



# Ecological Efficiency and Sustainable Regional Development in Russia <sup>†</sup>

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<sup>†</sup> Presented at the ICSD 2021: 9th International Conference on Sustainable Development, Virtual, 20–21 September 2021.

**Abstract:** We proposed an approach to evaluate ecological efficiency of an economy as the ratio of the created output of non-primary goods and services to the input of consumed resources (labor, capital, raw materials, environmental costs) using the DEA. The eco-efficiency of an average Russian region has been growing since 2003. Using econometric calculations, we have established it grew faster in densely populated areas with a high share of high-tech services, investment attractiveness, and intensive technology implementation; it decreased in most northern and Siberian regions. The simultaneous growth of GRP per capita and ecological efficiency in a region was considered as a model of sustainable development. We observed this pattern more than half of the period 1998–2017 in most Russian regions although the Russian economy mainly developed due to the extraction of raw materials.

**Keywords:** regional development; sustainability; Russian regions; environmental problems; data envelopment analysis; Kuznets curve; quality of economic growth



**Citation:** Zemtsov, S.; Barinova, V. Ecological Efficiency and Sustainable Regional Development in Russia. *Environ. Sci. Proc.* **2022**, *15*, 30. <https://doi.org/10.3390/environsciproc2022015030>

Academic Editors: Cheyenne Maddox and Lauren Barredo

Published: 9 May 2022

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## 1. Introduction

Climate change, ecological, and social problems require new goals, metrics and tools of economic policy, based on the principles of sustainable development [1,2]. However, over the latest 20 years, the increase in energy prices has led to a raw material growth model prevailing in Russia [3]. Could this growth have led to more sustainable regional development?

In our work, in accordance with the paradigm of sustainable development, ecological efficiency is the ability of economic agents to increase non-resource output in a region while minimizing the resources used (labour, capital, raw materials) and the level of environmental pollution. In fact, this can be used as an additional indicator for monitoring the quality of economic growth at different territorial levels: countries, regions, cities, etc. The simultaneous growth of per capita GRP and ecological efficiency might be considered as a possible approach to sustainable regional development.

The purpose of our work is to assess the ecological efficiency of the Russian regions and to determine the factors of its dynamics from 1998–2017.

## 2. Materials and Methods

To measure the sustainable development dynamics, the economic, social, and environmental characteristics are often used [1,2,4]. Hence there are problems in justifying the choice of indicators and the ratio of weights between them within the integral indices. In our article, we use an approach based on data envelopment analysis (DEA), which considers a combination of many variables. The method is based on linear programming [5].

Regions are compared with each other by the results of their activities, taking into account the resources they use (cost-benefit analysis) [6]. In the production function, costs are the estimates of the factors of labour, capital, and natural resources (fuel, water, land resources, etc.), and output is the gross regional product (GRP). Undesirable results, such as pollution [7], in our opinion, should be considered as environmental costs. In this case, we can consider that an ecologically efficient region with estimation 1 is a region that, in comparison with others, provides output with a minimum number of resources used and minimum pollution. Efficient regions are on the border of production capabilities. The least efficient regions have a DEA value close to zero.

Empirical studies confirm the higher ecological performance of developed countries and regions [7,8]. This confirms the hypothesis of a  $\Lambda$ -shaped relationship between economic growth and environmental pollution [Grossman, Krueger, 1991], called the ecological Kuznets curve. In the transition from an agrarian to an industrial society, costs rise. Then, the growing share of the service sector and the introduction of new technologies can reduce the number of resources used and reduce pollution. At the same time, as incomes grow, the demand for a clean environment increases.

To assess the results of sustainable economic activity in the region, we propose an indirect indicator of the output of non-primary goods and services-gross regional product (GRP) in constant prices minus mining activities and federal transfers, billion rubles. Federal transfers accounted for in GDP are mainly associated with the redistribution of oil rent between regions, therefore they are excluded from the assessment of regional ecological efficiency.

We use several variables that characterize resource costs:

- labour: number of labour force (million people);
- capital: the cost of fixed assets in constant prices (billion rubles);
- natural resources: electricity consumption (million kWh); water consumption (million cubic meters); value added by type of activity "Extraction of minerals" in constant prices (billion rubles);
- environmental costs: emissions of pollutants into the atmosphere (thousand tons).

The official data of the Russian statistical service from 1998–2017 were used.

Since the comparison in DEA is made for a sample, its change may lead to a revision of the estimates. The calculations were carried out simultaneously for the entire period 1998–2017, which made it possible to trace the dynamics of ecological efficiency.

### 3. Results and Discussion

#### 3.1. The Main Trends

In Russia, energy intensity increase during the crisis period of the 1990s, when output fell faster than energy consumption, but declined in the 2000s as the economy grew, underutilized production capacities were loaded, assets were renewed, and the price of energy resources rose. The share of fossil fuels in energy consumption generally declined prior to the 2009 crisis following higher raw material prices, but the share of renewables has declined since the mid-1990s due to a decline in the number of small hydropower plants. Due to the fall in industrial production, carbon dioxide emissions decreased in the 1990s, but then there was an increase due to growing capacity utilization and motorization.

Non-resource output more than doubled over the period due to the growth of the service sector, especially in large agglomerations of the country: trade, finance, transport, information, and communication technologies, etc. Minerals, considered the main source of growth, due to the favourable market conditions increased by 1.8 times. Economic growth in the early 2000s was accompanied by an increase in air pollution, but from 2005 to 2015, the volume of emissions shortened due to a reduction in the number of large industries, modernization of thermal power plants and their conversion to natural gas, the development of resource-saving technologies in new industries. This phenomenon is consistent with the Kuznets ecological curve hypothesis. But in 2018, the processes of motorization led to some excess of the values of 2000. Water use was reduced throughout

the entire period due to the modernization of water infrastructure, reduction of losses, and the closure of a number of large water consumers, including pulp and paper mills. Electricity consumption grew following economic growth, but at a slower pace, which is associated with a decrease in the specific share of energy-intensive industries, in particular, the closure and re-equipment of outdated metallurgical plants, and a decrease in losses after the modernization of power grids.

Eco-efficiency has decreased in most regions with low-tech industries: in Kemerovo (coal mining, metallurgy); Rostov (coal mining); Orenburg (oil, gas, copper) regions; Perm Territory (oil, gas, mineral fertilizers production); Karelia (metal mining, pulp, and paper industry); as well as areas that have increased their production capacity: Amur (iron); Astrakhan (natural gas); Irkutsk (gas, coal).

### 3.2. The DEA Estimations

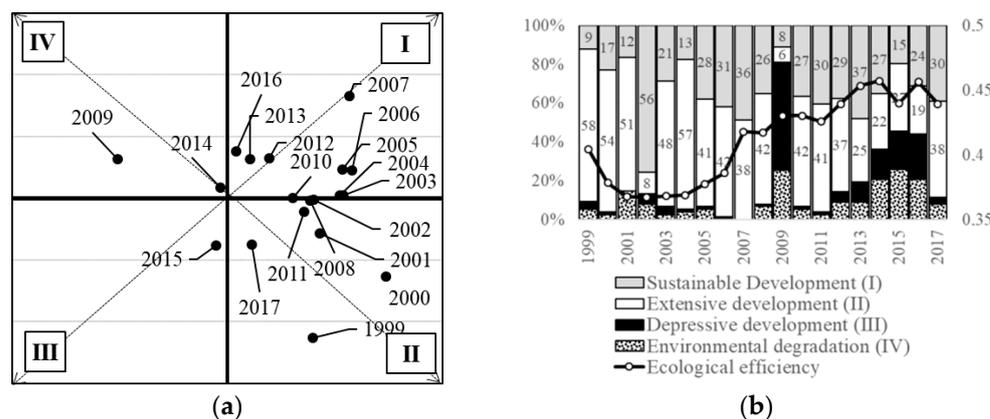
We identified several regions on the border of production capabilities, which demonstrate the best practice: Moscow, St. Petersburg, Yaroslavl, Sverdlovsk, Bryansk, Tambov regions, Mordovia, and Chuvashia. Increasing the efficiency of an average Russian region and becoming close to the leaders while maintaining the values of GRP, fixed assets, and labour force, would require a reduction in water, electricity, and emissions by 56%, and the volume of mineral extraction by 96%.

However, the volumes of non-resource output, and, accordingly, the estimates of the leaders' efficiency may be overestimated. First, despite the mechanical exclusion of mining from our estimates of non-resource output, the mining sector remains closely linked to the economies of all regions through financial services, trade, budget spending, etc.; the sector has a stronger influence on the largest agglomerations (Moscow, St. Petersburg). Secondly, although the federal budget transfers to the regions were excluded from the estimates, the natural resource rent was distributed by financing state organizations, whose products and services constitute a significant part of the non-resource output of the less developed leading regions (for example, Mordovia and Chuvashia). In general, the formed centralized fiscal system in Russia helped to equalize socio-economic and environmental inequality.

A preliminary analysis shows that regions with large agglomerations and relatively diversified economies are more ecologically efficient: Moscow, St. Petersburg, Nizhny Novgorod, Omsk, Sverdlovsk, Leningrad, Chelyabinsk regions. Due to the high share of the service sector, and the introduction of new technologies in these regions, the indicators of energy consumption, water use, and air pollution are lower. Separate regions with a high share of agriculture and public sector are also efficient: Chuvashia, Mordovia, Kabardino-Balkaria, Bryansk, Tambov regions. Due to the small number of large industries and lower incomes of residents in these regions, energy consumption and emissions from factories and vehicles are lower.

Low ecological efficiency was observed in regions with a high share of low-tech industry and, accordingly, with high specific volumes of emissions and energy consumption: Kemerovo region (ferrous metallurgy, coal mining), Krasnoyarsk region (non-ferrous metallurgy, pulp, and paper industry, brown coal mining), Orenburg region (ferrous and non-ferrous metallurgy, gas production), the Komi Republic (oil, gas and coal production), Irkutsk region (non-ferrous metallurgy, pulp, and paper industry), Khanty Mansi Autonomous Okrug and Tomsk region (oil and gas production).

The ecological efficiency of the average region in Russia declined from 1998 to 2003 (Figure 1b), when the fall in the ruble exchange rate and favourable external conditions contributed to the high utilization of obsolete fixed assets, the policy of preserving a number of inefficient and resource-intensive industries prevailed. However, with the renewal of production capacities and the structural transformation of the Russian economy, efficiency began to grow again in 2011 and increased until 2014. Economic growth then slowed down on the back of rising emissions from automobile transport and rising electricity consumption.



**Figure 1.** (a) Growth of GDP per capita in Russia (horizontal axis) and increase in ecological efficiency of an average Russian region (vertical axis) in 1998–2017, %. Method was firstly introduced by V. Bityukova [9]. (b) The structure of development models by the number of regions (%) and ecological efficiency (right axis) of an average region in 1999–2017.

The fastest growing eco-efficiency was in regions with the following features:

- (1) leading in terms of investment attractiveness, which have launched new production facilities and services, including through foreign direct investment and technology imports [3]: (for example, Leningrad, Belgorod, Yaroslavl, Kaliningrad regions);
- (2) large metallurgical centres, where large-scale modernization took place (for example, Sverdlovsk, Chelyabinsk, Vologda, Lipetsk regions);
- (3) producing regions where emissions of associated natural gas have decreased (for example, Sakhalin, Tomsk regions, the Komi Republic);
- (4) regions that have lost their former production specialization as a result of market transformations (for example, Ivanovo, Saratov regions, Kurgan, Volgograd, Omsk regions);
- (5) regions where land prices were actively increasing in large agglomerations, and the processes of tertiarization intensified—the growth of the service sector (for example, Moscow, Omsk, Sverdlovsk, Chelyabinsk regions).

### 3.3. Regional Sustainable Development

Comparing the dynamics of the eco-efficiency of an average Russian region and the dynamics of GRP per capita, four development models can be distinguished (in brackets are the quadrants in Figure 1a):

- sustainable (I)—economic growth and ecological efficiency increase (for Russia it was observed in nine out of twelve years);
- extensive (II)—economic growth, but a decrease in ecological efficiency (seven years);
- depressive (III)—a fall in per capita GDP (GRP), combined with an increase in ecological efficiency in the crisis years of 2009 and 2014;
- environmental degradation (IV)—economic contraction with a decrease in ecological efficiency in the crisis year of 2015.

Figure 1b clearly shows how regions differ in terms of development models in certain years and how strongly this is influenced by the crisis phenomena. In a third of the period considered, the model of extensive development was implemented, in a quarter—the model of sustainable development. Economic crises (2008 and 2015) led to a decrease in ecological efficiency in most regions, which is associated with a higher rate of decline in output compared to a reduction in costs. Therefore, the share of regions that implemented the model of depressive development and ecological degradation grew; the number of the latter is especially high in 2009 and 2015.

In 43 out of 74 regions, the sustainable development model has been implemented more often than other models, or as many years as the extensive model, and more than eleven years in St. Petersburg, Tambov, Leningrad, Tula, Lipetsk, Vologda, Oryol regions, Krasnoyarsk Territory, Dagestan, Transbaikal Territory, and Khakassia. In 34 regions, predominantly of raw materials specialization, an extensive development model prevailed. For more than five years, depressive development was observed only in Komi and Magadan Oblast, where the number of residents decreased due to migration to the southern regions, GDP shrunk, but, accordingly, the load on ecosystems also fell.

### 3.4. Factors of Ecological Efficiency

To identify and assess the influence of various factors described above on the dynamics of the ecological efficiency of regions, we have built several multifactorial models (Table 1). All dependent variables are weakly correlated with each other, there is no reason to assume the presence of multicollinearity. For verification purposes, several calculation methods are presented. The results of econometric assessments have confirmed the previously identified regional patterns.

**Table 1.** The results of econometric modeling. Dependent variable: assessment of the ecological efficiency of the Russian regions according to the DEA method (from 0 to 1). 1184 observations. Random effects.

Number	1	2	3
GRP per capita, thousand rubles per person	−0.001 (0.0003) ***	−0.0007 (0.0004) *	−0.0006 −0.0004
GRP per capita, thousand rubles per person <sup>2</sup>	$1.5 \times 10^{-6}$ ( $5.2 \times 10^{-7}$ ) ***	$1.1 \times 10^{-6}$ ( $5.5 \times 10^{-7}$ ) *	$9.4 \times 10^{-7}$ ( $5.5 \times 10^{-7}$ ) *
Share of the non-manufacturing sector in GRP,%	0.004 (0.001) ***	0.006 (0.001) ***	0.005 (0.001) ***
Ratio of imports of machinery and equipment to GRP,%	0.001 (0.0004) ***	0.001 (0.0004) **	0.001 (0.0004) **
Ratio of crop production to GRP,%	0.005 (0.002) ***	0.006 (0.002) ***	0.006 (0.002) ***
Crimes per capita	$-2.4 \times 10^{-5}$ ( $1.1 \times 10^{-5}$ ) **	$-3.5 \times 10^{-5}$ ( $1.2 \times 10^{-5}$ ) **	$-3.5 \times 10^{-5}$ ( $1.2 \times 10^{-5}$ ) ***
Average number of study years of an employee	0.02 (0.008) **	0.02 (0.007) ***	0.02 (0.007) ***
Population density, people per sq. km	$4.1 \times 10^{-5}$ ( $1.1 \times 10^{-5}$ ) ***	$3.2 \times 10^{-5}$ ( $1.1 \times 10^{-5}$ ) ***	$2.8 \times 10^{-5}$ ( $1.1 \times 10^{-5}$ ) ***
Number of cars per capita		−0.0003 (0.0002) **	−0.0004 (0.0002) **
Coal is mined in the region (dummy variable)	−0.16 (0.05) ***	−0.16 (0.05) ***	−0.1 (0.05) **
Ferrous or non-ferrous metals are mined in the region (dummy variable)			−0.18 (0.06) ***
Constant	0.44 (0.1) ***	0.32 (0.1) ***	0.37 (0.1) ***

Estimates of the coefficients and directions (+/−) of the influence of variables. The robust standard errors are in parentheses. Asterisks indicate significant estimates: \*\*\*-most significant ( $p$ -value < 0.01), \*\*-less significant ( $p$ -value < 0.05), \*-least significant ( $p$ -value < 0.1).

It was confirmed that post-industrial regions with high per capita GRP and agricultural regions with low productivity and pollutant emissions were more efficient, even consider-

ing many other factors. The positive, albeit weak, coefficient of the squared variable GRP per capita confirms the hypothesis of the ecological Kuznets U-curve.

Equipment upgrades have reduced emissions and improved energy efficiency in factories. Therefore, the higher is the share of imports of machinery and equipment in GRP in a region, the higher the ecological efficiency could be. The coefficient at the variable “the ratio of the investments to GRP” is not significant, that is, in regions with large volumes of investments there were no higher values of eco-efficiency. Since these are predominantly northern regions, in which most of the investments were directed to the raw materials sectors.

The region’s ability to attract investment in new industries and renew funds depends on the risks for investors and entrepreneurs, as well as on the concentration of human capital, so regions with high crime and low education levels are generally less efficient. For policy purposes, it is important that these factors can be influenced by regional authorities.

The indicator of the share of crop production in GRP is positively associated with ecological efficiency, respectively, in the northern regions, where this share is minimal, ecological efficiency is lower, and in many cases, it decreased due to growing transport, energy, and other costs. It was confirmed that the regions where coal and metals are mined are, on average, less ecologically efficient. Thus, the possibilities for sustainable development are, to some extent, determined by natural conditions and resources.

In regions with a high population density, ecological efficiency is higher and increased due to agglomeration effects: the variety of activities, the intensity of agent connections, the size of the market, etc. due to growing pollution. For the purposes of regional policy, it is important that it is impossible to overcome the environmental problems of large cities by building highways and increasing the number of cars, but only by restricting the use of personal vehicles.

Environmental policy measures (investments in environmental protection) turned out to be insignificant in any of the models (contradicting our initial hypothesis), since they are aimed at solving the existing problems of ecologically less efficient regions.

#### 4. Conclusions

Economic growth in Russia over the past twenty years has been based primarily on the use of the natural resources of certain regions. However, the mechanisms of regional policy based on interbudgetary (federal) transfers made it possible, to a certain extent, to smooth out socio-economic and ecological inequality.

Many regions that did not have significant natural resources also developed at a high rate [3]. This created the conditions for the implementation of a sustainable development model that combines the growth of per capita GRP and the growth of ecological efficiency. This model was observed in Russia in 2003–2007, 2010, 2012–2013, and 2016, which can be explained by the increase in the share of the non-manufacturing sector and the renewal of fixed assets. Therefore, the model prevailed in regions that actively attracted investments in new production and services: in Moscow, Leningrad, Kaliningrad, Belgorod regions, in production centres that carried out large-scale modernization: in the Vologda, Lipetsk, Sverdlovsk regions.

The likelihood of implementing a sustainable development model in a region depends not only on objective factors (geographic location, population density, economic structure, etc.), but also on the decisions of federal and regional authorities (interbudgetary transfers, investment incentive policies, improving the investment climate, etc.). Therefore, the proposed tool for assessing the quality of economic growth may be in demand when making political decisions.

In recent years, the share of regions that are implementing a sustainable development model has been decreasing against the backdrop of unstable economic growth, an increase in the share of the raw materials sector in the economy, and pollution from vehicles. But in 2020, due to the economic crisis caused by the consequences of the pandemic and the fall in oil prices, there is a high likelihood of a depressive development model that combines a

drop in per capita GDP (GRP) with an increase in ecological efficiency. This has already been observed in the crisis years of 2009 and 2014. The pace of motorization and, in general, the anthropogenic load as a result of quarantine measures and a reduction in the population's income will decrease, while small and medium-sized businesses will suffer, and growth based on the extraction of raw materials may stop.

Our research complements the list of works devoted to the goals, factors, and instruments of sustainable regional development in Russia. The approach proposed by the authors to assess ecological performance can be used in studies of economic development and in setting political goals. The results and conclusions obtained can be used to develop recommendations regarding the localization of sustainable development goals in different types of regions.

The national project "Ecology" in Russia by 2024 envisages a significant reduction in emissions of pollutants from stationary sources, the improvement of water bodies, and the expansion of environmental activities. Our calculations allow us to justify a number of additional tools.

Most regions of Russia require the creation of incentives for a significant increase in the efficiency of extraction and processing of raw materials, energy and water conservation, and reduction of atmospheric pollution. In many regions, there is a high potential for improving the energy efficiency of buildings and the development of alternative energy sources: wind, solar, tidal, geothermal, etc. [10].

We consider it expedient to introduce specialized financial instruments: a tax deduction for small companies and homeowners to compensate for part of the costs of installing roof panels, and wind turbines [10], the introduction of environmental vouchers; you need to expand your connectivity to public networks. Various measures on emission quotas and taxation have not lost their relevance.

In order to reduce emissions from vehicles in the largest agglomerations, it will be necessary to introduce the principles of an eco-city into the practice of urban planning activities: the development of public electric transport, bike paths, car sharing, a decrease in the number of stories of buildings, restrictions on the movement of personal vehicles and other measures.

Most of the measures supporting the development of high-tech industries and knowledge-intensive services actually increase the possibilities for sustainable development. In turn, increasing the complexity of regional economies through the introduction of eco-innovation, and resource-saving technologies contributes to an increase in the productivity and competitiveness of regions. The structural transformation of the Russian economy is interconnected with an increase in ecological efficiency, and, accordingly, with opportunities for sustainable development.

**Author Contributions:** Conceptualization, V.B.; methodology, S.Z.; formal analysis, S.Z.; investigation, S.Z.; writing—review and editing, V.B.; visualization, S.Z. All authors have read and agreed to the published version of the manuscript.

**Funding:** The study was prepared as part of the state assignment of the RANEPА.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Acknowledgments:** The authors thank Vera Kidyayeva, Tatiana Lanshina, Victoria Bityukova, Natalia Koldobskaya for valuable comments.

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

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