowledge with the greatest efficiency in order to obtain the best result at the end. In addition, it becomes possible to take a more selective approach to the management of individual territories in the entire totality of the controlled system in order to implement socially significant economic effects in a manner that is sustainable for them in the long term.

6. Conclusion

In accordance with the set goal, it can be concluded that the algorithm proposed in the study, based on the perceptron model, allows us to successfully cluster territorial objects for purposes of further modelling of correct dependencies of the socio-economic metrics found in them. Amongst the positive features of the proposed algorithm, it is worth noting its universality.

Furthermore, in this study, we obtained the following results:

The results of earlier research in the direction of clustering of territorial objects were generalised and systematised. This allowed us to identify aspects such as: 1) the lack of universal cluster analysis methods for territories and the fact that their grouping is based on the specifics of industry clusters located on them and large industrial facilities; 2) the main tools used in such studies constitute different variations of correlation analysis, which does not give unambiguous answers with different types of information being studied.

The clustering algorithm based on the application of the perceptron model allowed us to divide the data set under study in such a way that we could model monotonically increasing or decreasing dependencies inside them.

The use of the developed algorithm successfully proved itself when tested on Rosstat statistical data on investments in R&D, wages and average per capita income, GRP and innovation activity. The experiment provided a good result, confirmed by the majority of finite linear regression models with a determination coefficient of 0.8 units and higher.

The models constructed in the work can be used within specific territories of Russia, allowing for the adjustment of the growth of wages and average per capita income of the population, GRP and innovation activity of companies in accordance with the monetary investments in science in these regional subjects.

The universality of the algorithm can be successfully applied in the construction of other functional dependencies of socio-economic indicators and for administrative territories of other countries.

One further development of this study could focus on the technical side and be expressed in the refinement of the clustering algorithm via the introduction of a genetic algorithm and the building of more accurate final models based on the data included in the final clusters. Also, another development of the study could focus on the managerial side to determine the most favourable regions of the entire study population, represented by the territorial landscape of Russia, for purposes of scientific component development from which the best response to the growth of the well-being of the citizens living in these regions could be extracted.

The tools developed and used in this work can also be applied, using analogy, to other territorial entities.

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