# Green investment and green economic development in Russia, 2010–2021

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This study aims to assess the impact of green investment on the quality of green economic development in 85 constituent entities of Russia during the period 2010–2021. The research findings indicate that the development of green economic practices in these entities is not random but has interrelationships with neighbouring entities. Green investment is an important factor in promoting the quality of green economic development, not only within a single entity but also spilling over to neighbouring entities. Furthermore, the authors also discovered that green investment not only directly affects the quality of green economic development but also indirectly enhances it by reducing environmental pollution. In terms of policy implications, the spillover effects in green investment, $CO_2$ emissions, and green economic development in the constituent entities of Russia highlight the importance of cooperation among entities in jointly advancing green economic development. Careful consideration should also be given to environmental impacts in the formulation of development policies, as they can affect neighbouring entities. Given the limited participation of entities and financial resources for green investment, the Russian government needs to design a clear roadmap for transitioning to a green economy, particularly through policy tools such as taxes and subsidies for green companies and projects, while also encouraging financial institutions to participate in the provision of green financial instruments.

**Keywords:**
green investment,
spatial economy,
green economic development,
sustainable growth,
green economy,
environmental economy

## Introduction

In the quest for a sustainable and prosperous future, the imperative of transitioning towards a sustainable and resilient green economy has garnered substantial attention. Visionaries, scholars, and researchers alike have emphasized the paramount importance of this transition in safeguarding our precious environment and fostering sustainable development. However, the emergence of the Covid-19 pandemic has thrusted this imperative into the spotlight with unparalleled urgency. This global health crisis has reverberated across the globe, impacting public health, economies, and societies on a profound scale (Clemente-Suárez et al. 2021, Kneip et al. 2022). It has acted as a powerful catalyst, laying bare the vulnerabilities of economies worldwide and illuminating the critical need to prioritize environmental sustainability, resource management, and economic resilience (European Environment Agency 2022). Against this backdrop of challenges and transformation, the call to expedite the transition to a high-quality and resilient green economy resonates with unwavering significance and urgency. It is an opportunity to forge a path towards a brighter future, where the harmonious coexistence of economic growth, environmental preservation, and societal well-being is not just a lofty ambition but a tangible reality. By embracing this imperative, we pave the way for a world that thrives in balance and ensures the well-being of future generations.

The convergence of the pandemic and economic sanctions has significantly disrupted Russia's economic stability, highlighting the vulnerability of its traditional industries, including energy and manufacturing (European Council 2022, UNCTAD 2022, World Bank 2023). The crisis has revealed the necessity of diversification and the urgency to reduce dependence on sectors that are prone to external shocks. A green economy offers a viable alternative, providing a framework that not only addresses environmental concerns but also offers sustainable solutions to promote economic recovery and future prosperity.

To delve into the intricacies of this transition, this study embarks on a journey of exploration and analysis. First, a comprehensive green economic development index system is developed for the 85 constituent entities in Russia, spanning from 2010 to 2021. This robust index system serves as a holistic framework, empowering policy-makers and stakeholders to assess the progress and performance of each entity in their green economic development endeavours. By identifying regional strengths, weaknesses, and variations, targeted strategies can be devised to foster sustainable economic growth. Moreover, the study also delves into the evolution of the green economy in Russia over the years, providing a valuable comparative reference point. This comparative analysis not only offers a broader perspective but also enables the identification of best practices and lessons learned that can inform Russia's own green economic transition. By drawing from successful experiences, Russia can accelerate its journey towards a sustainable and resilient future. Additionally, spatial autocorrelation analysis is conducted to examine the interdependence and spatial patterns of green economic development across the 85 constituent entities. This insightful analysis uncovers collaborative opportunities and challenges that arise in the pursuit of a green economy. It underscores the need for synchronized efforts and coordinated initiatives among regions to maximize the impact of sustainable development and promote shared prosperity. Furthermore, the study investigates the crucial role of green investment and the impact of environmental pollution on the development of the green economy in Russia. By exploring the relationship between investment in environmentally friendly projects and the overall performance of the green economy, as well as addressing the detrimental effects of pollution, this analysis emphasizes the criticality of green investment in driving sustainable economic growth. It emphasizes the urgency of addressing environmental challenges to ensure a resilient and prosperous future for Russia. This study underscores the imperative for Russia to transition to a green economy, transcending its reliance on the fossil energy industry. Through the development of a green economic development index, analysis of the green economy's trajectory, examination of spatial patterns, and investigation of the impact of green investment and environmental pollution, this research offers a comprehensive understanding of the challenges and opportunities that lie ahead. By embracing a green economy and prioritizing sustainable investment, Russia can position itself as a global leader in sustainable development, fostering long-term prosperity while safeguarding the environment for the well-being of future generations.

## Literature review

### Green economy: Approaches for assessing the quality of the green economy

The green economy emerged in the 1980s and 1990s when environmentalists and policy-makers recognized the importance of sustainable development in protecting the environment and promoting social development. The report of the Brundtland Commission, “Our Common Future”, published in 1987, highlighted the importance of balancing economic development with environmental protection and social development (Brundtland Commission 1987). The United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992 marked a significant turning point in the development of the concept of a green economy. The conference presented Agenda 21, a comprehensive blueprint for sustainable development, that recognized the role of the economy in promoting environmental sustainability (UNCED 1992). Since then, the green economy has been developed to include a range of economic activities and policies that promote sustainable development. The utilization of terms such as “green growth” or “green economic development” is not incongruent with sustainable development. It is imperative to comprehend that green growth or green economic development does not serve as a substitute for sustainable development but rather as a means to attain it (OECD 2011, World Bank 2012).

The fundamental principles of the green economy include resource efficiency, low carbon emissions, and social inclusion (World Bank 2013). Its objective is to establish a more sustainable and equitable economic system by advocating for the utilization of renewable energy, sustainable agriculture, and eco-friendly technologies (UNEP 2008b, c). Numerous countries and international organizations have embraced the concept of a green economy as a means to tackle environmental challenges, alleviate poverty, and promote sustainable development (World Bank 2013, 2017). The United Nations Environment Program (UNEP) defines a green economy as one that not only enhances human welfare and social equity but also substantially reduces environmental risks and ecological scarcities (UNEP 2008a). This definition surpasses the simple inclusion of negative environmental impacts in a nation's gross domestic product (GDP) calculation. It provides a comprehensive framework that promotes sustainable development through investments in capital, infrastructure, employment, and skills, with the aim of achieving both social welfare and environmental sustainability (UNEP 2008a, UNESCAP 2012, World Bank 2013, ADB 2020). Recent academic research underscores the importance of transitioning to a green, low-carbon, and circular economy to achieve carbon neutrality and address ecological challenges (Attahiru et al. 2019, Lin et al. 2021). The undeniable link between carbon emissions and economic growth necessitates a balance between energy security, environmental protection, and economic expansion, thus highlighting the need for a green economy. Scholars have demonstrated the adverse effects of the existing economic model and have presented evidence, such as Japan's experience, showcasing the benefits of investing in green economy sectors and research and development (R&D) to enhance food quality and life expectancy, ultimately promoting societal welfare (Maria et al. 2015). Transitioning to a green economy can improve a nation's health and strengthen the factors that contribute to social and economic prosperity and well-being (Maclean–Plascencia 2012, Weber–Cabras 2017). Consequently, it is essential to recognize that the concept of a green economy rests on three fundamental pillars: environmental conservation, sustainable economic growth achieved through emissions reduction and resource efficiency, and the enhancement of well-being and social equality.

Creating a reliable method for assessing the quality of the green economy is a complex task that necessitates a specific approach and accurate indicators to measure progress. This study aims to establish and evaluate the effectiveness of the Quality of the Green Economy Index by employing a variety of global practices and pertinent research. The Green Economy Index, published by UNEP (2008b, c, 2015), comprises 40 indicators divided into three categories: environmental interventions, policy interventions, and well-being and equity. In 2017, the United Nations Program on the Global Environment (UNPAGE 2017) introduced a framework for measuring progress in the green economy, which includes three groups (economy, social, and environment) and thirteen indicators. This framework aims to provide a comprehensive and holistic approach for assessing progress in the green economy. The economy category includes indicators such as GDP, renewable energy investments, and resource efficiency. The social category encompasses poverty reduction, access to education and health care, and gender equality, while the environmental indicators include air and water quality, biodiversity, and greenhouse gas emissions. These indicators were chosen to provide a complete picture of the progress of the green economy. There are several versions of the green economy index, such as the Organisation for Economic Co-operation and Development's (OECD) Green Growth (2017) and Dual Citizen's Global Green Economy Index (2022). Under the OECD's auspices, 26 green growth indicators grouped into four categories have been introduced: productivity, natural asset base, quality of life, and policies. Dual Citizen's Global Green Economy Index provides a comprehensive view of the green economy through 18 quantitative and qualitative indicators. The index evaluates four essential factors: climate change and social equity, sector decarbonization, markets and ESG investment, and environmental health. Recent studies in China have emphasized the importance of resource utilization, environmental protection, social construction, economic performance, and the promotion of sustainable living in developing a high-quality green economy. Zheng et al. (2022), Jiang et al. (2022) and Zhou (2022) highlight the importance of these factors in forming a high-quality development of the green economy index for provinces and cities in China.

Until now, there has been no empirical research in Russia proposing a measurement index for assessing the level of green economic development across its constituent entities. The application of indices such as the OECD's Green Growth Index and the Dual Citizen's Global Green Economy Index is not feasible. The primary reason for this is that these methods rely on numerous indicators that are primarily available at the national level. Additionally, due to Russia's vast territorial expanse, multiculturalism, and ethnic diversity, as well as the significant natural variations among its constituent entities, it is not practical to use methods that select indicators from a country with conditions similar to those of Russia, such as China (Zheng et al. 2022, Jiang et al. 2022, Zhou 2022).

## The importance of green investment in facilitating the advancement of green economic development

Green investment refers to the allocation of financial resources into projects, businesses, and initiatives that have a positive environmental impact. It involves directing capital towards activities that promote sustainability, mitigate climate change, and protect natural resources (Inderst et al. 2012). Eyraud (2011) posited that green investment encompasses the following components: (i) financial investments in renewable technologies, including large-scale hydropower projects, (ii) capacity investments in the nuclear sector, (iii) the adoption of energy-efficient technologies, (iv) R&D in green technologies, and (v) investments in carbon sequestration. Green investments typically focus on sectors such as renewable energy, energy efficiency, clean technologies, sustainable agriculture, waste management, and conservation (Dato 2018, Strielkowski et al. 2021). The objective of green investment is to support the transition to a low-carbon and resource-efficient economy while also generating financial returns (UNEP 2008a). It involves considering both the environmental benefits and the financial viability of investment opportunities. Green investments can be made by individuals, companies, financial institutions, and governments (ADB 2020, UNEP 2018). Green investment plays a crucial role in facilitating the green economy by promoting the development and adoption of clean technologies, reducing greenhouse gas emissions, improving resource efficiency, and supporting sustainable practices (UNEP 2008a, UNESCAP 2012). It contributes to the creation of green jobs, enhances energy security, and fosters innovation in environmentally friendly industries (ADB 2020, UNESCAP 2012). Gajjar (2020) demonstrated that green investment in the coal sector of India yields positive outcomes for the economy by implementing advanced technologies with high efficiency and low emissions. Mo et al. (2022) revealed that green investment has a positive long-term impact on green growth in heavily polluted economies such as China, India, and Russia. Furthermore, R&D investment also fosters green growth in predominantly highly polluted Asian countries. Jaeger et al. (2021) substantiated that green investments generally generate more employment per USD 1 million than unsustainable investments. Therefore, in terms of mechanisms, green investment can stimulate green economic development through the promotion of green technologies and innovation (Shuwaikh et al. 2021, Zhang et al. 2023), the creation of green employment opportunities (Simas et al. 2022), green production (Zhang et al. 2023), and the reduction of $CO_2$ emissions (Huang 2023). Overall, green investment aligns economic activities with environmental objectives, resulting in lower $CO_2$ emissions and an enhancement of green economic development.

Recent interest has emerged in Russia regarding the analysis of the significance of green investment, with businesses increasingly recognizing it as a crucial key to integrating into the global green economy (Tagaeva et al. 2022, Kabir–Rakov 2023). This parallels the growing momentum of green investment observed in the European Union (Kwilinski et al. 2023). However, Tarkhanova–Fricler (2020) have highlighted that green investment in Russia is still in its nascent stage, predominantly relying on companies' own funds, necessitating consideration of developing a mechanism for state support towards nonprofit organizations engaged in green investment activities and the involvement of such organizations in environmental project implementation through the development of green financing instruments (Dubrova et al. 2021). The growth of green investment in the Russian economy is attributed to foreign direct investment inflows, increased fees for negative environmental impact, expanded extractive product production, and the rise in $CO_2$ emissions (Tarkhanova–Fricler 2020). Key motivators for Russian companies to engage in green investments include the opinions of foreign investors, global commitments to greenhouse gas reduction, and partial tightening of national environmental legislation (Kabir–Rakov 2023), which differs from practices in other developed countries where public sector funding and specialized manufacturers play a primary role (Tarkhanova–Fricler 2020). Several significant obstacles hinder the development of green investment in Russia, including the absence of a regulatory legal framework, insufficient state support to attract such investments, and the lack of a system for verifying "green" securities (Gaddy–Ickes 2019, Tarkhanova et al. 2020). Overcoming these barriers and mobilizing financial resources are crucial for establishing a "green" economy in Russia and ensuring sustainable development (Tarkhanova et al. 2020). Undoubtedly, the importance of green investment in facilitating the transition to a green economy in Russia has been increasingly recognized. Semenova et al. (2020a, b) extensively analysed the state of green finance across Russian constituent entities from 2000 to 2018, underscoring its critical role in promoting economic growth. Green finance, as defined by Semenova et al. (2020a, b), encompasses financial resources from investments dedicated to environmental protection, sustainable use of natural resources, and current environmental expenditures. Pertseva–Paramonova (2021) emphasize that the development of green finance instruments in Russia is essential for safeguarding the interests of future generations by promoting a green investing channel for ensuring environmental safety and preservation. Additionally, investments in green technologies offer financial benefits and protection against global economic uncertainty. Makarov et al. (2021) argue that embracing greener economic development in Russia presents an opportunity to overcome the limitations of the current fossil fuel-dependent growth model, leading to a more sustainable and resilient prosperity for its citizens within a rapidly evolving global economy (Mitrova−Melnikov 2019). To achieve this type of development, efficient resource allocation, including the effective utilization of green finance, is imperative. Constituent entities of Russia are in dire need of enormous green finance resources to realize the urgent goals of environment and human well-being (Miroshnichenko 2020, Bilgaev et al. 2022). With no other choice, Russia must "green" its economy and financial system to ensure sustainability and mobilize resources for green investments. This will lead to economy-wide benefits, including savings on capital expenditures and improved energy efficiency that reduces carbon emissions and increases productivity and competitiveness. The process of greening the economy and financial system needs to originate from Russian constituent entities, which is the premise of creating new jobs and industries, extending economic benefits to vulnerable citizens and reducing poverty (Damianova et al. 2018: p. 67., Chernova–

Gridnev 2023). Based on the aforementioned arguments, we formulate the following hypothesis:

H1: Green investment reduces environmental pollution and consequently enhances green economic development within the constituent entities of Russia.

To address the hypothesis mentioned above, our approach will initially involve the establishment of a composite index to measure the quality of green economic development across the 85 constituent entities of Russia. Subsequently, we employ a fixed effect model to examine the impact of green investment on green economic development (Hypothesis 1). After that, we utilize an intermediary effect model to investigate whether green investment influences green economic development through intermediary effects, specifically, "green investment → environmental pollution (measured by $CO_2$ emissions per unit of gross regional product [GRP]) → the development of a green economy". The detailed methodology and the quantitative economic model approach will be presented in following section of this research.

## Material and methods

### Data sources

The study uses data from 85 Russian constituent entities for the period 2010-2021. Data sources include Statistical Year of the Russian Federation for the period 2010-2021, Federal State Statistics Service, Ministry of Economic Development of the Russian Federation, Federal Agency for Water Resources, Federal Service for Supervision of Natural Resource Usage, Global Forest Watch, Mongabay, The Global Data Lab, Human Development Reports (UNDP), IQAir and AQI.

### The calculation of Russia's constituent entities green economic development index

The entropy weight method is employed to compute the weight of each indicator in composing the green economic development index (Zheng et al. 2022, Nguyen−Khominich 2023). In this method, the evaluation is set up with m indicators and n samples, and the measured value of the $i^{th}$ indicator in the $j^{th}$ sample is recorded as $X_{ij}$. Let $P_{ij}$ be the standardized value of the $i^{th}$ indicator in the $j^{th}$ sample; its calculation is as follows:

$$P_{ij} = \frac{X_{ij}}{\sum_{j=1}^{n} X_{ij}} \; ; \; i = 1,2, \dots , m \quad (1)$$

The entropy value $E_i$ of the $i^{th}$ indicator is calculated by the following equation:

$$E_i = -\frac{\sum_{j=1}^{n} P_{ij} . \ln(P_{ij})}{\ln(n)} \;\; ; \;\; i = 1, 2, \dots , m \quad (2)$$

Table 1

## Construction of the quality of the green economy index

| First-level indicators | Basic indicators | Indicators' explanation | Unit | Property | Weight |
|---|---|---|---|---|---|
| Environment | Forest coverage | Comparison between forest cover with total land area | % | Positive | 0.2626 |
| | Air quality | Based on annual average PM2.5 concentration | μg/m³ | Negative | 0.2089 |
| | Air pollutant handling | Atmospheric pollutants captured and neutralized per USD of GRP | kg $CO_2$/USD | Positive | 0.1842 |
| | Untreated wastewater | Discharge of polluted sewage per capita | Cubic metre | Negative | 0.2148 |
| | Wastewater management | Recycled use of water per capita | Cubic metre | Positive | 0.1295 |
| Economy | Openness | Trade openness of a constituent entity | % | Positive | 0.1659 |
| | Businesses' performance | Share of loss-making organizations in total number of organizations | % | Negative | 0.1582 |
| | GRP per capita | GRP per capita (purchasing power parity [PPP] USD, 2017) | 1,000 USD | Positive | 0.3152 |
| | Industrial production | Volume of shipped own produced goods, | Million USD | Positive | 0.2468 |
| | Employment rate | Share of the labour force that is employed | % | Positive | 0.1139 |
| Social | Cultural life | Number of public libraries cultural and leisure organizations/1,000 people | units | Positive | 0.0912 |
| | Health worker density | Number of physicians/1,000 people | physicians | Positive | 0.2315 |
| | Poverty | Share of population with income below the subsistence minimum | % | Negative | 0.3235 |
| | Housing condition | Average area of dwellings per inhabitant | m² | Positive | 0.2212 |
| | Technology and communication | Percentage of households with access to the internet | % | Positive | 0.1326 |

The weight of the $i^{th}$ indicator ($W_i$) is calculated as in Equation 3. The weights of all 15 indicators and their properties are presented in Table 1. Regarding the selection of 15 indicators, first and foremost, these indicators must effectively reflect economic growth within the context where values related to environmental quality, well-being, and social equity have also improved correspondingly (UNEP 2008b, c, 2015, OECD 2017, Dual Citizen 2022). Second, the data for these indicators should be transparently published on an annual basis and easily accessible. Third, these indicators have been employed in previous reputable studies for the construction of the green economic development index (Zheng et al. 2022, Zhou 2022, Nguyen–Khominich 2023).

$$W_i = \frac{1-E_i}{\sum_{i=1}^{m}(1-E_i)} \quad (3)$$

Therefore, the value of an index is calculated as follows:

$$I_j = \sum_{i=1}^{m} w_i . X_{ij} \;\; ; \;\; j = 1, 2, \dots, n \quad (4)$$

Three separate indices are measured in this study using the entropy weight method: the environmental index, the economic index and the social index. The quality of the green economy index evaluates the progress towards an inclusive green economy by combining the progress made in three pillars and considering the number of indicators within each pillar to acknowledge that all indicators are of equal importance. As a result, the $a^{th}$ entity's green economy index in the $b^{th}$ year is calculated as follows:

$$\textit{The green economic development index}_{ab} = \frac{\text{env.index}_{ab}\times 5 + \text{econ.index}_{ab}\times 5 + \text{qgl.index}_{ab}\times 5}{15} \quad (5)$$

## Econometric models

$$\text{ged}_{it} = \alpha_0 + \alpha_1 * \text{gin}_{it} + \alpha_n * \sum_{n=2}^{n} Z_{it} + \delta_t + \varphi_i + \varepsilon_{it} \quad (6)$$

where $ged_{it}$ represents the green economic development index of $entity_i$ in $year_t$. The variable $gin_{it}$ denotes the green investment value in $entity_i$ in $year_t$. Furthermore, $Z_{it}$ comprises a set of control variables, namely, $env_{it}$, which denotes the proportion of local expenditure related to the purpose of environmental protection; $hdi_{it}$, which represents the human development index; $ef_{it}$, which represents the energy efficiency; and $in_{it}$, which denotes the share of innovative goods, works, and services. $a_0$ is the constant term, $\delta_t$ means time-fixed effect, $\gamma_i$ means individual fixed effect, and $\varepsilon_{it} \sim N(0, \delta^2)$ is the random error term of the model.

This study also considers $CO_2$ emissions per unit of GRP as an intervening variable. The reason for this is that we want to investigate whether there is an indirect effect through the following relationship: "*green investment → environmental pollution ($CO_2$ emissions per unit of GRP) → the development of green economy*" (see Figure 1). Therefore, the study continues to build Model (7) and then a combined model to examine the simultaneous impact of green credit and environmental pollution ($CO_2$ emissions per unit of GRP) on green economic development (Model 8). Equation 7 examines the impact of green investment on environmental pollution, and it is presented as follows:

$$\text{ce}_{it} = \alpha_0 + \alpha_1 * \text{gin}_{it} + \alpha_n * \sum_{n=2}^{n} Z_{it} + \delta_t + \varphi_i + \varepsilon_{it} \quad (7)$$

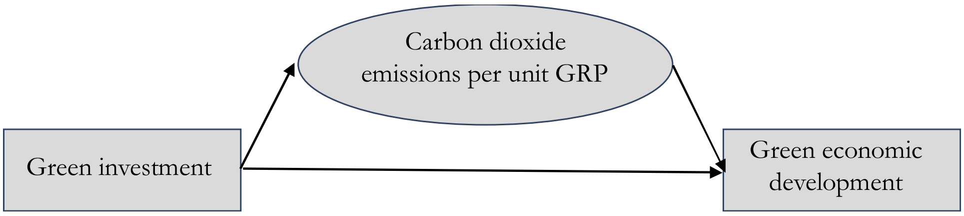
where $ce_{it}$ represents the carbon dioxide emissions per unit of GRP (environmental pollution).

Equation 8 concurrently investigates the influence of green investment and environmental pollution on the development of the green economy and is presented as follows:

$$\text{ged}_{it} = \alpha_0 + \alpha_1 * \text{gin}_{it} + \alpha_2 * \text{ce}_{it} + \alpha_n * \sum_{n=3}^{n} Z_{it} + \delta_t + \varphi_i + \varepsilon_{it} \quad (8)$$

The symbols representing the variables involved in Equations 7 and 8 are analogous to those explained in Equation 6.

Figure 1
The potential relationship of green investment, environmental pollution and green economic development in Russian constituent entities




## Exploring the spatial autocorrelation of green economic development in Russia

The spatial autocorrelation of green economic development and green finance has recently become a topic of interest in certain nations. In China, studies conducted by Zheng et al. (2022) and Jiang et al. (2022) have concluded that there is spatial autocorrelation of green economic development across Chinese provinces, which is reasonable due to the acknowledged spillover effect of economic growth in spatial economics (Zhou 2022, Su et al. 2023). Kalantaripor–Najafi Alamdarlo (2021) found spatial effects on green GDP growth in China, India, Iran, Kazakhstan, Kyrgyzstan, Pakistan, Russia, Tajikistan and Uzbekistan. In contrast, there has been no empirical research conducted in Russia to examine the spatial autocorrelation between green economic development across all 85 constituent entities. However, recent studies have demonstrated that there are interrelationships between economic development across Russian constituent entities. Demidova (2015) observed a positive spatial correlation of macroeconomic indicators in western regions and both positive and negative externalities in eastern regions, with an asymmetric influence between the two. Kolomak (2019) indicated a shift of economic activities from resource-rich regions to manufacturing regions and larger cities serving as hubs that disseminate influence to surrounding regions. Balash et al. (2020) identified a statistically significant dependence of the average per capita GDP growth rate on the growth rate of technological innovation costs in neighbouring regions. Based on the aforementioned analyses, we posit the following research hypotheses in our study:

H2: The development of green economy processes within the constituent entities of Russia is not random but rather exhibits a spatial correlation.

H3: Green investment and environmental pollution exert both direct and indirect (spillover effects) influences on the quality of green economic development within the constituent entities of Russia.

To empirically assess the two hypotheses, we undertake the computation of Moran's I (Egri–Tánczos 2015, Fitriani et al. 2022), construct spatial weight matrices

(Sen–Bera 2014, Járosi 2017), and conduct spatial econometric regression modelling. Based on the analysis, we employ Moran's I to explore the spatial autocorrelation of green economic development across Russian constituent entities. The Moran's I statistic for spatial autocorrelation is given as (Zheng et al. 2022):

$$\text{Moran's I} = \frac{n}{S_0}\frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i-\bar{x})(x_j-\bar{x})}{\sum_{i=1}^{n}(x_i-\bar{x})^2} \quad (9)$$

where $x$ is the variable of interest, $\bar{x}$ is the mean of $x$, $w_{ij}$ is the spatial weight with zeroes on the diagonal (the construction of the spatial weight matrices is presented in following subsection), $n$ is equal to the total number of features, and $S_0$ is the aggregate of all spatial weights:

$$S_0 = \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij} \quad (10)$$

## The construction of spatial weight matrices

A matrix of spatial weight is represented by a positive, symmetric n × n matrix, denoted by W, with each element $w_{ij}$ located at i and j for n locations. The weights assigned to each pair of locations, denoted by $w_{ij}$, are determined by predefined rules that outline the spatial relationships between locations and affect the spatial autocorrelation statistics. By convention, $w_{ii}=0$ for the diagonal elements. In this study, we employed a contiguity matrix and inverse distance matrix to explore the spatial autocorrelation of green economic development across Russian constituent entities.

The contiguity matrix ($W_1$) is a (0, 1) weight matrix. When $entity_i$ is adjacent to $entity_j$, $w_{1,ij}=1$; otherwise, $w_{1,ij}=0$ (Wrigley et al. 1982):

$$w_{1,ij} = \begin{cases} 1 \\ 0 \\ 0 \end{cases} \quad (11)$$

The inverse distance matrix ($W_2$) is a (0, $1/d_{ij}$) weight matrix, where $d_{ij}$ represents the straight distance between the capitals of provinces, and $d_{ij}$ is calculated as follows:

$$d_{ij} = arccos[sin(90 - lat_i) \times sin(90 - lat_j) \times cos(lon_i - lon_j) + cos(lat_i) \times cos(lat_j)] \times R \times {}^{\pi}/_{180} \quad (12)$$

Specifically, $lat_i$ refers to the north latitude dimension of $entity_i$, while $lat_j$ represents the north latitude dimension of $entity_j$. Similarly, $lon_i$ shows the east longitude of $entity_i$, and $lon_j$ represents the east longitude of $entity_j$. We also use a regional radius, denoted by R, which is calculated as 6378.137 km. Finally, we use the mathematical constant π to make these calculations. By using the inverse distance matrix, we can take advantage of the first law of geography, which tells us that as distance increases between two locations, their spatial correlation gradually decreases (Tobler 1970).

$$w_{2,ij} = \begin{cases} 1/d_{ij} \\ 0 \end{cases} \quad (13)$$

## The spatial econometric model

If spatial autocorrelation is explored, we will reexamine the impact of green investment and environmental pollution on green economic development across Russian constituent entities using a suitable spatial econometric model. Generally, a spatial econometric model is presented as follows:

$$y_{it} = \rho W y_{it} + x_{it}\beta + W x_{it}\theta + u_{it} \quad (14)$$

where $u_{it} = \lambda W u_{it} + \varepsilon$

And: $y_{it}$ represents the dependent variable *i* in year *t*, and $x_{it}$ represents the independent variable i in year t. The vector of coefficients for the explanatory variables is represented by $\beta$, while $u$ is the vector of errors and $W$ is the spatial matrix. The general Model (14) includes endogenous spatial interaction $\rho W$y, exogenous spatial interaction $Wx\theta$, and interaction through errors $\lambda Wu$. According to Elhorst (2010), using Model (14) will result in inseparable endogenous and exogenous spatial interactions. Therefore, at least one of these interactions should be removed from the model, and the best way is to eliminate spatial interaction through errors. From Model (14), multiple variants of spatial models can be generated. However, in this study, the author focuses on the three most popular models: the spatial autoregressive model (SAR), spatial error model (SEM), and spatial Durbin econometric Model (SDM). One advantage of the SDM over the SAR and SEM is that it encompasses both the SAR and SEMs. Thus, the SDM can still provide unbiased estimates even if the data structure is SAR or SEM. This can be demonstrated by setting the $\theta$ coefficient to 0, which will result in the SAR model. Similarly, setting the $\theta$ coefficient to $-\beta\lambda$ will result in the SEM. Based on this property, model selection can be tested to choose the optimal model among the three SDM, SAR, and SEMs. Therefore, in this study, we first employ the Durbin spatial model. Subsequently, we will test the hypotheses of the coefficient $\theta = 0$ and $\theta = -\beta\lambda$ to determine which model is optimal. The SDM is constructed as follows:

$$ged_{it} = \propto + \rho W ged_{it} + \beta_1 gin_{it} + \beta_k \sum_{k=2} X_{it} + \lambda_1 W gin_{it} + \lambda_j W \sum_{j=2} X_{it} + \varepsilon_{it} \quad (15)$$

where the symbols of the variables and other parameters are the same as explained previously.

# Results and discussion

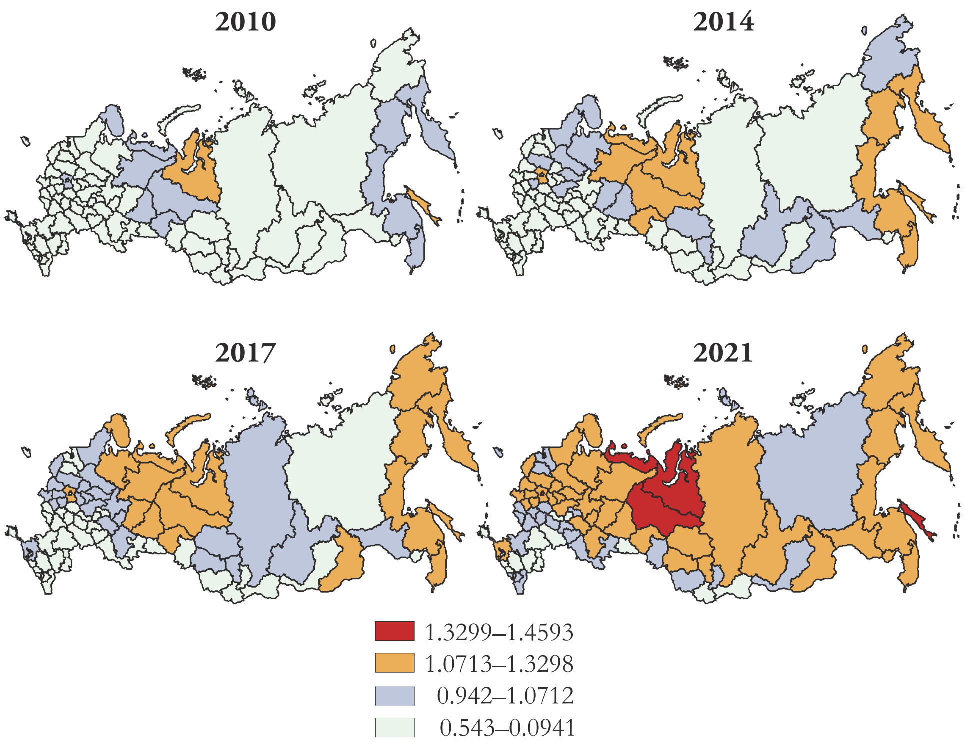
## The quality of green economic development across Russian constituent entities

During the period of 2010-2021, the green economic development index values of Russian constituent entities ranged from 0.5431 to 1.4593. The present study employed a cluster analysis technique to categorize the quality of green economic development among the constituent entities into four distinct groups: *Excellent, Good,* *Fair, and Poor*. The *"Excellent"* group was identified by a green economic development index value ranging from 1.3299 to 1.4593, while the *"Good"* group had a green economic development index value ranging from 1.0713 to 1.3299. The *"Fair"* group's green economic development index fell within the range of 0.9420 to 1.0713, and the *"Poor"* group had a green economic development index ranging from 0.5431 to 0.9420. The period under study revealed a notable increase in the quality of the green economy across the constituent entities. The findings indicate that in 2010, only a few constituent entities within the Central Federal District, Far Eastern Federal District, Northwestern Federal District, and Ural Federal District, namely, Moscow city, Sakhalin, Saint Petersburg, Khanty-Mansi, and Tyumen, exhibited a superior green economic development index compared to other entities. The details on the names and locations of the entities see in the internet appendix. However, over time, the trend of green economic development began to gradually spread to neighbouring entities. In Russian entities, economic development is largely reliant on fossil energy, metallurgy, and other heavy industries, which remains a predominant trend. However, noteworthy progress has been made in the development of the green economy during the period under consideration. The quality of life, as measured by the ratio of medical personnel per capita in these entities, has remained high in comparison to global standards. Concerning the environment, the entities have maintained a consistent level of tree coverage, and air quality is generally satisfactory and not detrimental to health. These results are visually represented in Figure 2.

The Central Federal District's green economic development is focused on Moscow city, which is the economic and political centre of Russia. Moscow has a high per capita income and is a leader in promoting sustainable initiatives and green projects. Moscow's green growth has spread to Moscow Oblast and nearby regions, including Tver, Kaluga, Yaroslavl, Ivanovo, and Smolensk. The Ural Federal District has significant historical significance as the oldest centre for oil, natural gas, and metallurgical production in Russia, with Sverdlovsk, Tyumen, and Khanty-Mansi being economically strong entities. Tyumen, Khanty-Mansi, and Yamalo-Nenets also exhibit impressive scores in standards of living indicators. Most entities within the Ural Federal District have shown a gradual increase in the quality of green economic development over time, except for Kurgan, where the poverty rate remained high. The Northwestern Federal District is one of the most economically advanced regions in Russia, with a highly developed transportation infrastructure and a well-educated workforce. Saint Petersburg, Komi, and Nenets were the most developed entities in terms of green economic development in 2010, with higher per capita income and comparative advantages in tourism and environmental protection. However, these entities faced challenges such as income inequality and dependence on high-emission industries. Over time, green economic development has gradually spilled over into neighbouring entities such as Khakassia, Kirov, and Arkhangelsk. The centre of green economic development in the Far Eastern Federal District is Sakhalin, which has a robust economic foundation due to its abundant reserves of oil, gas, and coal. The neighbouring entities of Khabarovsk, Primorsky, Magadan, and Kamchatka have all demonstrated higher green economic development indices than most other regions in Russia. In the Siberian Federal District and the Volga Federal District, entities in proximity to other districts, such as Tomsk and Omsk in the West or Amur in the East, have exhibited more rapid growth in the green economy compared to other entities. In the Southern Federal District and the North Caucasus Federal District, no entity demonstrated the potential to become a centre for green economic development between 2010 and 2014. However, as of 2017, in light of the significant strides made in the advancement of its green economy, Krasnodar has emerged as a noteworthy exemplar. This progression can be attributed to the triumphant hosting of the 2014 Winter Olympics and the concurrent enhancement of transportation infrastructure within the region. It is noteworthy that the development of transportation infrastructure has assumed paramount importance in catalysing various economic sectors, most notably tourism (Tóth et al. 2013). From the perspective of the analysis, it is highly expected that Krasnodar can have spillover effects on its neighbours.

Figure 2

**Quality of green economic development across Russian constituent entities**

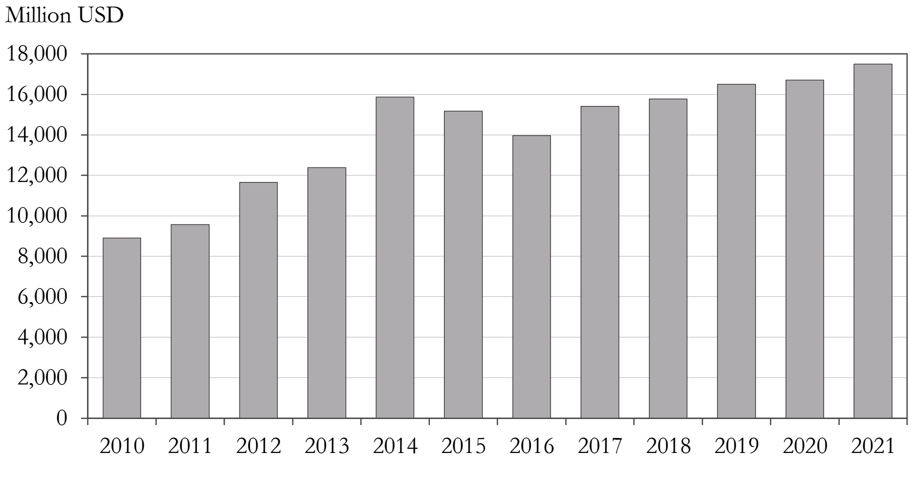


## The state of green investment in Russian constituent entities

Choosing an appropriate factor to represent green investment across Russia's 85 constituent entities is a challenging undertaking. The factor selected must be reported thoroughly throughout the research period and be in alignment with all 85 constituent entities. Some studies, such as Semenova et al. (2020a, b), identified investments in fixed assets, which aim to protect the environment and optimize the use of natural resources, as a representative factor for green finance. In this research, we employ the total value of investments in fixed assets, which aim to protect the environment, optimize the use of natural resources, R&D, innovation activities and human health and social work activities as green investment. Since the data values are reported in Russian rubles, we use the average exchange rate of each year to convert to USD for a more comfortable calculation. According to Figure 3, there has been a notable increase in green investment, with a rise from 8,909.3 million USD to 15,863.6 million USD between 2010 and 2014, followed by a decrease to 13,967.7 million USD in 2016. Since 2017, the trend has been on an upwards trajectory, with the value of green investment reaching its all-time high of 17,502.1 million USD in 2021.

Figure 3

**The state of green investment value in Russia**




*Source:* [1].

The distribution of green investment in Russia exhibits an uneven pattern. We employed a cluster analysis technique based on investments in fixed assets, which aim to protect the environment and optimize the use of natural resources, R&D, innovation activities and human health and social work activities as green investments. The analysis identified five clusters, and their details are provided in Table 2. The first cluster, comprising Moscow city, St. Petersburg, Tyumen, Nizhny Novgorod, Sverdlovsk, Novosibirsk, Moscow Oblast, and Krasnoyarsk, leads in terms of green investment. The second cluster, which includes Komi, Volgograd, Bashkortostan, Perm Territory, Sakhalin, Nenets, Primorsky, Yamalo-Nenets, Tatarstan, and Khanty-Mansi, also demonstrates an active policy and significant investments in fixed assets, which aim to protect the environment, optimize the use of natural resources, R&D, innovation activities and human health and social work activities as green investments. The third and fourth clusters are in the early stages of developing a green investment and green financing mechanism. However, the entities in the largest, fifth cluster reflect the general situation in Russia, as they are not yet involved in green investment and lack green finance for environmentally friendly projects. Table 3 presents the average values of green investment for each cluster.

Table 2

## Clustering Russian constituent entities by green investment

| Cluster | Constituent entities |
|---|---|
| I | Moscow city, St. Petersburg, Tyumen, Nizhny Novgorod, Sverdlovsk, Novosibirsk, Moscow Oblast, Krasnoyarsk |
| II | Komi, Volgograd, Bashkortostan, Perm Territory, Sakhalin, Nenets, Primorsky, Yamalo-Nenets, Tatarstan, Khanty-Mansi |
| III | Leningrad, Irkutsk, Omsk, Sakha (Yakutia), Omsk, Tomsk, Arkhangelsk, Bashkortostan |
| IV | Belgorod, Lipetsk, Vologda, Murmansk, Orenburg, Samara, Chelyabinsk, Kemerovo, Khabarovsk, Krasnodar, Rostov, Ulyanovsk |
| V | Vladimir, Voronezh, Ivanovo, Kaluga, Kostroma, Kursk, Oryol, Ryazan, Smolensk, Tambov, Tver, Crimea, Sevastopol, Tula, Yaroslavl, Karelia, Kaliningrad, Novgorod, Pskov, Adygea, Kalmykia, Astrakhan, Dagestan, Kabardino-Balkaria, Karachay-Cherkessia, North Ossetia-Alania, Chechen, Stavropol, Mari El, Mordovia, Udmurt, Chuvash, Kirov, Penza, Saratov, Kurgan, Altai, Buryatia, Tuva, Khakassia, Altai, Zabaykalsky, Kamchatka, Amur, Magadan, Jewish, Chukotka |

*Source:* [1], calculated and compiled by the authors.

Table 3

## Average values of green investment

(million USD)

| Year | Cluster | | | | |
|---|---|---|---|---|---|
| | I | II | III | IV | V |
| 2010 | 330.20 | 142.56 | 106.59 | 91.79 | 60.76 |
| 2011 | 367.61 | 163.23 | 125.82 | 106.84 | 57.89 |
| 2012 | 439.92 | 192.70 | 146.37 | 125.14 | 74.99 |
| 2013 | 471.51 | 207.94 | 159.17 | 135.63 | 77.31 |
| 2014 | 601.52 | 264.39 | 201.57 | 172.03 | 100.60 |
| 2015 | 576.79 | 253.96 | 194.01 | 165.41 | 95.48 |
| 2016 | 530.21 | 233.23 | 178.03 | 151.86 | 88.23 |
| 2017 | 585.04 | 257.46 | 196.57 | 167.66 | 97.10 |
| 2018 | 598.59 | 263.39 | 201.07 | 171.53 | 99.47 |
| 2019 | 626.69 | 275.75 | 210.56 | 179.59 | 104.09 |
| 2020 | 634.37 | 279.12 | 213.12 | 181.77 | 105.40 |
| 2021 | 664.65 | 292.42 | 223.30 | 190.45 | 110.40 |

*Source:* [1], calculated and compiled by the authors.

## Characteristic factor analysis

The present study presents a comprehensive analysis of the green economic development index and green investment, which are examined in detail in previous subsections, respectively. The characteristic factor analysis is summarized in Table 4, which indicates that the energy efficiency has an average value of 1,702.1 kWh/1,000 USD, with minimum and maximum values being 69.1 kWh/1,000 USD and 6,612.3 kWh/1,000 USD, respectively. Furthermore, the Human Development Index (HDI) has an average value of 0.7555, with the smallest and largest values being 0.5982 and 0.9443, respectively. Most Russian entities exhibit a high HDI, with Moscow city and Khanty-Mansi surpassing the threshold of 9.0, which is among the highest in the world. Regarding carbon emissions, the average amount of $CO_2$ emitted per 1,000 USD of GRP is 396.1 $kgCO_2$/1,000 USD, with minimum and maximum values of 62.2 $kgCO_2$/1,000 USD and 5,001.1 $kgCO_2$/1,000 USD, respectively. Regarding the percentage of innovative goods, works, and services in the total volume of goods shipped, works performed, and services, we identified entities such as Mordovia, Tatarstan, and Khabarovsk with high percentages in the range of 18%-21%, while Nenets exhibited a rate of 0%. In terms of environmental expenditures, the average rate of expenditure for environmental purposes is 0.8387%. Due to the large discrepancy between the minimum and maximum values of green investment, $CO_2$ emissions per unit of GRP and energy efficiency, this study employs the logarithm of green investment, $CO_2$ emissions per unit of GRP and energy efficiency in the econometric models. Figure 4 presents a scattered chart of green investment and green economic development.

Table 4

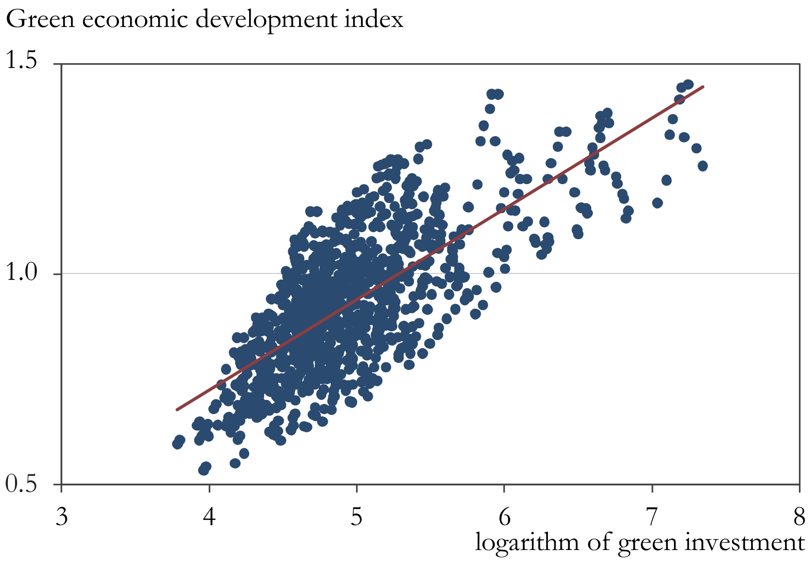
### Analysis of characteristic factors

| Variable | Unit | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|---|
| Green economic development *(ged)* | / | 1020 | 0.9416 | 0.1683 | 0.5431 | 1.4592 |
| Energy efficiency *(ef)* | Energy consumptions per 1,000 USD of GRP (kWh/ 1,000 USD) | 1020 | 1,702.1 | 1,001.4 | 69.155 | 6.6123 |
| Logarithm of energy efficiency (*lnef*) | / | 1020 | 7.2438 | 0.6968 | 4.2363 | 8.7966 |
| Human development index *(hdi)* | / | 1020 | 0.7555 | 0.0783 | 0.5982 | 0.9443 |
| Innovation *(in)* | % | 1020 | 4.2503 | 4.1791 | 0.0000 | 21.7903 |
| Proportion of environmental expenditures *(env)* | % | 1020 | 0.8387 | 0.1654 | 0.4431 | 1.3068 |
| Green investment *(gin)* | Million USD | 1020 | 177.99 | 172.27 | 44.07 | 1548.96 |
| Logarithm of green investment (*lngin*) | / | 1020 | 4.9676 | 0.5707 | 3.7859 | 7.3453 |
| $CO_2$ emission per unit of GRP *(ce)* | $CO_2$ emitted per 1,000 USD of GRP ($kgCO_2$/1,000 USD) | 1020 | 396.18 | 781.77 | 62.2003 | 5,001.1 |
| Logarithm of $CO_2$ emission per unit of GRP (*lnce*) | / | 1020 | 5.9816 | 0.6718 | 4.1303 | 8.5174 |

*Source:* [1], calculated and compiled by the authors.

Figure 4

**Scattered chart of green finance and green economic development**




## Benchmark regression analysis and endogeneity problem

In this section, we examine the impact of factors that affect the green economic development of constituent entities of Russia in 2010-2021 using Equation (6); the spatial effect is not considered. Table 5 presents the findings of a regression analysis that investigates the relationship between green investment and green economic development. The table comprises four columns, each representing different regression models. In Column (1), the impact of green investment on the quality of green economic development is examined while controlling for nonfixed time and individual effects. In Column (2), the time effect is considered without taking into account the solid effect, and its impact on the quality of green economic development is reported. Column (3) presents the results of the regression analysis that simultaneously accounts for both time and solid effects and examines their impact on the quality of green economic development in the presence of green investment. In Column (4), robust standard error is further considered, and the impact of green investment on the quality of green economic development is re-examined while controlling for both time and solid effects.

Table 5 presents the results of our analysis, which examines the effects of green investment and energy efficiency on the green economic development of Russian constituent entities. Our findings show that both variables have significant effects on green economic development at the 1% level of significance in all four models. Specifically, green investment has a positive effect on the quality of the green economy, whereas energy efficiency has negative effects, meaning that an increase in energy consumption per 1,000 USD of GRP leads to a deterioration in the quality of the green economy. Moreover, the variables HDI, innovation, and environmental expenditures also have a positive impact on the quality of green economic development at the 5% significance level in Models (1) and (2). However, in Models (3) and (4), only HDI has a statistically significant positive effect on the quality of the green economy at the 10% significance level, while innovation and environmental expenditures do not have statistically significant effects.

Table 5

**Regression results**

| Dependent variable | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Green investment (*lngin*) | 0.0068***<br>(0.0011) | 0.0066***<br>(0.0062) | 0.0066***<br>(0.0491) | 0.0066***<br>(0.0491) |
| Energy efficiency (*lnef*) | –0.1470***<br>(0.0114) | –0.1919***<br>(0.0159) | –0.1679***<br>(0.0238) | –0.1679***<br>(0.0238) |
| Human development index (*hdi*) | 0.0081**<br>(0.0011) | 0.0076**<br>(0.0011) | 0.0098*<br>(0.0012) | 0.0098*<br>(0.0012) |
| Innovation (*in*) | 0.0044**<br>(0.0009) | 0.0038**<br>(0.0008) | 0.0040<br>(0.0009) | 0.0040<br>(0.0009) |
| Environmental expenditures (*env*) | 0.0702**<br>(0.0082) | 0.0835**<br>(0.0185) | 0.0742<br>(0.0232) | 0.0743<br>(0.0232) |
| Constant term | 0.1583***<br>(0.0064) | 0.1759***<br>(0.0183) | 0.1929***<br>(0.0922) | 0.2035***<br>(0.0902) |
| Time-fixed effect | No | Yes | Yes | Yes |
| Individual fixation effect | No | No | Yes | Yes |
| Robust standard error | No | No | No | Yes |
| Sample size | 1020 | 1020 | 1020 | 1020 |
| R-square | 0.5529 | 0.6735 | 0.9123 | 0.9158 |

*Note:* *, * * and * * * represent significance at the level of 10%, 5% and 1%, respectively.

Several factors impact green economic development across Russian constituent entities. In this study, the regression model incorporates the proportion of local expenditure related to the purpose of environmental protection (environmental expenditures), the human development index, the energy efficiency, and the share of innovative goods, works, and services as the main control variables. Although this approach to some extent addresses the problem of missing variables, it is possible that endogenous problems such as reverse causation may arise due to measurement error or omission of variables. Therefore, this paper adopts the instrumental variable method to resolve endogeneity problems. First, the one-stage lag of green finance was utilized as an instrumental variable for regression, following the study by Hsiao–Taylor (1991). Second, control variables in the regression analysis were selected to lag one stage, following the study by Zheng et al. (2022). The regression results, as presented in Table 6, are consistent with the empirical results, indicating that the research conclusions are reasonably robust.

Table 6

**Endogeneity problems**

| Dependent variable | Taking one-year lag of green investment as instrumental variable (Model 5) | Taking one-year lag of the control variables (Model 6) |
|---|---|---|
| Green investment (*lngin*) | 0.0163***<br>(0.0212) | 0.0164***<br>(0.0221) |
| Constant term | 0.1963***<br>(0.0916) | 0.1975***<br>(0.0903) |
| Kleibergen–Paap rk LM statistic | 58.30***<br>[0.0016] | / |
| Cragg–Donald Wald F statistic | 78.63<br>{16.38} | / |
| Control variables | Yes | Yes |
| Time-fixed effect | Yes | Yes |
| Individual fixation effect | Yes | Yes |
| Robust standard error | Yes | Yes |
| Sample size | 935 | 935 |
| R-square | 0.7654 | 0.4625 |

*Note:* * * * represents significance at the level of 1%. [] represents the P value of Chi-Sq, and {} is the critical value of Stock-Yogo test at the significance level of 10%.

## Test of the intermediate mechanism of environmental pollution and reexamination considering spatial effects

The analysis conducted above provides evidence that green investment is a significant factor in promoting green economic development across Russian constituent entities. To further investigate the impact of green investment on green economic development, this study focuses on examining whether green investment affects environmental pollution ($CO_2$ emissions per 1,000 USD of GRP), which in turn impacts green economic development. Based on the method from the studies of Wen et al. (2004), Iacobucci et al. (2007), and Zhang et al. (2022), this study found that the intermediary effect accounts for approximately 7.1941%, clearly stating that there is a transmission channel of "*green investment → environmental pollution ($CO_2$ emissions per unit of GRP) → green economic development*" (see Table 7). We confirm Hypothesis H1 that green investment reduces environmental pollution and consequently enhances green economic development within the constituent entities of Russia.

Table 7

## Test of the mediating effect of green credit on the high-quality development of the green economy

| Dependent variable | Model 7 | Model 4 | Model 8 |
|---|---|---|---|
| | *$CO_2$ emissions per unit of GRP (lnce)* | *Green economic development (ged)* | |
| Green investment *(lngin)* | –0.5025*** (0.0093) | 0.0066*** (0.0491) | 0.0061*** (0.0420) |
| $CO_2$ emissions per unit of GRP *(lnce)* | / | / | –0.0108** (0.0855) |
| Control variables | (Yes) | (Yes) | (Yes) |
| Constant | 1.1526*** (0.1237) | 0.2035*** (0.0902) | 0.1979*** (0.0843) |
| Mediation | 7.1941% | / | / |
| Time-fixed effect | (Yes) | (Yes) | (Yes) |
| Individual fixation effect | (Yes) | (Yes) | (Yes) |
| Robust standard error | (Yes) | (Yes) | (Yes) |
| Observation | 1020 | 1020 | 1020 |
| R-square | 0.4585 | 0.9158 | 0.9206 |

*Note:* Standard errors are shown in parentheses (). *, **, and *** at the 10%, 5%, and 1% significance levels, respectively. Please note that we reuse the estimation result of Model 4 for the intermediate mechanism test of green credit on high-quality development of green economy.

Table 8 shows that under the contiguity weight matrix, Moran's I varies from 0.5170 to 0.5195, and under the inverse distance matrix, Moran's I varies from 0.1842 to 0.1857. The Moran indices are all positive, indicating that green economic development has a positive spatial correlation regardless of the contiguity weight matrix or the inverse distance matrix and passes the significance test. The result indicates that green economic development has spatial characteristics, and the green economic development level of the green economy in one constituent entity will obviously drive the green economic development level of the green economy in adjacent entities.

Table 8

## Moran's I of green economic development

| Year | Contiguity matrix | | | Inverse distance matrix | | |
|---|---|---|---|---|---|---|
| | Moran's I | Z value | P value | Moran's I | Z value | P value |
| 2010 | 0.5170 | 6.7718 | 0.0000 | 0.1842 | 9.8246 | 0.0000 |
| 2011 | 0.5173 | 6.7757 | 0.0000 | 0.1846 | 9.8416 | 0.0000 |
| 2012 | 0.5176 | 6.7797 | 0.0000 | 0.1848 | 9.8516 | 0.0000 |
| 2013 | 0.5185 | 6.7919 | 0.0000 | 0.1850 | 9.8648 | 0.0000 |
| 2014 | 0.5188 | 6.7958 | 0.0000 | 0.1850 | 9.8665 | 0.0000 |
| 2015 | 0.5172 | 6.7746 | 0.0000 | 0.1853 | 9.8782 | 0.0000 |
| 2017 | 0.5195 | 6.8035 | 0.0000 | 0.1851 | 9.8699 | 0.0000 |
| 2018 | 0.5175 | 6.7785 | 0.0000 | 0.1853 | 9.8800 | 0.0000 |
| 2019 | 0.5194 | 6.8038 | 0.0000 | 0.1857 | 9.9019 | 0.0000 |
| 2020 | 0.5163 | 6.7653 | 0.0000 | 0.1856 | 9.9007 | 0.0000 |
| 2021 | 0.5194 | 6.8038 | 0.0000 | 0.1857 | 9.9019 | 0.0000 |

From the perspective of the Moran's I value of green economic development between 2010 and 2021, this study concludes that the green economic development in Russia is not random in space. However, it has a certain trend of spatial autocorrelation, which means that it is particularly important to consider the spillover effects when analysing the quality of green economic development and green finance in constituent entities of Russia. At this point of the study, we can confirm that spatial autocorrelation of green economic development exists among the constituent entities of Russia (Hypothesis H2).

Table 9

**Estimation results of the spatial Durbin model**

| Denomination | Using contiguity spatial weight matrix (7) | Using inverse distance weight matrix (8) |
|---|---|---|
| Direct effect | | |
| Green investment *(lngin)* | 0.0054***<br>(0.0033) | 0.0063***<br>(0.0044) |
| $CO_2$ emissions per unit of GRP *(lnce)* | –0.0056***<br>(0.0013) | –0.0084***<br>(0.0013) |
| Indirect effect | | |
| Green investment *(lngin)* | 0.0025***<br>(0.0033) | 0.0018***<br>(0.0028) |
| $CO_2$ emissions per unit of GRP *(lnce)* | –0.0026***<br>(0.0024) | –0.0028***<br>(0.0051) |
| Total effect | | |
| Green investment *(lngin)* | 0.0079**<br>(0.0017) | 0.0081***<br>(0.0021) |
| $CO_2$ emissions per unit of GRP *(lnce)* | –0.0082***<br>(0.0022) | –0.0112***<br>(0.0054) |
| Spatial rho (ρ) | 0.3572***<br>(0.0407) | 0.5805***<br>(0.0804) |
| sigma2_e | 0.0001***<br>(0.0085) | 0.0002***<br>(0.0090) |
| Sample size | 1020 | 1020 |
| R-square | 0.4523 | 0.4421 |

*Note:* (1) *, * * and * * * represent significance at the level of 10%, 5% and 1%, respectively. The values in () represent the Z values. (2) The result of Hausman test using contiguity weight matrix (Chi-square = 36.28, P value = 0.0005) and the result of Hausman test using inverse-distance weight matrix (Chi-square = 16.03, P value = 0.0377) both indicate that fix-effect model fits better than random-effect model in this study. (3) Test results for SAR are Chi-square = 124.41, P value = 0.0000 (using contiguity weight matrix) and Chi-square = 55.68, P value = 0.0000 (using inverse distance weight matrix). The results indicate that SDM should be adopted in this study. (4) Test results for SEM are Chi-square = 114.12; P value = 0.0000 (using contiguity weight matrix) and Chi-square = 33.35, P value = 0.0000 (using inverse distance weight matrix). The results indicate that SDM should be adopted in this study.

The testing results in Table 6 indicate, at a significance level of 5%, that the SDM is more appropriate than the SAR and SEM. The Hausman test also shows that using fixed effects models is more appropriate than using random effects models. As anticipated, the study findings demonstrate that green investment is a crucial factor in enhancing the quality of green economic development in Russian entities between 2010 and 2021. The growth of green investment not only has a direct impact on the green economic development of a given entity but also results in positive spillover effects on the green economic development of neighbouring entities. Similar studies conducted in China, such as those by Zheng et al. (2022) and Zhou (2022), have observed negative spillover effects. At this point of the study, we conclude that green investment has an important driving impact on green economic development in Russian constituent entities. The results of the spatial regression model also demonstrate that environmental pollution not only negatively impacts the green economic development of a specific constituent entity but also leads to a deterioration in the green economic quality of neighbouring constituent entities (see Table 9). However, we emphasize that the results for the different constituent entities can be understood only relative to each other and not in absolute terms or relative to other regions outside of the country. At this point of the study, we can confirm hypothesis 3 that green investment and environmental pollution exert both direct and indirect (spillover effects) influences on the quality of green economic development within the constituent entities of Russia.

## Conclusion and policy implications

This study makes significant contributions to the understanding of green economic development and investment in Russian entities, distinguishing itself from previous studies, by providing a comprehensive analysis of the various facets of a genuine green economy. By incorporating 15 indicators across three pillars, namely, environment, economy and social equality, we have identified the limitations in green economic quality in Russia, particularly regarding environmental pollution, poverty rate and economic performance. This study goes beyond the conventional focus on GDP and income growth, shedding light on the critical aspects of green economic quality.

The research findings demonstrate a positive correlation between green investment and green economic development as well as a negative correlation between environmental pollution and green economic development, with evidence of spillover effects on neighbouring entities. This supports the notion that green investment plays a pivotal role in driving green economic progress within Russian constituent entities during the period of 2010-2021 and that pollution reduces the quality of a green economy. However, spatial autocorrelation analysis reveals that green economic development is not a random process and is influenced by neighbouring entities, emphasizing the need for collaborative efforts among entities and spatial considerations in promoting sustainable economic development. To foster green investment and advance towards a sustainable future, it is imperative for the Russian government to formulate a comprehensive green roadmap. This entails promoting environmentally friendly projects, augmenting financial resources, and addressing challenges such as market volatility, geopolitical risks, and technological advancements. To facilitate sectoral growth, the government should enhance the legal framework, establish specialized institutions, introduce tax incentives, implement a standardized certification system, and incorporate environmental considerations into financial decision-making. These measures will create a favourable environment for green investment activities, stimulate sustainable economic growth, and contribute to Russia's long-term development goals.

The implications of this study underscore the urgency for greater attention and investment in green finance in Russia. While progress has been made, it lags behind that of developed countries and other nations facing similar conditions. To bridge this gap, increased emphasis on green finance and investment is necessary to support the transition towards a more sustainable and environmentally friendly economy. Additionally, the positive spillover effect of green finance on neighbouring entities highlights the potential for collaborative approaches and necessitates policy-makers to consider the spatial dimensions of green economic development.

***Limitations of the study and future research directions.*** As previously stated, developing an index that accurately measures the overall quality of green economic development across the constituent entities of Russia is a highly intricate task for two main reasons. First, there are several indicators necessary for evaluating sustainable development goals that are not yet registered at the local level. Second, Russia is a vast country with diverse climates and cultures, making it challenging to incorporate these factors into the green economic development index. Therefore, additional research is needed to further enhance the green economic development index in the future.

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