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Environmental risks and sustainable development of russian regions in times of crises

ABSTRACT
Relevance. Russia is currently facing sanctions, which have had significant economic and social consequences. These crises have revealed vulnerabilities in the socio-economic system, highlighting the importance of studying them to better address current challenges and mitigate future risks.
Objective. The study aims to identify the vulnerabilities in particular aspects of sustainable development across Russia's regions during the crises of the past 15 years.
Data and methods. The study draws on data from the Federal Statistical Service (Rosstat) to calculate a sustainable development index for regions, which tracks the impact of crises on their economic, social, and environmental sustainability. The index is constructed using a classical method, comprising three averaged sub-indices, each representing one of the three components of sustainable development. A higher index value indicates greater sustainability, with the impact of crises varying across regions.
Results. During the 2014 crisis, regions specializing in export-oriented industries or those with a significant share of foreign capital in their economies were hit the hardest. Socially, the most vulnerable regions were those along the Chinese border in the Far East, which were impacted by trade restrictions. The 2020 pandemic had economic effects on nearly all regions, with cities of over a million people and their agglomerations suffering the most due to the abrupt suspension of the tertiary sector. The social sphere responds most quickly to crises, while the environmental component is more inert but shows a negative trend despite the crises.
Conclusions. For regions with underdeveloped and monocentric economies, support measures should focus on diversifying industries, particularly those aimed at mass consumption. In coal-mining regions, it's important to develop service sectors related to the industry during stable periods. For the Far Eastern regions, the main support measure is to stimulate industries geared towards meeting Chinese demand.

KEYWORDS
environmental risks, sustainable development, factors of socio-economic development, regions of Russia, integral indices, crises

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Экологические риски и устойчивое развитие регионов России в условиях кризисов

АННОТАЦИЯ
Актуальность. В настоящее время Россия подвергается санкционному воздействию, что влечёт за собой экономические и социальные последствия. За последние 15 лет страна проходила через несколько кризисных этапов и уже располагает опытом для их преодоления. Любой кризис демонстрирует уязвимости действующих социально-экономических си-

КЛЮЧЕВЫЕ СЛОВА
экологические риски, устойчивое развитие, факторы социально-экономического развития, регионы России, интегральные индексы, кризисы

стем, а их изучение позволяет определить, каким образом можно облегчить преодоление нынешних и будущих кризисных явлений.
Цель исследования заключается в определении уязвимости составляющих устойчивого развития в разрезе регионов России в ходе кризисов последних 15 лет.
Данные и методы. На основе данных Росстата авторами рассчитан индекс устойчивого развития регионов, позволяющий отследить влияние кризисов на экономическую, социальную и экологическую устойчивость регионов. В основе – классический метод составления индекса, состоящего из трёх осреднённых субиндексов, характеризующих одну из трёх составляющих устойчивого развития. Более высокое значение индекса соответствует более высокой устойчивости, но влияние кризисов неодинаково.
Результаты. В ходе кризиса 2014 года больше пострадали регионы с отраслями специализации, ориентированными на экспорт, либо те, где значимую роль в экономике играли предприятия с высокой долей иностранного капитала. В социальном плане более уязвимыми оказались приграничные с Китаем регионы Дальнего Востока, вследствие торговых ограничений. В результате пандемии 2020 года в экономическом отношении пострадали почти все регионы, особенно сильно – города-миллионники и их агломерации, из-за резкой приостановки работы третичного сектора. Наиболее быстро реагирует на кризисы социальная сфера, экологическая же составляющая инерционна, но имеет негативный тренд, несмотря на кризисы.
Выводы. В качестве мер поддержки для регионов с отсталой и монопрофильной экономикой – диверсификация промышленности за счёт отраслей, ориентированных на массовое потребление. Для регионов со специализацией на угледобыче необходимо развитие отраслей, связанных с обслуживанием данной отрасли в период, когда кризисы отсутствуют. Для регионов Дальнего Востока основным вариантом поддержки является развитие отраслей, ориентированных на китайский спрос.

БЛАГОДАРНОСТИ
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危机条件下俄罗斯各地区的环境风险与可持续发展

摘要
现实性：俄罗斯目前正受到的制裁造成了经济和社会后果。在过去的15年中，俄罗斯经历了数次危机，并积累了克服危机的经验。任何危机都可使当前社会经济体系的脆弱性显现，对其进行研究可以确定如何渡过当前和未来的危机现象。
研究目**标：**目的是确定俄罗斯各地区在过去15年危机期间可持续发展各组成部分的脆弱性。
数据与方法：根据俄罗斯统计局的数据，作者计算出了地区可持续发展指数，使我们能够跟踪危机对地区经济、社会和环境可持续性的影响。该指数基于经典的指数编制方法，由三个平均的子指数组成，分别表征可持续发展的三个组成部分之一。指数值越高，可持续性越强，但危机的影响并不等同。
研究**结果：**在2014年危机期间，出口导向型产业或外资企业在经济中发挥重要作用的地区受到的影响更大。在社会方面，与中国接壤的远东地区由于贸易限制而更加脆弱。由于2020年的疫情，几乎所有地区的经济都受到了影响，特别是拥有数百万居民的城市及其城市群，它们的第三产业也突然被中止了。社会领域对危机的反应最为迅速，而环境部分则并不明显，尽管发生了危机，但仍呈负增长趋势。
结论：对经济落后和经济单一地区的支持措施应以牺牲面向大众消费的产业为代价，从而实现产业多样化。对于专门从事煤炭开采的地区，有必要在无危机时期发展与该行业相关的产业。对于远东地区，主要的支持方案是发展面向中国需求的产业。

关键词
环境风险、可持续发展、社会经济发展因素、俄罗斯地区、综合指数、危机

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Introduction

Stable systems are generally less vulnerable to crises, but such events often reveal their underlying weaknesses. Over the past 15 years, Russia has faced multiple crises, providing valuable experience in navigating these challenges. This makes it particularly relevant to analyze the socio-economic issues experienced by Russian regions during recent crises, including the sanctions crisis following the annexation of Crimea in 2014 and the COVID-19 pandemic. Such an analysis can help identify vulnerable areas that need to be addressed to prevent or minimize the impact of future crises.

In this context, the assessment of regional resilience is necessary in order to determine which regions are more or less likely to suffer during crises, as well as identify the tools and strategies to support them—insights that are critical not only for immediate crisis response but also for fostering long-term resilience and stability.

This study aims to examine the vulnerabilities of sustainable development (SD) components across Russian regions during the crises of the past 15 years. Specifically, the objectives are as follows: develop a regional-level SD index; track changes in this index and its components during crises (starting from 2013); analyze how crises have affected different SD components in various regions; identify the most problematic aspects of SD during crises; and propose policy measures to ensure smoother crisis recovery and enhance regional resilience.

The research focuses on sustainable development and its components, with particular attention to crisis-induced changes and their spatial distribution across Russia's regions. A key challenge lies in defining the components of SD. In this study, sustainable development is understood as the integration of economic growth, social equity, and environmental balance—a framework that supports the well-being of current and future generations (Anisimov et al., 2023).

The study explores the following hypotheses:

1. The economy and social sphere are the most vulnerable components of sustainable development and will play a decisive role in determining the territorial distribution of the most problematic regions during crises.

2. The environmental component of SD will not respond immediately to crisis situations but will gradually deteriorate in the aftermath of crises.

Overall, the study is structured as follows: it begins with a review of research on the concept of sustainable development and the evaluation of its individual aspects at the subnational level in Russia. Indicators are then selected to characterize the specific components of SD, and calculations are performed to derive the SD index and sub-indices representing these components. A classical methodology is applied for constructing the index: each sub-index is based on three indicators, which are normalized and averaged. The overall index is calculated as the mean of its components. The study analyzes changes in the national average values of these indices relative to 2012 and examines the regional distribution of these changes. As a result, the most critical areas and regions are identified, and recommendations are proposed for addressing crisis situations.

Theoretical framework

In both Russian and international academic literature, there are two main approaches to understanding the resilience of economic development (Malkina, 2021). The first approach interprets "sustainable" development as a process accompanied by positive social, economic, and environmental effects. The second approach views "resilience" as the ability of a region to resist internal and external shocks, recover from them, and transition to a qualitatively new trajectory of development (Malkina, 2021).

Within the sustainable approach, there are also diverse perspectives on what constitutes sustainable development (Mensah, 2019). Some researchers define it as a process of improving and maintaining the "health" of economic, environmental, and social systems (Gray et al., 2013; Mensah et al., 2018; Shepherd et al., 2016).

Others argue that sustainable development involves the efficient and equitable allocation of the limited resources of ecosystems, not only within a single generation but also between generations (Stoddart, 2011). The Brundtland Report similarly states that sustainable development meets the needs of the current generation without compromising the ability of future generations to meet their own needs (Schaefer et al., 2005).

Another perspective (Ben-Eli, 2015) defines sustainable development as a dynamic equilibrium, where humanity fully realizes its potential without causing significant negative impacts on the environment.

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Given that the key issues of sustainable development revolve around ensuring economic growth, environmental protection, and social equity (Taylor, 2016), three conceptual pillars can be identified: "economic sustainability," "social sustainability," and "environmental sustainability" (Mensah, 2019).

Economic sustainability is understood as a production system that considers the limitations of natural resources and meets the needs of current generations without compromising the ability of future generations to meet their needs (Lobo et al., 2015). To minimize the negative impact of economic development on the environment and social progress, all aspects of sustainability are taken into account (Zhai et al., 2019).

Social sustainability is defined as ensuring principles of fairness, equal opportunities and rights, and institutional stability in society (Daly, 1992; Gray, 2010; Guo, 2017). This concept focuses on reducing poverty levels (Littig et al., 2005), viewing poverty reduction as a way to also mitigate the negative environmental impacts of inequality (Farazmand, 2016). However, the concept makes clear that poverty reduction must not come at the cost of environmental degradation or economic instability (Kumar et al., 2014; Scopelliti et al., 2018). Social sustainability does not aim to satisfy every individual's needs directly but rather to create conditions where each person can realize their potential (Kolk, 2016).

Ecological sustainability assumes that natural resources are both a source of economic resources and a "sink" for waste. Resources must be extracted at a rate lower than their natural regeneration, and waste must be generated at a rate below nature's capacity to assimilate it (Brodhag, 2006; Goodland et al., 1996; Diesendorf, 2000; Evers, 2018).

The concept of sustainable development is founded on the following principles: the preservation of ecosystems and biodiversity, the maintenance of productive systems, population growth control, human resource management, and the promotion of progressive cultural development (Mensah et al., 2018; Mensah, 2019; Molinoari et al., 2019).

Zemtsov and co-authors (2020) propose a model of sustainable development based on the combination of per capita GRP growth and ecological efficiency, which is defined as the ratio of the output of non-resource goods and services to the costs of resources (labor, capital, raw materials) and environmental costs. Grishina and Polynyev (2020) evaluate the impact of the pandemic crisis on regional socio-economic development. The integral indices used in the analysis were calculated within the framework of the SDGs and include social components (demographic indicators, income levels, employment, environmental condition, social infrastructure) and economic components (innovation and innovative development, infrastructure provision, investments and financial situation, level of economic activity). Klimanov, Kazakova, and Mikhailova (2019) assess the shock resilience of Russian regions by calculating an integral index of regional resilience for each constituent entity of the Russian Federation for the period 2007-2016, based on 17 indicators reflecting comprehensive socio-economic development. Regions with low shock resilience predominantly include those from the Southern, North Caucasian, Siberian, and Far Eastern Federal Districts.

Mikheeva (2021) evaluates the economic resilience of Russian regions by examining the characteristics of economic crises at the regional level. The study analyzes the impacts of the 2009 and 2015 crises on Russian regions and identifies the factors that influenced regional resilience to crisis shocks. To assess these factors based on regional characteristics, the author categorizes the indicators into three groups. The first group consisted of objective regional characteristics, such as the proportion of urban population, transport accessibility, the share of exports in GRP, and the average annual growth rate of the regional economy over the 8 years before the crisis. The second group focused on the population's characteristics and the region's human and innovation potential, including the proportion of poor people, per capita income, and the share of workers with higher or secondary education. The third group covered economic policy parameters, such as the growth rate of investments in fixed capital, the proportion of employees in small enterprises, and per capita social spending from the regional budget.

Globally established approaches to measuring sustainable development can be broadly divided into two categories. The first focuses on developing systems of indicators that assess specific areas, such as the economy or ecology. The second aims to create a single, comprehensive indicator that integrates metrics from various fields. A

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Table 1

Ratings for the assessment of sustainable development and its components at the regional and city levels

Ranking/index	Source	Focus
Ranking of Sustainable Development of Russian Regions and Cities	SGM Agency	Comprehensive: economy, environment, social sphere, institutions.
Regional Quality of Life Ranking	RIA-Rating	Comprehensive: economy, environment, social sphere, infrastructure
Ranking of Fundamental (Environmental-Energy) Business Efficiency	Interfax-ERA	Environmental and energy efficiency of enterprises
Environmental-Economic Index of Russian Regions	WWF of Russia	Environmental and economic
ESG Ranking of Russian Regions	RAEX	Comprehensive: environment, social sphere, administration
National Environmental Rating of Russia's Regions	The Green Patrol Organization	Environmental
SDG Achievement Index of Russian Regions	Center for Spatial Economics of the Institute of Public Administration and Civil Service (IPAE) of RANEPA	Comprehensive
Urban Quality of Life Index	WEB.RF	Comprehensive
European Cities SDG Index	UN SDSN	Comprehensive: economy, environment, social sphere, institutions
Arcadis Sustainable Cities Index	Arcadis	Comprehensive: economy, environment, social sphere, infrastructure, institutions
The Corporate Knights Sustainable Cities Index	Corporate Knights	Environment+infrastructure
US Sustainable Development Report	SDSN USA	Comprehensive: economy, environment, social sphere, institutions
US Greenest States 2023	World Population Review	Environmental
OECD Regional Well-Being	OECD	Comprehensive
Quality of life in European cities	European Commission	Comprehensive

Source: compiled by the authors

hybrid approach is also possible, where indicator systems are aggregated into a unified index. However, this method brings a host of methodological problems, including the aggregation of diverse metrics, the need for consistent statistical tracking, and ensuring alignment with national policy priorities.

Numerous rankings, ratings, and indices have been developed both in Russia and worldwide to address specific aspects of sustainable development—primarily socio-economic or environmental—at the subnational level (see Table 1). A key issue is the lack of comparability, difficulties in verification, and the problems with access to original data to integrate the most successfully analyzed aspects into a more comprehensive index. Developers of international rankings and indices face a number of challenges, particularly in ensuring the comparability of national statistical data.

International academic literature approaches the impact of crises on regional sustainable development from a variety of perspectives. Analysis of a case should consider the following variables: the scale of the crisis (local or global), the nature of the crisis (economic, political, ecological, social), the region's resilience to the crisis, cultural and historical factors, and social capital. Crises can disrupt sustainable regional development by impacting various dimensions, including ecological, social, economic, and political factors. Additionally, the transition to sustainable development on the regional level can be seen as a strategy for combating the crisis.

Method and Data

In this study, the classical method of index construction was applied to assess sustainable development at the regional level. To accurately represent the situation in a particular region, it's best

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Table 2

Indicators included in the sustainable development index for regions of Russia, by sector

	Economic development	Units of measurement
1	Investments in fixed capital per capita (at comparable 2021 prices)	ths rub per capita
2	Gross Regional Product (GRP) per capita, adjusted for the cost of the consumer basket (at comparable 2020 prices)	rub/person.
3	Level of innovation activity of organizations	%
	Social development	
1	Population growth rate	%
2	Taxable monetary income of individuals and individual entrepreneurs (per capita), adjusted for the cost of the consumer basket (at comparable 2021 prices)	ths rub per capita
3	Total residential floor space per capita	sq.meters per capita
	Environment	
1	Emissions of pollutants into the atmosphere from stationary sources and motor transport, as a percentage of GRP	t/ rub.
2	Discharge of polluted wastewater into surface water bodies as a percentage of GRP	cubic meters/rub.
3	Ratio of timber harvesting to forest regeneration	cubic meters/ha

Source: compiled by the authors

to use a small number of meaningful indicators that effectively capture key processes and outcomes. For example, population growth rates are determined by the balance between natural increase and migration. If natural decline is offset by migration, it can indicate the economic attractiveness of a region; conversely, the reverse process suggests a shrinking population reproduction and a relatively less favorable socio-economic environment in the region.

For the calculations, we selected nine indicators, three for each sphere characterizing sustainable development: economic, social, and ecological (Table 2). The data source was the annual publication "Regions of Russia: Socio-Economic Indicators" by the Federal State Statistics Service, which provides updated information for each Russian region.

To assess the level of economic development in regions, we used the classical indicator of Gross Regional Product (GRP) per capita. The prospects for economic growth were examined through investments in fixed capital per capita, and the quality of economic growth, through innovation activity of organizations. This indicator, however, has several methodological limitations that need to be considered. For instance, innovations can be not only product- or technology-based but also process-related, involving changes in business processes, which are more common in large businesses. Furthermore, data on innovation activities are collected through *Form 4 – Innovations*[1], which many researchers consider statistically unreliable (Bortnik et al., 2013). The statistics are often significantly underestimated because businesses are reluctant to fill out the form due to the high labor costs involved, leading them to enter zero values across all fields.

For the social sphere, we used population growth rates and taxable income as indicators. To assess living conditions, we considered the amount of living space per capita, which reflects both the rate of new housing construction and population density in the region.

The environmental indicators used in this study correspond to various types of pollution. First, we included indicators of air pollution from both stationary and mobile sources, which allowed us to consider regions with large industrial enterprises as well as those without significant stationary pollutants but with high population density. To assess water quality, we used the indicator of polluted water discharge into surface water bodies and thus identified regions with major industrial enterprises, large urban centres, or outdated and underdeveloped infrastructure. To ensure comparability, all indicators were standardized by Gross Regional Product (GRP). The third indicator, the ratio of timber harvesting to forest restoration, may be less relevant for the Far North

[1] *Form 4 – Innovations* is a reporting form used by Rosstat to collect data on innovation activities of organizations.

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and southernmost regions but can be useful for most other regions, as it reflects the impact on forest ecosystems.

Since the standard of living varies widely across Russian regions, all monetary indicators, except for investments in fixed capital, were adjusted by the cost of the consumer basket. This coefficient was calculated by comparing the cost of a standard consumer basket in a region to its average cost across the country.

Each indicator was normalized using linear scaling. Environmental indicators with an "inverse" relationship—meaning that higher values indicate worse outcomes—were normalized as follows: for all other indicators, 1 represents the best value and 0 the worst, while for environmental indicators, the values were reversed. The SD index was calculated by averaging three indicators for each sphere, which were then further averaged. To analyze comparable dynamics, the calculations were based on 2012: the maximum values from 2012 were assigned a score of 1, and the minimum values were assigned a score of 0.

As a result, each region received a normalized score between 0 and 1. To analyze the overall trends in the sustainable development score and its components across the regions, the average scores for all regions were calculated.

Cities of federal significance (Moscow, St.Petersburg, and Sevastopol) were excluded from our analysis, as comparing large centers with other regions is not entirely appropriate in terms of comparability. The Republics of Chechnya and Ingushetia, as well as the Khanty-Mansi Autonomous District, were excluded due to the lack of data on the dynamics of certain indicators.

Results and Discussion

Dynamics of sustainable development components: The calculation of the SD index relative to 2012 shows that after a decline in 2015, the index stagnated until 2018, which was followed by a drop in 2020. However, since no significant changes occurred in the index compared to 2012, it can be concluded that regions have shown little to no progress toward a sustainable development trajectory (Figure 1).

The dynamics of the "Economic development" subindex closely mirror the overall index, although while the decline in both values due to the 2014 crisis is comparable, the drop in the subindex reflecting the level of economic development in 2020 is much more severe, surpassing both the 2014 effect and the overall index decline (Figure 2).

The dynamics of individual components show that the "Investments in fixed capital" indicator was most strongly affected by the 2014 crisis and did not recover afterward, continuing to decline almost every subsequent year. The GRP per

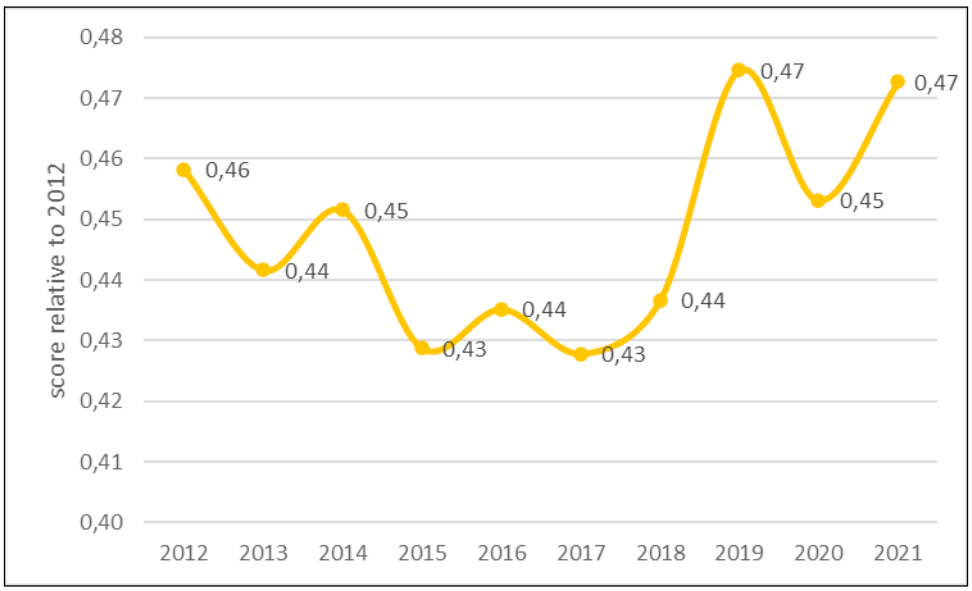

Figure 1. *Dynamics of the SD index relative to 2012*

Source: the authors' calculations are based on Rosstat data, statistical yearbook "Regions of Russia. Socio-economic indicators". Accessed: 22.07.2023.

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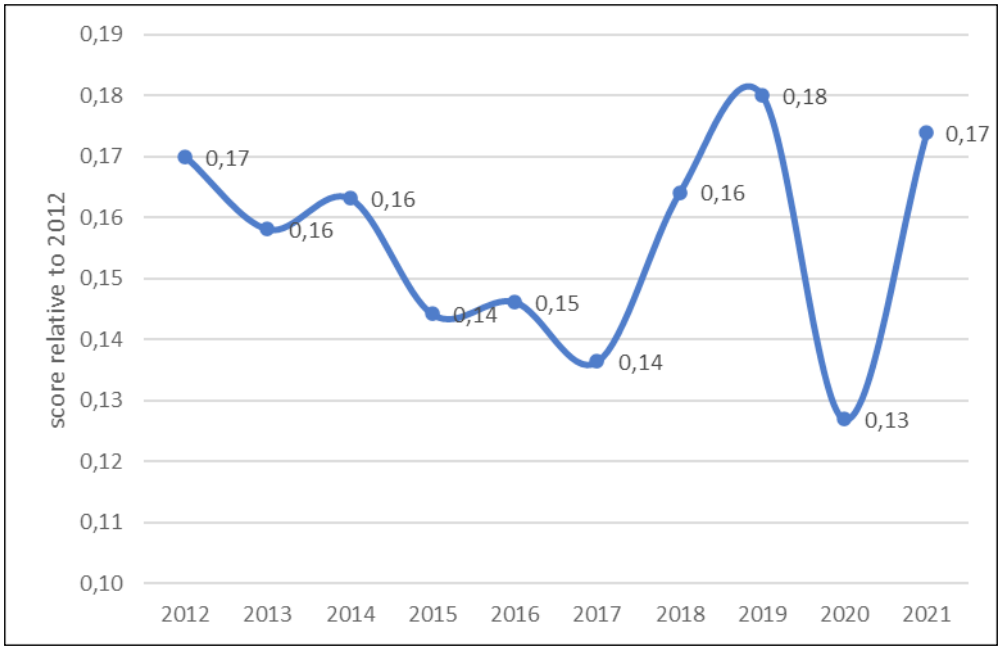

Figure 2. *Dynamics of the "Economic development" sub-index.*

Source: the authors' calculations are based on Rosstat data, statistical yearbook "Regions of Russia. Socio-economic indicators". Accessed: 22.07.2023

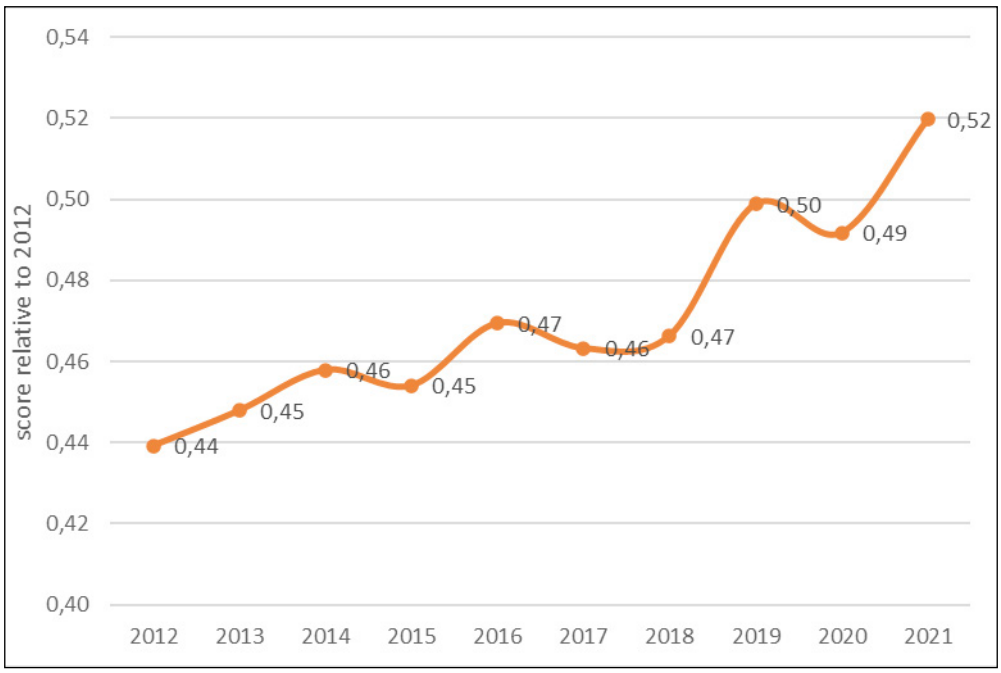

Figure 3*. Dynamics of the "Social development" sub-index.*

Source: the authors' calculations are based on Rosstat data, statistical yearbook "Regions of Russia. Socio-economic indicators". Accessed: 22.07.2023

capita indicator reacted more significantly to the pandemic, shifting from modest growth to a decline, which was subsequently offset by a recovery in 2021.

The most significant fluctuations are observed in the level of innovation activity among organizations. Although it mainly shows negative changes after 2014, this indicator grew steadily until 2020. Unfortunately, the methodology for this indicator raises several questions (see above), making it difficult to explain its dynamics definitively. However, the sharp decline in this indicator in 2020 like-

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ly reflects a decrease in business activity during that period, a trend also observed after 2014.

Negative changes in the social component of the index are less noticeable, as they are offset by the overall positive trend (Figure 3). In this case, the values of the sub-index for each specific year are more indicative, as they reflect the general decline in household incomes. The social component also showed a decline and stagnation in 2014, and a decrease in 2020. However, the decline in the social component, unlike the economic one, is less pronounced than that of the overall index: the pandemic's impact on the regions primarily affected the economy.

Among the indicators comprising the "Social development" sub-index, tax revenues from the population are the most sensitive to crises. These revenues significantly decreased starting from 2014 but returned to modest growth rates by 2016 and continued to show positive dynamics even in 2020. This trend is attributed to active regional and federal policies aimed at maintaining household incomes during the pandemic. The most stable indicator is the growth in residential area per capita, although this growth is largely driven by major cities.

The population growth shows a general downward trend, which is linked to demographic processes in the regions, such as the entry into childbearing age of the relatively small cohort born in the 1990s. Additionally, the trend can partly be explained by declining birth rates amid a more challenging economic environment, leading to uncertainty in family planning. The decline in population numbers in 2020 can be explained by increased mortality during the pandemic.

The environmental component exhibits a downward trend—while the sub-index value was 0.77 in 2012, it dropped to 0.72 by 2021 (Figure 4). This decline persisted throughout most of the period, with the exception of three specific intervals, and significantly intensified during the following crises. The overall trend remains negative.

The components of the *"Environment"* sub-index generally remained stable throughout the analyzed period. However, each indicator proved sensitive to crises, showing negative dynamics in response to the 2014 crisis.

These patterns were not observed in 2021, which can be attributed to the specific nature of the crisis. Due to the increase in disease incidence

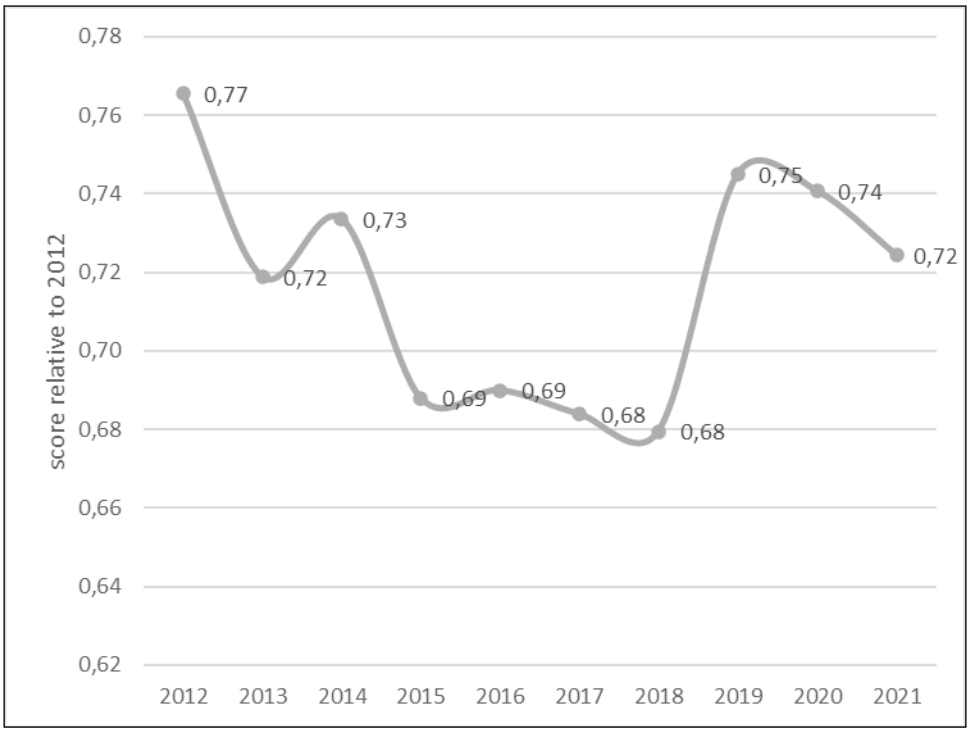

Figure 4. *Dynamics of the "Environment" sub-index.*

Source: the authors' calculations are based on Rosstat data, statistical yearbook "Regions of Russia. Socio-economic indicators". Accessed: 22.07.2023

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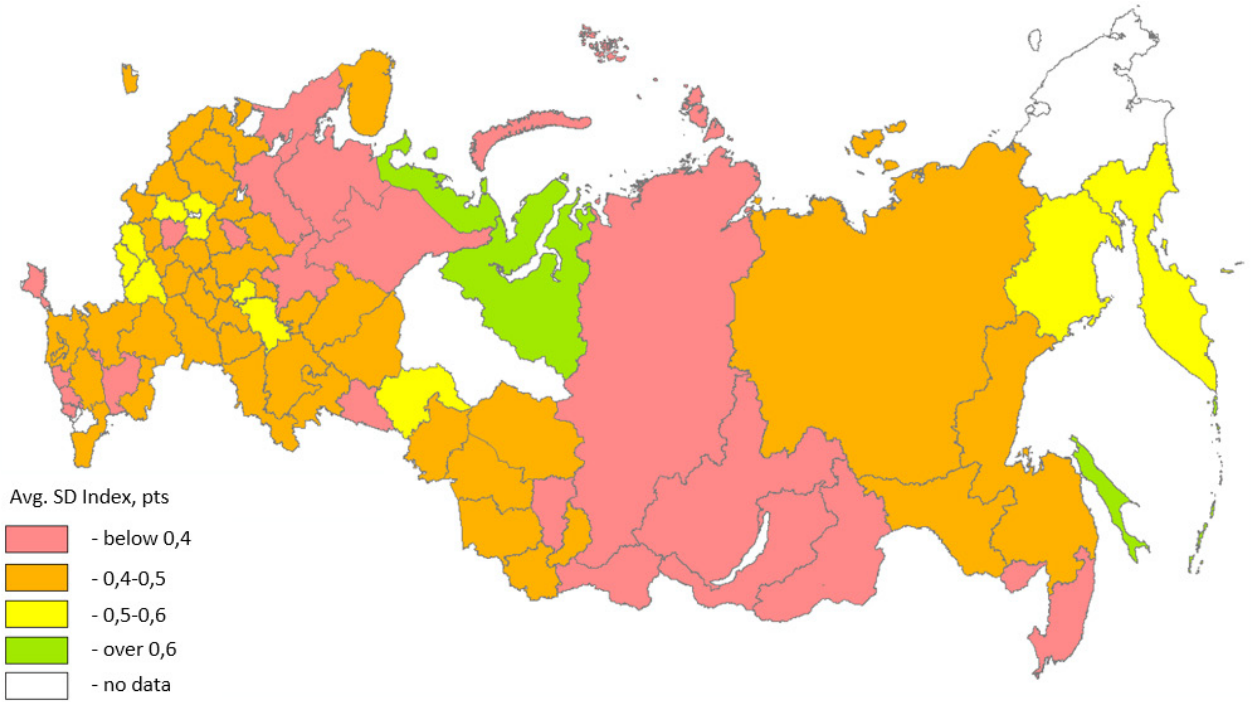

Note: The borders of the Russian Federation are shown as they were during the periods of the crises in 2014 and 2020.

Figure 5. *Average value of the SD index for 2012–2021*

Source: the authors' calculations are based on Rosstat data, statistical yearbook "Regions of Russia. Socio-economic indicators". Accessed: 22.07.2023

and subsequent anti-epidemic restrictions, production levels declined, leading to a reduction in emissions.

The only indicator that exhibited consistently negative dynamics throughout the analyzed period was the ratio of pollutant emissions to GRP. Although the increase in 2019 was statistical, the overall trend suggests a deceleration in the rate of decline.

Analysis of the selected indicators suggests that among the three components of sustainable development, the economic component is the most sensitive to crises. The environmental component experiences smaller-scale declines but demonstrates long-term negative trends. Social development is also impacted by crisis; however, Russian regions exhibit an overall positive trend in this sub-index primarily due to indicators such as "Taxable monetary incomes of individuals and sole proprietors (per capita), adjusted for the cost of the consumer basket (in comparable 2021 prices)" and "Average residential area per capita."

Regional differences in the dynamics of the SD index: Northern regions specializing in natural resource extraction scored highest in the SD index for 2012–2021 (Figure 5). These include the three highest-ranking regions (Yamalo-Nenets and Nenets autonomous districts, and Sakhalin region) and a third of the regions in the higher-score group (e.g., Tyumen and Magadan regions).

Magadan region stands out due to its low population density, high economic performance, and reliance on hydropower. However, it also experiences significant environmental pressure, particularly from dredging and open-pit mining for gold and other minerals, which are not covered by the indicators included in the index.

Another group of regions with high scores comprises central regions with developed industries and agriculture (e.g., Moscow, Kaluga, Belgorod, and Voronezh regions), excluding the Republic of Tatarstan. A similar situation is observed in Kursk and Belgorod regions, where iron ore extraction is carried out in the Kursk Magnetic Anomaly.

The comparison of this approach and its results with other SD rankings has brought us some interesting observations. Other rankings tend to use a larger number of indicators reflecting various aspects of sustainable development. Never-

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theless, the results we obtained are largely consistent with those of our colleagues. The similarity in results may support the validity of our approach, which uses fewer indicators, making it simpler to apply.

The leading regions in our calculations largely align with the findings of colleagues from the SGM agency[2]. However, due to higher living standards, southern regions also rank among the top, while some regions in the Far East drop out of the leading positions. The lagging regions are mostly consistent across rankings, which points to both objectively low economic and social indicators in these areas and statistical nuances in some of them (e.g., the republics of the North Caucasus and southern Russia, Tuva Republic, Jewish Autonomous Region, Pskov Region, etc.). However, some regions we identified as leaders are laggards in SGM rankings, primarily due to factors such as innovation and living conditions. One significant methodological distinction of the SGM ranking is that it's based not on raw indicators but on the positions of regions in specialized rankings compiled by other organizations (e.g., RAEX, AIRR, Skolkovo School of Management, HSE University). Additionally, it distinguishes innovation and digitalization as a separate measurable aspect of development.

In contrast to our methodology, the RAEX ranking[3] focuses on regions' exposure to risks across various domains and their capacity to mitigate them. This approach involves pairing indicators, with one representing a risk and the other representing a means of reducing it. The ranking incorporates 24 indicators in total. This focus results in outcomes that differ somewhat from ours. For example, insufficient emphasis on the economic component places regions like Tver and Irkutsk and the Chuvash Republic in the top ten, with the Republic of Tatarstan as the leader. Meanwhile, Magadan and Kamchatka regions, which we classify as regions with high SD, are positioned as laggards in the RAEX ranking due to prolonged outflows of human capital. Similarly, many regions specializing in oil, coal, and metallurgy—industries with high emissions and comparatively low capture rates—are also classified as laggards in this ranking.

The Environmental-Economic Index of Russia's regions[4] is based on the calculation of the adjusted net savings index, which is correlated with the region's GRP. This index is determined by subtracting investments in the extractive sector, as well as the depletion of natural resources and environmental damage caused by economic activities, from gross fixed capital formation. At the same time, it adds expenditures on human capital development, environmental protection, and the positive contribution of protected natural areas (PNAs). Since resource depletion is a key component of the index, regions that are heavily reliant on resource extraction for export generally do not rank among the leaders. However, regions specializing in the extraction of non-fuel mineral resources tend to perform better and often rank near the top. This trend aligns with our findings, where regions such as Magadan and Kamchatka are ranked in the top twenty. Interestingly, many regions with less developed economies, which traditionally fall into the "outsider" group, such as the Chechen Republic, the Republics of Ingushetia and Tuva, and the Jewish Autonomous Region, are also among the leaders.

The orientation of the RIA rating[5] leads to some differences in results compared to our assessment. Unlike our approach, which focuses on sustainable development, the RIA rating emphasizes quality of life. Its methodology encompasses a broader set of indicators (70), assessing 11 aspects of quality of life, including factors not accounted for in our sustainable development framework, such as climatic conditions, housing quality, and residential safety.

Despite some overlap among the leading regions of Central Russia and the Volga Region (e.g., Moscow, Belgorod region, the Republic of Tatarstan), regions like Krasnodar and Kaliningrad are also at the top of the RIA rating. However, resource-extracting regions in the north and northeast, such as the Nenets and Yamalo-Nenets

[2] Ranking of Sustainable Development of Regions of the Russian Federation. SGM Agency: [website]. Available at: https://agencysgm.com/ratings/ (accessed: 21.05.2024)

[3] ESG Ranking of Russian regions// RAEX Rating Group: [website]. Available at: https://raex-rr.com/ESG/ESG_regions/ESG_rating_regions/2021/ (accessed: 21.05.2024)

[4] Bobylev S.N. et al. Environmental-Economic Index of Russian Regions // WWF Russia, RIA Novosti: [website]. Available at: https://rnei.de/wp-content/uploads/2013/09/index.pdf (accessed: 21.05.2024)

[5] Ranking of Russian Regions by Quality of Life — 2023 // RIA Novosti: [website]. Available at: https://ria.ru/20240212/kachestvo_zhizni-1926120093.html (accessed: 21.05.2024)

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autonomous districts, Kamchatka and Magadan regions, cannot lead in such a rating.

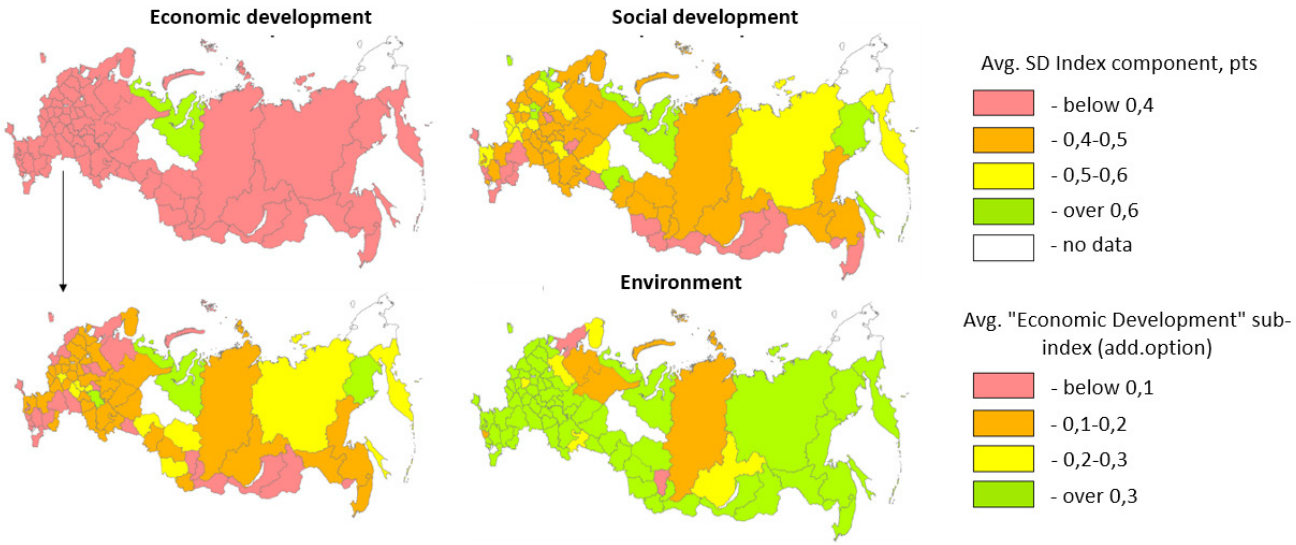
Among these, the Yamalo-Nenets Autonomous District has the highest score, due in part to its relatively high corporate social expenditures. The economic and social differences between regions, as well as variations in environmental conditions, become clearer when we analyze specific components of our index. Figure 9 demonstrates that the gap between the Nenets and Yamalo-Nenets autonomous districts and other regions in the "Economic Development" sub-index is so significant that standardized group classification used for all sub-indices (as shown in Figure 6) does not apply, as it relegates all other regions to the "outsider" category. This does not reflect the actual situation. Therefore, it is necessary to introduce an additional classification scheme for the "Economic Development" sub-index to better highlight regional differences. Regions specializing in mineral extraction (oil, gas, gold), some metallurgical regions (e.g., Lipetsk region), and regions with diversified industries (e.g., the Republic of Tatarstan) exhibit high values in the "Economic Development" sub-index, which cannot necessarily be interpreted as a shift toward sustainable development.

Regions with high values in the "Social Development" sub-index are characterized by either high incomes or favorable agro-climatic conditions. Examples of the former include Tyumen and Moscow regions, while the latter include Voronezh, Kursk, and Belgorod regions.

Regions with low values in the "Environment" sub-index include those with developed metallurgy (e.g., Krasnoyarsk and Chelyabinsk regions), open-pit coal mining and coal energy production (e.g., Kemerovo and Krasnoyarsk regions), and the pulp and paper industry (e.g., Arkhangelsk region). These industries are among the largest contributors to environmental emissions.

The 2015 crisis had a particularly negative impact on coal-mining regions oriented toward exports (Figure 6). These regions proved less resilient to the crisis caused by sanctions because coal is easier and faster to phase out compared to other types of fuel resources. Additionally, the global shift toward "green" policies has led to a general decline in the demand for thermal coal, which means that these regions need to gradually explore and develop new economic specializations. The most resilient regions in this period were those in the central European part of Russia, as many of them focus on meeting domestic demand, including that of large urban agglomerations.

After 2020, declines in the index were more influenced by institutional factors, such as decisions made by local leaders. However, the regions



Note: The borders of the Russian Federation are shown as they were during the periods of the crises in 2014 and 2020.

***Figure 6**. Values of the components of the SD index for 2012–2021*

Source: the authors' calculations are based on Rosstat data, statistical yearbook "Regions of Russia. Socio-economic indicators". Accessed: 22.07.2023

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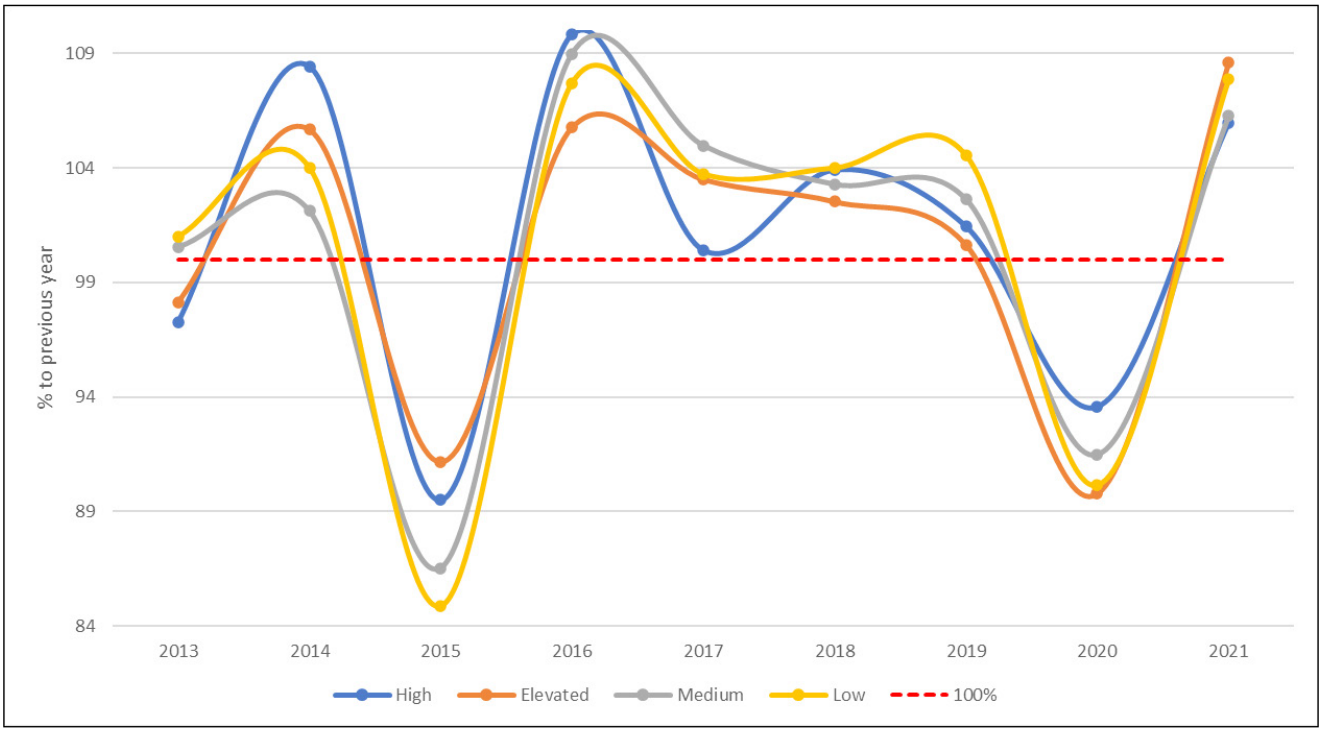

Figure 7. *Dynamics of sustainable development index values in regions of different groups, 2013–2021*

Source: the authors' calculations are based on Rosstat data, statistical yearbook "Regions of Russia. Socio-economic indicators". Accessed: 22.07.2023

most affected were those with major cities (due to closures in the tertiary sector and reduced industrial activity) and regions bordering China (due to border closures).

An analysis of the SD index dynamics across regional groups confirms that regions with higher index values are more resilient to crises, which is reflected in smaller fluctuations and less pronounced declines in the index during crisis years (Figure 7). The least resilient regions are those with lower index values, partly due to the "low base" effect. However, during crises, the greatest declines are observed in regions with low or average index values, which comprise the majority of the regions in question.

Regions with above-average index values also exhibit greater resilience. However, in 2020, these regions experienced declines of similar magnitude to those of the two lower-tier groups, due to the suspension of economic activities. The top-performing group was an exception, as their resource-based economies allowed mining activities to continue without interruption during this period. Over the analyzed period, the growth of the index decreases with each successive group: regions with high SD index values saw a 12% growth, those with above-average values grew by 7%, regions with average values grew by 3%, while regions with low index values experienced a decline.

From the perspective of the "Economic development" sub-index, the 2014 crisis primarily affected either export-oriented regions or those with established industrial ties to foreign countries (Figure 8). During the 2020 crisis, nearly all regions faced economic challenges due to widespread suspension of economic activities.

The social component appeared less vulnerable during both crises compared to other sub-indices. However, slower declines in the index do not imply an absence of issues. For instance, during the crises, far eastern regions bordering China showed lower resilience, and in 2020, regions with million-plus cities or their agglomerations were hit harder. For the sub-index measuring environmental conditions, it is difficult to separate the impact of the crises from the ongoing negative trends. The most significant negative changes occurred in regions already facing severe environmental issues. This underscores the need for targeted policies in these areas, which should include not only penalties but also incentives to

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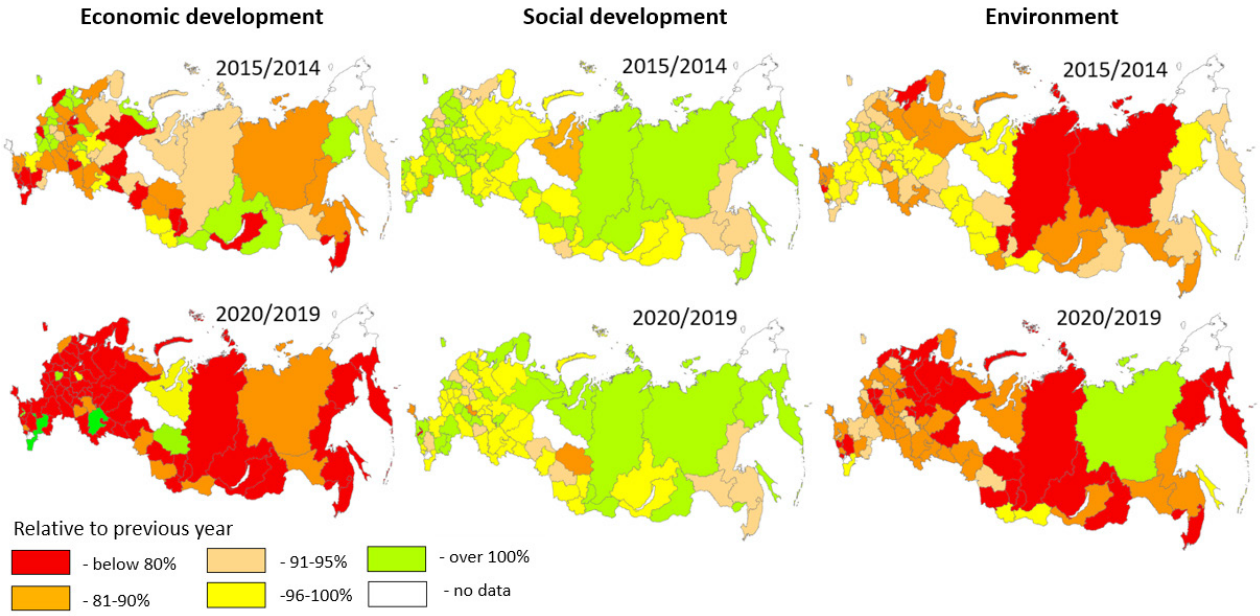

Figure 8. *Changes in the components of the SD index in the crisis periods of 2014–2015 and 2019–2020*

Source: the authors' calculations are based on Rosstat data, statistical yearbook "Regions of Russia. Socio-economic indicators". Accessed: 22.07.2023

encourage businesses to adopt more environmentally responsible practices.

Conclusion

This study analyzed SD index dynamics to identify regional crisis response patterns, confirming the initial hypotheses and providing insights into the current situation.

The sanctions imposed on Russia in 2022 and their ongoing intensification can be compared to the 2014 crisis, induced by the Crimea-related sanctions. The economic component of the index may show a decline, primarily due to the drop in investments in fixed capital. Our analysis revealed that this indicator significantly decreased after 2014. However, the reduction in foreign investments could be offset by government funding directed at the defense industry. Given the widespread presence of defense-sector enterprises across the country, this has a notable positive economic impact, partially compensating for the decrease in foreign investment. The increased volume of orders for these enterprises, however, is likely to negatively affect the environmental component of the index, as these industries are not focused on environmental efficiency.

The environmental indicators are the most resilient, which can be explained by their inertia: for negative changes to manifest, a crisis situation must last more than one or two years. In the context of the current crisis and significant restrictions on technology imports from developed countries, the environmental sector is expected to face clear negative consequences, primarily due to limitations on the use of foreign filtration and purification technologies.

The social sphere reacts most visibly to crises, due to the sharp decline in real disposable incomes in such periods. This is also a common strategy for Russian businesses to maintain profitability during crises, often involving significant cuts to incentive payments while only official wages are retained. The recovery of this indicator is also slow and requires at least two years. The experience of the pandemic showed the need for prompt action from the government: access to financing should be simplified, and social support measures should be introduced.

Systematic measures are needed for the environmental component, including not only penalties for businesses that violate regulations but also positive incentives to support businesses in improving their environmental efficiency, for example, tax breaks.

Regions with a low SD index, which are the most vulnerable during crises, require greater support to promote industries oriented toward mass domestic consumption. Additionally, specialized

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support measures are necessary to reduce economic monocentricity in coal-mining regions and in the regions of Russia's Far East bordering China.

Our findings can be used to develop tailored support strategies for different types of regions. Regions with underdeveloped and monocentric economies require industrial diversification by fostering industries that are relatively easy to enter and focus on mass consumption.

Coal-mining regions, with their economic reliance on a single industry, prove extremely vulnerable during crises in Russia. In this case, a comprehensive program for developing alternative industries is essential in periods of stability. These efforts should focus on coal-related machinery manufacturing and maintenance industries, as there will continue to be a demand for equipment in the mining sector, making it a niche yet essential specialization for these regions.

Another group of vulnerable regions is the Russian Far East, especially those bordering China, where the primary support strategy focuses on developing industries aimed at meeting Chinese demand. This approach not only fosters economic growth in these regions but also creates a foundation for further diversification efforts.

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