ORIGINAL ARTICLE

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Does income inequality matter for CO$_2$ emissions in Russian regions?

Abstract

Research background: Intensive economic growth in Russian regions during recent decades has been associated with numerous environmental issues, particularly increasing CO$_2$ emissions, as well as income inequality. To achieve sustainable development, it is necessary to resolve these issues.
Purpose of the article: To shed light on the impact of income inequality on CO$_2$ emissions based on Russian regional data covering the years 2004–2018.
Methods: Gini index and decile dispersion ratio are used to measure income inequality. To study the impact of income inequality on CO$_2$ emissions in the Russian regions, we estimate econometric models with fixed and random effects and apply GMM method. We test the hypothesis of the environmental Kuznets curve to determine the impact of economic growth on CO$_2$ emissions.
Findings & value added: The results show that CO$_2$ emissions increase in tandem with growth in income inequality between 10% of people with the lowest income and 10% of people with the

highest income. Simultaneously, CO_2 emissions decrease with growth of Gini coefficient. The hypothesis of the Environmental Kuznets Curve was confirmed based on GMM method. Our findings underscore that the activities of the extraction and manufacturing sectors, as well as energy consumption, increase CO_2 emissions. The chief significance of this paper is the finding that large income gap between extremely rich and extremely poor population cohorts increases CO_2 emissions. This implies that economic policy aimed at reducing income inequality in Russian regions will also reduce CO_2 emissions, especially if accompanied by increased use of environmentally friendly technologies. From the international perspective, our research can be extended to study other countries and regions.

Introduction

Climate change and greenhouse gas emissions have been increasingly recognized as urgent economic and political issues. Burning fossil fuels and deforestation for industrial and household utilization result in increasing the volumes of CO_2 emissions. These issues have long attracted the attention of the international community. Socio-economic development is premised on sustainable economic growth, and income inequality is another urgent problem related to economic growth and technological progress.

Inequality has been analyzed for the Russian regions (Slobodenyuk & Mareeva, 2020). However, the role of income inequality in CO_2 emissions has received much less attention in the research on Russia, on the regional level (Vornobytsky & Boyce, 2010) and country level (Aye, 2020; Burakov & Bass, 2019). Our paper covers this gap in the literature and explores the relationships between income inequality and CO_2 emissions, based on the Russian regional data covering the years 2004–2018.

Sustainable Development Goals (SDGs) for 2030 agreed by 193 UN Member States in 2015 targeted economic inequality reduction and increased environmental sustainability. Researchers and policy makers emphasize the importance of inequality and the environment in sustainable development (Liu *et al.*, 2019). According to the International Energy Agency, despite the decisions made concerning the decrease in CO_2 emissions caused by human activity, the emissions level linked with production and consumption of electrical energy remained the same in 2019 as in the preceding year (33.3 bln tons). Air pollution results in economic loses equivalent to 3.3% of global GDP. In Russia, during the first quarter of 2020, 44 cases of high level of air pollution were registered, a 57% increase on the same period in 2019, and the highest in the last five years (Podobedova, 2020).

The lockdown policies enacted in response to the COVID-19 abruptly limited economic activity for extended periods, causing a collapse of energy demand (by 18–25% per week) resulting in decreased CO_2 emissions.

A previous substantial decrease in CO_2 emissions occurred in 2009, related to the economic crisis of that period, but it was quickly reversed by subsequent carbon-based (i.e., unsustainable) economic development. While taking measures aimed at economic recovery, it is important to consider climate issues.

Income inequality has always been a significant socio-cultural and political problem; moreover, it inhibits economic development by limiting the access of talented people to education and jobs. A common critique of globalization is that while it generally tends to decrease inequality between countries (e.g., between Western European and North American economies on one hand, and newly industrialized BRICS economies on the other), it often creates an increase in internal inequality within states. Inequality in Russia has been persistently high since the liberalization of the economy in the 1990s, although its level is gradually decreasing. In 2018 a fifth of the Russian population accounted for half of total monetary income.

The health and economic crisis of 2020 sharpened the inequality in all countries worldwide, throwing many workers with lower incomes and in traditional economic sectors into extreme circumstances, due to the impossibility of working from home or using online tools for their economic production. Additionally, online learning facilities increase gaps in access to education, with poorer and rural children having less access to online substitutes for forbidden classroom learning during lockdowns. Furthermore, unemployment levels have increased.

Our research focuses on the impact of income inequality on CO_2 emissions, and provides a background for economic policy aimed at decreasing such emissions. The next section explains the research background more precisely, followed by discussion of data and methods. Afterwards, the results are described, and the discussion and conclusions follow.

Literature review

The environmental Kuznets curve (EKC) posits that the relationship between economic development and environmental pollution can be represented by an inverted U shape, whereby an increase in GDP per capita leads to an increase in environmental pollution during the early stages of development, but after a certain GDP threshold is attained, further development results in a decrease in environmental pollution (Kuznets, 1955; Grossman & Krueger, 1995).

The discussion of the impact of inequality on the greenhouse gas emissions started in the 1990ies. CO_2 emissions in the world are very concen-

trated in the regions and countries (Chancel & Piketty, 2015). Boyce (1994) argued that economic activity leads to deterioration of the environment, balancing the power between those who benefit from economic activity and those who bear net costs.

Hao *et al.* (2016), based on the EKC showed that if the economic growth–inequality and economic growth–environmental pollution connections are characterized by the inverted U-shaped curve, both inequality and environmental pollution should first increase in line with increased GDP per capita, and should subsequently decrease after a certain threshold of GDP per capita.

While studying the impact of income inequality on environmental pollution, researchers introduced several approaches to understand the mechanisms behind this relation, based either on production or consumption.

The production approach involves two methods. The first one was introduced by Boyce (1994). According to him, rich population groups receive benefits from economic activity associated with environmental pollution, then they apply their economic and political power to create barriers to environmental protection. Countries with low levels of income inequality thus have lower emissions levels and higher environmental standards and regulations. More recently, Boyce (2008) extended this to argue that high environmental standards and high costs associated with decreased CO_2 emissions in developed countries have stimulated the transfer of carbon-intensive production (e.g., manufacturing) to developing countries.

Using sulfur dioxide, smoke, and dust as the environmental quality indicators, it was empirically proven that income inequality can lead to deterioration of the environment, while income gaps and deteriorating environmental quality coexist in the low-income countries (Torras & Boyce, 1998). Grossman and Krueger (1995) also concluded that wealthy population groups are interested in economic costs and benefits, while the relatively poorer majority of the population bears environmental consequences. The policy resulting from this balance of powers leads to environmental deterioration.

The second approach within the production approach is the 'Veblen effect', which posits that income inequality increases working time, resulting in increased energy consumption and CO_2 emissions (Bowles & Park, 2005).

Besides, there are two methods based on consumption point of view. The first one involves working time allocation: poorer population groups work more to imitate the lifestyle of people with higher incomes, whereby their consumption increases, including that of carbon-intensive products, and pollution consequently increases (Bowles and Park, 2005). The second

method unites the theory of marginal accepted emissions and Veblen effect and states that people's propensity to consume goods of a certain level of environmental pollution varies, depending on the consumption structure (Borghesi, 2006; Grunewald *et al.*, 2017).

Jorgenson *et al.* (2017) claim that consumption trends determine the emissions level. It is assumed that the poorest population groups have higher marginal propensity to CO_2 emissions than the wealthiest, because low carbon products are generally more expensive. Moreover, poorer groups of population are more likely to utilize inefficient sources of energy associated with higher marginal propensity to CO_2 emissions (Ravallion *et al.,* 2000). However, some more recent studies have challenged the assumptions about the relationships between socio-economic phenomena and energy use.

Grunewald *et al.* (2017) find that in developed countries the reduction of inequality may lead to decreased CO_2 emissions, because of specific political economy mechanisms, and because of the relatively reduced power of owners of capital. However, in developing countries, the middle class group is the largest emitter, therefore decreased inequality may actually provoke increased CO_2 emissions; this can be mitigated by covering higher energy needs with renewable energy technologies, but the latter are inhibitively expensive compared to relatively cheaper conventional energy from fossil fuel combustion. To summarize, Grunewald *et al.* (2017) find that in high-income *countries*, higher income *inequality* increases CO_2 emissions per capita, while Kasuga and Takaya (2017) and Ravallion *et al.* (2000) found the opposite effect, and Jorgenson *et al.* (2017) found an insignificant impact. For middle-income *countries*, higher income *inequality* decreases CO_2 emissions per capita (Grunewald *et al.*, 2017). For low-income *countries* some researchers found positive impacts (Hao *et al.*, 2016; Baloch *et al.*, 2018), while Grunewald *et al.* (2017) reported that higher income *inequality* decreases CO_2 emissions per capita. For the overall sample of countries, no statistically significant relationships have been confirmed among these phenomena (Borghesi, 2006).

As for the relation between *economic growth* and *environmental pollution*, Al Mamun *et al.* (2014) find that EKC is typically affirmed by most countries globally, but it is not necessarily sustained by the example of high-income countries. Pao *et al.* (2011), find no evidence to support the EKC hypothesis based on Russian data for the period 1990 to 2007, but they note a negative impact of output on emissions. Yang *et al.* (2017) studied Russian data for the years 1998–2013 and found no turning point in EKC. They underscored the need to optimize the energy structure to decrease greenhouse gas emissions associated with economic growth. Li and Jiang (2018) reported a net decrease in CO_2 emissions in Russia over the

period 1992–2017, which they attribute to progress in energy efficiency, less carbon-intensive fuels, and decreased population.

At the *regional level*, economic growth, energy intensity, energy structure, industrialization, and urbanization are found to affect CO_2 emissions in the provinces of China for the period 1990–2014, based on quantile regression method (Xu, 2016). There are articles on the regions of Russia devoted to the determinants of CO_2 emissions that have confirmed the EKC hypothesis (Ivanova, 2019; Ketenci, 2018; Mariev *et al*., 2020). Moreover, researchers found that modern technologies decrease CO_2 emissions and mitigate emissions from energy consumption, while environmental policy is effective in decreasing CO_2 emissions (Sohag *et al.*, 2021). Nevertheless, most of the regions in Russia are on the ascending part of the inverted U-shaped curve, i.e., with the increase in GRP per capita CO_2 emissions increase (Ivanova, 2019).

New technologies are found to decrease CO_2 emissions; moreover, if urbanization is accompanied with new technologies, it is found to decrease CO_2 emissions (Mariev *et al*., 2020). Energy consumption, real income, education, and urbanization are significant for CO_2 emissions in the Russian regions (Ketenci, 2018). Regional environmental efficiency (the ratio of commodities not based on natural resources to labor, capital, natural resources expenditures and to environmental costs) has been growing since 2003 due to the development of the services sector of the economy and the progressive closure of traditional polluting enterprises. Growth has been more rapid in densely populated regions with more developed R&D and investment attractiveness (Zemtsov *et al*., 2019).

Environmental policy stringency significantly reduces CO_2 emissions in Russian regions with relatively higher GRP (Sohag *et al*., 2021). Polycentric environmental policy, i.e., increased regional autonomy in environmental policy, is essential for decreasing air pollution in the Russian cities, with regional governors' connections with the federal government (governors' influence on the federal level) being a proxy for decentralization, and taking into account the role of COVID-19 pandemic (Hartwell *et al*., 2021).

Poverty and inequality in the Russian regions as socio-economic phenomena have received extensive research attention (Slobodenyuk & Mareeva, 2020), but there has been a dearth of consideration of the impact of income inequality on the environmental. Few works have considered the impact of inequality on CO_2 emissions in the regions of Russia, and on the country level. Vornobytsky and Boyce (2010) studied the impact of income inequality on the uncontrolled air pollution for the Russian regions over the period 2000–2005 using *the income share of the bottom quintile*. They found that higher within-region income inequality leads to higher uncon-

trolled air pollution. However, the main focus of their paper was the impact of economic inequalities among the regions of Russia on environmental degradation. In this regard, they found that poorer regions have higher air pollution, and they claim that pollution-shifting is present between the regions of Russia, i.e., location of polluting industries in less developed regions.

As for the national-level research on Russia, Aye (2020) analyzed Russia in the context of other BRICS countries for the years 2000–2014, finding that increased wealth inequality, GDP per capita, and population all increase CO_2 emissions, while financial development decreases them. The study did not address *income* inequality, but wealth inequality, using *the top decile of wealth share* as an indicator of the latter. Burakov and Bass (2019), based on Russian data over the period 1996–2018, find that CO_2 emissions, corruption, and income inequality are cointegrated, while income inequality does not have a statistically significant association with CO_2 emissions, and increased corruption leads to increase in CO_2 emissions.

Aye (2020) and Vornobytsky and Boyce (2010) used random effects and fixed effects methods to study the Russian regions, but these methods do not account for endogenous aspects like simultaneity, and do not capture the dynamic process, as in GMM. Various research strategies deployed in national analyses have used fixed and random effect methods (Aye, 2020; Jorgenson *et al*., 2017; Vornobytsky & Boyce, 2010), quantile regression (Xu, 2016), and ARDL approach (Burakov & Bass, 2019). Therefore, this study addresses the gap in regional level research for Russia by using two indicators of income inequality: Gini index and decile dispersion ratio, covering a more extended time period, from 2004 to 2018, and employing GMM.

The main value added of this study is in showing that a large income gap between extremely rich and extremely poor population cohorts increases CO_2 emissions. This implies that economic policy aimed at reducing income inequality in the regions of Russia will also help reduce CO_2 emissions. Besides, our findings underscore that the activities of extraction and manufacturing sectors (as well as energy consumption *per se*) increase CO_2 emissions, which emphasizes the need for green technologies. Overall, we contribute to understanding the nexus between social, economic, and environmental issues in the regions of Russia. From the international perspective, our research methodology and the findings can be extended for the regional level research in the other countries.

Research method

We employ data covering 73 regions of Russia provided by the Russian Federal State Statistical Service (Rosstat), the Unified Interdepartmental Statistical Information System (UISIS), and the Ministry of Energy of the Russian Federation for the years 2004–2018. This research period covers the years of centralization in Russia associated with the decrease in quality of the environmental policy, until the health and economic crises caused by COVID-19 (Hartwell *et al.*, 2021).

The analysis is carried out on the regional level. The variables used in our research are presented in Table 1.

The dependent variable is CO_2 emissions per capita, i.e., the ratio of CO_2 emissions to the regional population. This measure is used in the literature (Aye, 2020; Grunewald, 2017). To estimate the inequality level, indices such as Gini index and decile dispersion are applied. Other indices can be employed to measure inequality, such as the Theil (1967), Atkinson (1970), entropy, and polarization indices. The inequality measures employed in our analysis are decile dispersion ratio and Gini coefficient (Jorgenson *et al*., 2017).

Our main hypothesis is that increased income inequality results in increased CO_2 emissions. The owners of the enterprises, possibly representing wealthy population groups, can be associated with negative externalities for the environment. Large emissions can occur due to a lack of green technologies, and the prevalence of energy-intensive technologies aimed at cost minimization. This is partly due to imperfect regulation, and incoherent implementation of existent regulation. In their turn, poor population groups negatively affect the environment due to the increase in working time, consumption of carbon-intensive (cheaper) products, and increased energy consumption caused by lack of energy efficiency.

We test the EKC hypothesis (Grossman & Krueger, 1995) on the relation between economic growth and environmental pollution, as discussed above. Therefore, GRP per capita is included in the model. The control variables include indicators of the regional industrial structure: the shares of the most polluting industries (extracting and manufacturing sectors) in the GRP. To estimate the role of regional consumption, the model contains the variables *energy consumption per capita* and *consumption expenditures per capita*.

The urbanization level (*city population share*) and regional population density reflect regional economic activity and can lead to the increase in pollution level. At the same time, the increased share of city population can

lead to economies, for example due to the use of public goods and transport that decrease net emissions.

The variable *alternative energy sources* reflects the presence in the region of large energy generators, relying on the renewable energy. The presence of such energy generators in regions can decrease CO_2 emissions.

Table 2 contains descriptive statistics of the variables used in the model.

Based on the literature analyzed above, the model was specified as follows:

$$C_{i,t} = \beta_0 + \beta_1 \ln(Y_{i,t}) + \beta_2 \ln(Y_{i,t})^2 + \beta_3 F_{i,t} + \\ + \beta_4 G_{i,t} + \varphi z_{i,t} + \varepsilon_{i,t}, \tag{1}$$

where:
i	region;
t	year;
$C_{i,t}$	CO_2 emissions per capita in region i during the year t;
$\ln(Y_{i,t})$	logarithm of gross regional product per capita (GRP pc);
F	decile dispersion ratio;
G	Gini coefficient;
z	control variables.

The model was estimated based on panel data, using random effect method, fixed effect method, fixed effect method with Driscoll-Kraay approach for correcting standard errors (FEMDK), and generalized method of moments (GMM). A more detailed discussion of the used estimation methods can be found in previous studies (e.g., Hao *et al.*, 2016; Kasuga & Takaya, 2017; Rojas-Vallejos & Lastuka, 2020), which claimed that fixed and random effect methods have a limited capacity to deal with endogeneity. Unlike random effect method, fixed effect method addresses endogeneity arising from unobserved heterogeneity (Aye, 2020). However, the limitation of the fixed effect method is that it cannot account for endogeneity associated with simultaneity, which can lead to biased coefficients. To deal both with unobserved heterogeneity and with simultaneity, we apply generalized method of moments (GMM) (Arellano & Bond, 1991). Besides, GMM accounts for dynamic process. A limitation of this method is that it does not account for short- and long-run effects. To account for the dynamic factor, we introduced the lag of dependent variable, CO_2 emissions per capita, $(C_{i,t-1})$:

$$C_{i,t} = \beta_0 + \beta_1 C_{i,t-1} + \beta_2 \, ln(Y_{i,t}) + \beta_3 \ln(Y_{i,t})^2 + \\ \beta_4 F_{i,t} + \beta_5 G_{i,t} + \varphi z_{i,t} + \varepsilon_{i,t}, \tag{2}$$

The notations are the same as in equation (1). The results of the estimation are provided in the following section.

Results

Table 3 shows the results of estimating the model discussed above with random effect method, fixed effect method, FEMDK for correcting standard errors, and GMM.

For random effect method, fixed effect method, and FEMDK for correcting standard errors, R-squared shows that from 10.9% to 36% of variation in CO_2 emissions per capita is explained by the independent variables in the model. For GMM, the Wald Chi-Squared test shows that a set of the explanatory variables in the model are significant: the p-value is less than 0.05, therefore, we reject a null hypothesis that the coefficients are equal to zero. The Arellano-Bond test shows that second order autocorrelation is not present. The significance of the variables is marked with stars, and standard errors are presented in parentheses.

The variables logarithm of GRP per capita and logarithm of GRP per capita squared are significant when the model is estimated with GMM; the results indicate that the impact of income level on CO_2 emissions is characterized by an inverted U shape, confirming the EKC hypothesis.

Both indicators of inequality proved to be statistically significant. CO_2 emissions increase with increase in the decile dispersion ratio (the difference in income of the poorest and richest 10% of population). At the same time, the increase in Gini coefficient results in decreased CO_2 emissions.

The increase in the share of extracting and manufacturing industries in GRP increases CO_2 emissions. In GMM model, only extracting industries remain significant.

The increase in consumption expenditures is also found to increase the level of air pollution. Population density decreases CO_2 emissions according to all models except GMM.

Energy consumption has an expected positive sign, and is significant in GMM model. The alternative energy variable had an expected negative sign, but turned out to be insignificant based on our model and data.

Discussion

Our results of the econometric estimation confirm the EKC hypothesis. This finding is in line with the literature, where this hypothesis is proven for the Russian regions (Ivanova, 2019; Sohag *et al.*, 2021). For the other countries the evidence on EKC is mixed (Wang *et al.*, 2018; Xie & Liu, 2019).

Our finding on the impact of inequality on CO_2 emissions is in line with the evidence for world countries with various income levels (Grunewald *et al.*, 2017; Hao *et al.*, 2016; Ravallion *et al.*, 2020), a study on BRICS countries including Russia (Aye, 2020), and studies of Russian regions (Vornobytskyy & Boyce, 2010).

We have revealed different impacts of two indicators of inequality, probably due to the different aspects of inequality captured by them: decile dispersion ratio reflects the contrasts of extreme poverty and extremely high incomes. In line with the approaches discussed in the literature review, the increase in extreme poverty and further increase in the highest percentile of income leading to the increase in this index results in higher CO_2 emissions. In turn, higher Gini index reflecting the deviation of income distribution from the ideal equality is not limited to comparison of these extreme percentiles.

Our analysis of the role of extracting and manufacturing industries in the GRP shows that structural changes in the regional economy and increased energy efficiency facilitate a decrease in CO_2 emissions. This result is in line with research on China by Zheng *et al.*, (2019) and on the regions of Russia by Vornobytskyy and Boyce (2010). The empirical results of Zemtsov *et al.* (2019) on the regions of Russia show that ecological efficiency is growing faster in the regions with high population density, with a substantial share of high-tech services, investment attractiveness and intensive technology implementation (Moscow, Saint Petersburg, Sverdlovsk, Tomsk, Belgorod, and Kaliningrad regions, etc.).

The result that population density leads to decrease in CO_2 emissions according to all models except GMM is in line with the findings of Sohag *et al.* (2021) on the regions of Russia. They found either negative and significant or insignificant impacts of population density on CO_2 emissions. This result underscores the opportunities of cities to use common infrastructure and to develop green technologies.

Our results demonstrate a significant and positive impact of energy consumption on CO_2 emissions in the GMM model. This result is also in line with the literature on Russia (Ketenci, 2018), and specifically on the Russian regions (Mariev *et al.*, 2020; Sohag *et al.*, 2021). This finding empha-

sizes the necessity for energy efficiency, green energy (Grunewald, 2017), and eco-innovations in the energy sector.

Conclusions

Based on data covering 73 regions of Russia for the period from 2004 to 2018, we have analyzed the impact of income inequality on CO_2 emissions and tested the EKC hypothesis. The dependent variable in our study was CO_2 emissions per capita. The main independent variables were decile dispersion ratio, Gini index, and GRP per capita. The econometric model was estimated using random effect method, fixed effect method, FEMDK for correcting standard errors, and GMM method to deal with endogeneity issues.

Based on the dynamic estimation of the panel data by GMM, the EKC hypothesis is confirmed, implying an inverted U-shaped relationship between regional economic growth and CO_2 emissions. Estimation results also show that the increase in decile dispersion ratio leads to increase in CO_2 emissions, while the increase in Gini coefficient results into decrease in CO_2 emissions. It is likely that the population groups both with the highest and the lowest income negatively affect the environment, while a more even income distribution is more favorable for the environmental quality.

The extracting and manufacturing industries are the main sources of CO_2 emissions caused by human activities. This emphasizes the importance of developing circular economy (Wiesmeth, 2020) and implementing low-carbon and carbon-free technologies (Chancel & Piketty, 2015). Both administrative and economic measures are being introduced to regulate CO_2 emissions worldwide (Gao *et al*., 2020). These include carbon taxes, to reduce CO_2 emissions levels in production and carbon-intensive products in consumption (Chancel & Piketty, 2015). Increased energy efficiency and the prioritization of environmentally friendly technologies are essential policy goals (Grunewald *et al*, 2017), and there is a potential to develop an effective emissions trading system (Gao *et al*., 2020).

Our findings underscore that the activities of extraction and manufacturing sectors, as well as energy consumption, increase CO_2 emissions. Our *main value added* consists in showing that a large income gap between extremely rich and extremely poor population cohorts increases CO_2 emissions. This implies that economic policy aimed at reducing inequality in the regions of Russia will also help reducing CO_2 emissions, especially if accompanied by environmentally friendly technologies. From the internation-

al perspective, our research can be extended to study other countries and regions.

Our research has the limitation of a relatively short period of observation and data availability. A longer period of observation and richer data on regional level characteristics, such as variables on green energy and on the environmental policy, would be an advantage for future research.

For further research, we propose the following ideas. First, other measures of income inequality should also be analyzed to find the best way of estimating the impact of income inequality on CO_2 emissions. Second, the role of advanced technologies in reduction of CO_2 emissions is also of interest. Third, alternative energy potential should be considered in more detail, in terms of approaches to its development and its impacts on the indicators of environmental degradation. Another important issue is addressing economic policy measures aimed at stimulating implementation by firms of technologies associated with lower CO_2 emissions on the regional level. Finally, economic policy aimed at decreasing income inequality is of interest. Indeed, the impact of income inequality on CO_2 emissions is an additional incentive for decreasing the income gap across population.

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Annex

Table 1. Data description

Variable	Unit	Data source	Expected relationship
CO_2 emissions per capita	Tons per thousand people	Rosstat[*]	
GRP per capita	Roubles	Rosstat	Inverted U-shape
Decile dispersion ratio	%	UISIS	?
Gini coefficient	%	UISIS	?
Share of natural resources extraction in GRP	%	UISIS	+
Share of manufacturing in GRP	%	UISIS	+
Energy consumption per capita	thousands kWh	Rosstat	+
City population share	% of total regional population	Rosstat	+
Consumption expenditures per capita	Thousands roubles	Rosstat	+
Alternative energy sources	Dummy-variable 0 – missing 1 – at least 1	Ministry of Energy[**]	-
Population density	people/sq.km.	Rosstat	+

Note:

[*] Russian Federal State Statistical Service (Rosstat) https://www.gks.ru/ (24.01.2020).

[**] Open data – Ministry of Energy of the Russian Federation https://minenergo.gov.ru/opendata (30.01.2020).

Source: compiled by the authors in the statistical package Stata 14.

Table 2. Descriptive statistics

Variable	Number of obs.	Mean	St.dev.	Min	Max
CO_2 emissions per capita	1,095	11.97	13.56	0	110.18
GRP per capita	1,095	239854.5	194232	28133	2407929
Decile dispersion ratio	1,095	12.57	2.15	7.9	20.7
Gini coefficient	1,095	38.04	2.39	31.1	45.2
Natural resources extraction	1,022	7.60	12.03	0	71
Manufacturing	1,022	19.19	10.24	0.7	55.6
Population density	1,095	28.44	26.46	0.31	171.44
City population share	1,095	69.23	11.59	26	96.1
Energy consumption	1,095	6.87	4.68	1.23	33.13

Table 2. Continued

Variable	Number of obs.	Mean	St.dev.	Min	Max
Consumption expenditures	1,095	12.74	7.34	1.13	43.15
Alternative energy sources	1,095	0.56	0.50	0	1
ln (GRP per capita)	1,095	12.15	0.69	10.25	14.69

Source: compiled by the authors in the statistical package Stata 14.

Table 3. Estimation results

Dependent variable: CO_2 emissions per capita	RE	FE	Driscoll-Kraay (FE)	GMM
CO_2 emissions per capita $_{i,t-1}$				0.652***
				(0.04)
Ln (GRP_pc$_{i,t}$)	-18.81*	-14.4	-14.4	40.28**
	(9.11)	(9.25)	(22.22)	(13.06)
Ln (GRP_pc$_{i,t}$)^2	0.595	0.38	0.38	-1.907***
	(0.40)	(0.41)	(0.90)	(0.57)
Decile dispersion ratio$_{i,t}$	1.962***	1.959***	1.959***	0.903*
	(0.37)	(0.37)	(0.55)	(0.42)
Gini coefficient$_{i,t}$	-1.297***	-1.277***	-1.277***	-0.910**
	(0.31)	(0.32)	(0.29)	(0.33)
Natural resources extraction $_{i,t}$	0.226***	0.232***	0.232*	0.195**
	(0.05)	(0.05)	(0.09)	(0.06)
Manufacturing $_{i,t}$	0.114*	0.196***	0.196***	0.0165
	(0.05)	(0.05)	(0.05)	(0.06)
Energy cons. $_{i,t}$	0.133	0.129	0.129	0.574*
	(0.17)	(0.23)	(0.32)	(0.28)
City popul. share $_{i,t}$	0.107	0.198	0.198	-0.0681
	(0.08)	(0.15)	(0.15)	(0.29)
Cons. expenditures $_{i,t}$	0.367***	0.426***	0.426**	0.492***
	(0.08)	(0.09)	(0.15)	(0.10)
Alternative energy$_{i,t}$	-0.104	-0.0361	-0.0361	-0.321
	(0.27)	(0.27)	(0.23)	(0.23)

Table 3. Continued

Dependent variable: CO$_2$ emissions per capita	RE	FE	Driscoll-Kraay (FE)	GMM
Population density$_{i,t}$	-0.267***	-0.313*	-0.313***	-0.123
	(0.03)	(0.14)	(0.09)	(0.29)
Const	167.8**	138.0*	138.0	
	(52.04)	(55.06)	(131.01)	
Number of obs.	1022	1022	1022	949
R-sq	0.36	0.109	0.109	
Wald chi2(12)				348.060
Prob > chi2				(0.000)
AR(2)				0.305

* p<0.05, ** p<0.01,*** p<0.001; standard errors are in parentheses

Source: compiled by the authors in the statistical package Stata 14.