THE IMPACT OF GDP GROWTH ON CO_2 EMISSIONS: TESTING ENVIRONMENT KUZNETS CURVE FOR THE CASE OF UKRAINE

by

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Abstract

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The paper studies the presence of a quadratic relationship between GDP growth and CO2 emissions. It tests the Environment Kuznets Curve, which assumes that at the development stage increase of countries income led to corresponding growth of CO2 emissions. However, at a certain point, society becomes sustainable and with an increase in income, CO2 emissions began to decay. We test the hypothesis using data on regions level during the 2006-2019 and come to the conclusion that Ukraine is still not on the sustainable path and the relationship between GDP and CO2 is U-shaped. Moreover, we got a result showing the uneven distribution of environmental pollution between regions. This makes it possible to formulate the necessary conclusions regarding allocation of budget collected from environment fees.

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And thanks to Stasys Paulauskas, who a few years ago, during my Erasmus, awakened my interest in alternative energy, hence the interest in environmental changes.

Also, many thanks to KSE for the opportunity to get a decent and high-quality education. For all the atmosphere that stimulates learning like nowhere else. This incredible place is truly a temple of knowledge.

LIST OF ABBREVIATIONS

EKC. Environment Kuznets Curve. Key concept of current work, which suggests that emissions dependence from countries income, has a squared form.

EU ETS. EU Emissions Trading System. "Cap and trade" system provided by Europe Union to catch up the emission reduction targets.

GDP. Gross Domestic Product. Value added created by production or services provided in particular country.

GHG. Greenhouse gases. Gases as carbon dioxide, nitrous oxide, methane, and ozone which absorb by atmosphere and bring warm effect on the Earth.

GRP. Gross Region Product. Value added created by production or services provided in particular region of country.

SSSU. State Statistics Service of Ukraine.

Chapter 1

INTRODUCTION

The problems of greenhouse gas emissions are of increasing concern to the society. Greenhouse effect is a normal process which formed because Earth gives back thermal energy absorbed from the Sun. In the atmosphere, part of this energy is retained and decomposes into gases (CO2, methane, etc.). However, due to people's development, the number of greenhouse gases began to increase, which created an imbalance in the atmosphere and led to an increase in temperature.

According to the Global Climate Report (2019), for the last 140 years the hottest year was 2019 and the temperature for the year deviated from the average by + 0.95 ° C. Such changes were not even surprising, given that the nine warmest years fall in the period 2005-2019. In Ukraine science 1961, the average temperature increase by 1.1°C. These changes were most notable in warmer winters and reduced difference between the minimum and maximum temperatures for the year. Such movement significantly affects the agro-industry, change in flora and fauna, affect people's well-being.

But does this mean that dramatic climate change is inevitable? After all, humanity continues to develop, and is it really necessary to slow down development to stop global warming? Grossman and Krueger (1995) assumes that this is not so. They developed a theory that told that growth induces damage to the environment, but at some point, people become more aware and the damage starts to decrease. This is exactly what is happening now. Concerned about global climate change and growing pollution, developed countries have sounded the alarm. In the 90s, the UN began to draw the attention of countries to the problems associated with the active development of the industry and to stimulate something to change. Now we can see an active transformation of the energy, transport sector and energy-intensive industry. Energy is switching to green generation, and among European countries there is a new trend of coal phase-out, that means termination of coal mining and the transformation of coal-fired power plants. In the transport sector, electric vehicles and alternative fuels are actively gaining momentum. Industry is follows the no-carbon production.

In 2019 Ukraine has 181.8 Mt of CO_2 emissions and among the Europe countries Ukraine is TOP 7 contributor of carbon pollution. As could be seen from the Figure 1, CO_2 emission reduction relates mainly to Ukrainians economic instability. Every time the economy experiences an increase, CO_2 emissions return to previous levels.

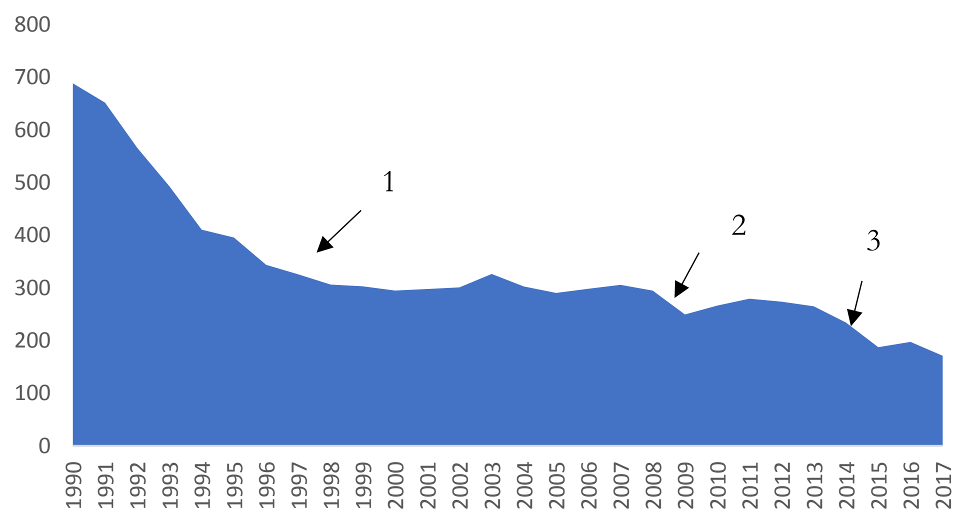

Figure 1. CO_2 emissions from fuel combustion, kt of CO_2
Source: International Energy Agency (IEA)

Numbers in Figure 1 corresponds to macroeconomic factors: 1) Economic downturn after the collapse of the Soviet Union; 2) Global Economic Crisis; 3) Armed conflict in the Donbass. To grasp real situation more relevant refer to CO2 emissions to Total Energy Supply ratio (Figure 2).

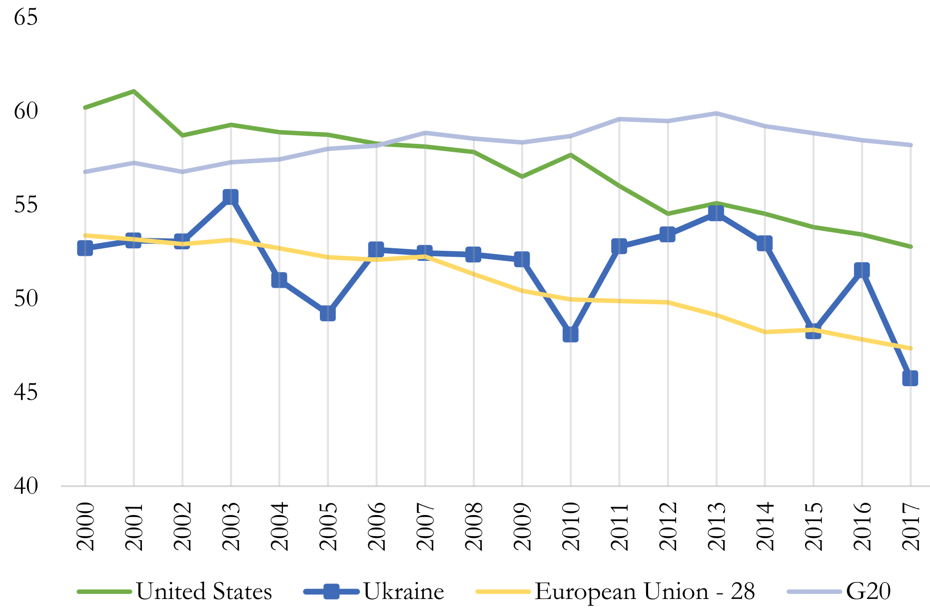

Figure 2. CO2 emissions / TPES, Tones of CO2 per terajoule

Source: International Energy Agency (IEA)

Note: TPES Calculated by EIA using the total CO2 fuel combustion emissions and total energy supply (including biofuels and other non-fossil forms of energy)

While leading countries gradually reduce emissions, Ukraine does not have a declining trend, the ratio, presented on Figure 2, is volatile which indicates a lack of consistent policy. Such a situation may be fraught with the fact that soon international organizations will start actively demand from Ukraine to follow by a sustainable growth path.

Considering all the problems described above, in this paper, we would like to cover three main issues related to CO_2 emissions:

1) to understand whether there is a square relationship between CO_2 emissions and GDP in Ukraine. This will help us determine whether the stage of sustainable development has begun in the country. To answer this question we going to estimate Environment Kuznets hypnosis which assume U-shaped relationship between CO_2 emission and GDP.

2) to determine which macroeconomic factors most affect CO_2 emissions in Ukraine. Having determined the effect of each factor, we will be able to understand to what extent it increases or decreases CO_2 emissions, which means that we can provide recommendations concerning the direction the government should direct its efforts.

3) regional specifics will help us determine how emissions are distributed across Ukrainian regions, which will answer the question regarding the budget allocation for environmental initiatives within the country.

Chapter 2

LITERATURE REVIEW

Environment Kuznets Curve was developed in 1955. The hypothesis described that income inequality first rise and then fall, following the economic growth. In 1991 Grossman and Krueger applied this hypothesis in the context of pollution. The World Bank drew attention to this and popularized it among the people. The essence of the theory is that the growth of technology led to the economy growth, but the development of technology also leads to a rapid increase in environmental pollution. But at some point, as income grows, the demand for good conditions increases, and, accordingly, increase demand for improving the environment.

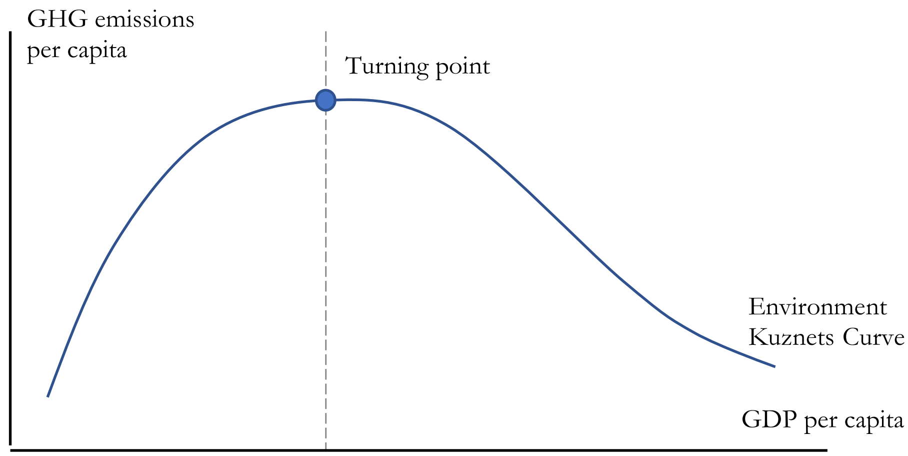

Figure 3. Environment Kuznets Curve
Source: own design

One of the key assumptions of a theory is economic structure changes. The higher level of development, led to economic transformation to more information and service-intensive, which continue to contribute a high added value, but contribute low to pollution. Also, more significant investment on environment and better technology and innovations led to a slowdown in degradation (Panayotou 1993). In this point not only income growth responsible for pollution increase, but also verity of different factors.

The problems of ecology and global warming have become especially active in society for the last 20 years. Researchers are striving to identify the relationship between the instruments used by the government and their effect on emissions. Many authors have taken up the issue of studying the relationship between economic development and CO2 emissions. It has led to numerous studies on the impact of GDP or GDP per capita on GHG. The Kuznets curve quickly became popular in this matter.

The authors gradually began to add specific factors to the initial model. Mariano and Juan (2020) broadly described determinant of GHG emissions. There was analyzed 18 variables from different literature sources, 13 of which include in estimation of GHG cause for 10 EU countries. Study showed that GDP and energy intensity are key factors that explains GHG emissions. Renewables was significant for 5 countries, while fuel prices insignificant through the all studied countries.

Sterpu et al. (2018) use the environmental Kuznets curve to estimate environment degradation including per capita gross inland energy consumption and energy consumption from renewable sources for EU-28 countries. Manta and Florea (2020) discover the relationship between CO2 emissions, energy use, economic growth and financial development for 10 CEE countries. Some authors estimate similar effects for certain country like Turkey, China, and Pakistan.

Zaekhan' and Nachrowi (2012) used the EKC to track the impact of renewable energy sources on CO_2 emissions for G-20. They confirm inverse relationship of CO_2 and GRP in G-20 and that renewables contribute significantly to CO_2 emissions reduction.

Some researchers have drawn attention to problem of CO_2 emissions in Ukraine. Kubatko (2008) use EKC model and cross-region data for Ukraine to investigate pollution dependence from country development. Except the main independent variable – GDP per capita, the author has also used variables such as average annual temperature, percentage of wind, precipitation, and smog days in each city. As the dependent variable several types of pollution were used – Carbone dioxide, nitrogen dioxide, sulfur dioxide and dust. The author concluded that there is no square relationship between income and emissions. However, there is an inverse square relationship. In this regard, the key finding for 2008 was that pollution would continue to grow. In our opinion, after ten years, it makes sense to test the theory again.

There are also several papers that investigate the relationship between GDP and CO_2 emissions using cross-country data, including Ukraine. Kubatko et al. (2018) are present model for 8 CEE countries similar for Ukraine in terms of economic development. They come to an inference that as the richer economy becomes the more CO_2 emissions it contributes. An important remark is that the economy structure (% of industry) has a significant influence on GHG emissions. And it should be taken into account during the variables selection process. Koilo (2019) represent the model of EKC for Eastern Europe and Central Asia countries which include Ukraine. The key factor is the quadratic relationship of CO_2 emissions and GDP per capita. As in the Kubatko study, the attention to the structure of the economy, especially to the transformation of the selected countries' economy from agro to industry. As a result, quadratic relationship appears significant and sufficient. Therefore, there is reason to assume that for Ukraine, the shape of the EKC is squared. Thus, we are going to try to investigate it in our paper.

Chapter 3

METHODOLOGY

3.1 Theoretical Framework

Environment Kuznets Hypothesis was introduced in 1955 as a U-shaped relationship between pollution and income per capita. A standard form of EKC looks like Cobb-Duglas production function with an output – pollution (Grossman and Kruger 1991):

$$Pollution/population = GDP/population_{\alpha t} \times GDP/population\ b_t * u_t \quad (1)$$

where

t – year indicator

αi b – elasticities parameters that shows contribution of each factor to total pollution.

As basic model we used the model for the cross-country data, because of a small study of the EKC hypothesis within one country. We adopt this model to region-level data. The model we going to estimate to test Environment Kuznets Curve hypothesis is

$$Y_{it} = \beta_0 + \beta_1 X_{it} + \beta_2 (X_{it})^2 + \beta_3 Z_{1it} + \beta_4 Z_{2it} + \beta_5 Z_{3it} + u_i \quad (2)$$

where,

i – is region indicator, t is time indicator;

Y – dependent variable which denotes environmental pollution or in our case is CO_2 emissions per capita in particular region in particular year;

X – variable of interest – growth of economy, which represented by GRP per capita in particular region in particular time;

Z1… Z3 – other variables that explain CO_2 emissions variations;

u_{it} is the error term.

3.2 Econometric model

A good guideline for model specification selection is a literature survey provided by Shahbaz et al. (2018). The paper has collected a large number of research reviews for different countries and data types for the period 1992 - 2017. We focused on the cross-country data type. Also, the priority was the papers that cover the regions closest to Ukraine - Europe, EMEA, CEE, and the most relevant papers. Most often, FMOLS and a fixed-effect model are used to determine the EKC shape. But many other specifications are used to compare effects, including Pooled OLS, Panel Regression, DOLS.

Our benchmark paper use fixed effect model and we agree with this approach. First, because we have dataset for Ukraine by regions that form a complete population. Second, if we aggregate the data by region, then the data does not vary much over time, which means we have not random effect, this is a natural difference between regions (Table 1). To confirm last assumptions we made a Bera, Sosa-Escudero and Yoon locally robust test (one-sided) and obtain that we don't have a random effects.

Table 1. Data aggregated by regions, Ukraine 2006-2019

Year	CO2C	GRPC	INDC	Urban
2006	70 418	220 066	214 687	104 665
2007	71 723	286 727	281 012	105 690
2008	70 230	382 589	358 968	105 598
2009	60 357	372 393	319 866	95 359
2010	64 555	444 060	417 307	104 110
2011	79 253	543 631	524 717	106 903
2012	78 346	603 178	551 427	109 303
2013	78 982	623 436	540 935	107 525
2014	70 366	694 432	595 808	105 926
2015	60 895	891 536	770 904	98 260
2016	65 117	1 062 163	942 788	97 395
2017	58 163	1 340 679	1 160 085	98 235
2018	59 758	1 613 484	1 352 774	100 302
2019	57 682	1 819 712	1 339 944	96 777

Source: Author's estimates

One more important moment is define if we need control for time, individual or both effects. Simple analysis for log form variables show a trend which confirm dependence of GRP per capita and CO2 emissions per capita (APPENDIX G). Its seems that dependence more or less constant within one year (notice that colors on graph changed slowly), but highly very between regions. We estimate correlation between GRP and CO2 emissions for each region separately and come that it highly varies – from strong negative to strong positive (Table 2). It confirms assumption about high variation between regions and importance of individual effect control.

Table 2. Correlation between GRP per capita and CO2 emission for regions

Region	Level form	Log form
Kyiv	-86%	-84%
Odesa	-85%	-73%
Kherson	-76%	-78%
Kharkiv	-70%	-69%
Volyn	-65%	-69%
Donetsk	-58%	-62%
Ternopyl	-56%	-73%
Zakarpattya	-56%	-66%
Cherkasy	-41%	-32%
Vinnytsya	-9%	-10%
Chernivtsi	-5%	29%
Zaporizhzhya	0%	-9%
Khmelnitsky	0%	-5%
Chernihiv	7%	26%
Mykolayiv	7%	-5%
Sumy	10%	-11%
Zhytomyr	14%	21%
Dnipropetrovsk	29%	57%
Kirovohrad	32%	18%
Poltava	53%	69%
Lviv	68%	78%
Luhansk	69%	85%
Rivne	76%	71%
Ivano-Frankivsk	77%	74%

We prepare studentized Breusch-Pagan test which confirm heteroscedasticity. However, from graphical analysis (APPENDIX E) we come that we don't have heteroscedasticity.

Searching for unobserved individual effect we provide Wooldridge's test for unobserved individual effects and it confirm presence of such effect in population. And this is a grounds to use fixed effect model controlling for individual effect.

We are going to estimate a model using "within" estimator controlling for individual and time effect:

$$Ln(CO2C_{it}) = \beta_0 + Yt + \beta_1 ln(GRPC_{it}) + \beta_2 \, ln((GRPC_{it})^2) + \beta_3 ln(INDC_{it}) + \beta_4 \, ln(URBUN_{it}) + \beta 5 \, ln(INVC_{it}) + \beta_5 \, ln(POWERC_{it}) + u_{it} \qquad (3)$$

where βn – percentage amount of each factor contribution to CO2 emission growth; αi – parameter that represent difference between countries/regions, but model assume that even with the different amounts of emissions and GDP, elasticity still should be the same in all countries/regions. t – parameter that controls for time effect and assume that stochastic shocks are the same for all countries.

Another estimation issue relates to possible serial correlation. Indeed, there is high probability that we have serial correlation in data. Mainly it is due the fact that we have dataset for regions across single country and probably economic, political and other macroeconomic shocks will affect each region at some moment of time. We provide Durbin-Watson test for serial correlation in panel models and Wooldridge's first-difference test for serial correlation in panels. We reject null hypothesis in both cases and confirm alternative - serial correlation in idiosyncratic errors and in differenced errors.

We should also account for cross-sectional dependence, as regions could influence development of each other and downward of one region could cause slowdown in other and otherwise. We perform Pesaran CD test in panels and come to conclusion we reject the absence of cross-sectional dependence on 95% confidence level, but we still can't reject it on 90% confidence level.

In order to control for serial correlation we will also try to estimate model with FGLS estimator. It includes two-step procedure: first it estimates fixed effect OLS and second it use residuals to estimate covariance matrix in error terms. So, we expect to obtain robust results against cross-sectional correlation and heteroscedasticity.

Chapter 4

DATA

4.1. Data sources and variables selection

We use the data from State Statistic Service. Table 3 presents all the variables that can potentially be useful for further model estimation. The selection of data based on a detailed literature review. Author on its own creates dataset. It contains 14 variables and cover period from 2006 to 2019 for 24 Ukrainian regions. Total amount of observations is 336.

In the model, the dependent variables are CO2 emissions per capita is used as a proxy for GHG emissions, and GRP per capita, as an indicator of a country's economic growth. The rest of the variables should explain as much variation in the model as possible.

Based on literature review we take into account economy structure. Since the main source of emissions is industry, we decided to add a variable that explain a level of industrialization of the economy. The best proxy could be the industry value added, however we also consider the index of industry GDP growth. Generation is another major source of pollution. We have included in the model data on the volume of generation per person in kilowatt hours[1]. Another factor influencing the growth of CO2 emissions is urbanization. Most of the

[1] As State Statistic Service of Ukraine is not published data for Zhytomyr electricity generation for 2016 and 2017, we calculate this data based on electricity supply assuming that power plants additional needs of power for internal consumption is around 5% of supply

pollution comes from cities rather than from rural areas. To do this, the dataset includes the quantity of urban population.

Table 3. Variables description

Variables names	Description	Expected effect
CO2C	Co2 emissions per capita, ton of CO2/capita	Dependent variable
GRPC	Gross regional product, UAH	+
SGRPC	Squared gross regional product, UAH	-
IND	Indices of industrial production, %	+
URBPOP	Urabun population, person	+
INVEST	Capital investments on environmental protection, in current prices, thud. UAH	-
INVESTC	Capital investments on environmental protection, in current prices, thud. UAH per capita	-
QPOWER	Electricity production, GWh	+
POWERC	Electricity production per capita, kWh/capita	+
INDC	Volume of industrial products, UAH per capita	+

Source: Author's estimates

We estimate the correlation between all variables that could influence GHG emissions. We have identify a high correlation of GRP per capita which is expected, as large share of Ukrainian GDP creates by industry sector. It could potentially create a multicollinearity in regression model. All other variables that we are going to use in model have weak correlation between each other.

Table 4. Correlation matrix between chosen variable 2006-2019

Variable name	CO2C	GRPC	IND	INDC	URBPOP	INVESTC	POWERC
CO2C	1,00	0,10	-0,12	0,42	0,84	0,31	0,18
GRPC	0,10	1,00	0,08	0,83	0,15	0,40	0,03
IND	-0,12	0,08	1,00	0,02	-0,20	0,03	0,00
INDC	0,42	0,83	0,02	1,00	0,42	0,41	0,20
URBPOP	0,84	0,15	-0,20	0,42	1,00	0,31	0,03
INVESTC	0,31	0,40	0,03	0,41	0,31	1,00	0,05
POWERC	0,18	0,03	0,00	0,20	0,03	0,05	1,00

Source: own estimates

We also decide to present visually the relationship between the key variable of interest – GDP per capita and dependent variable – CO2 per capita. In Figure 4 we could clearly see the difference during the time.

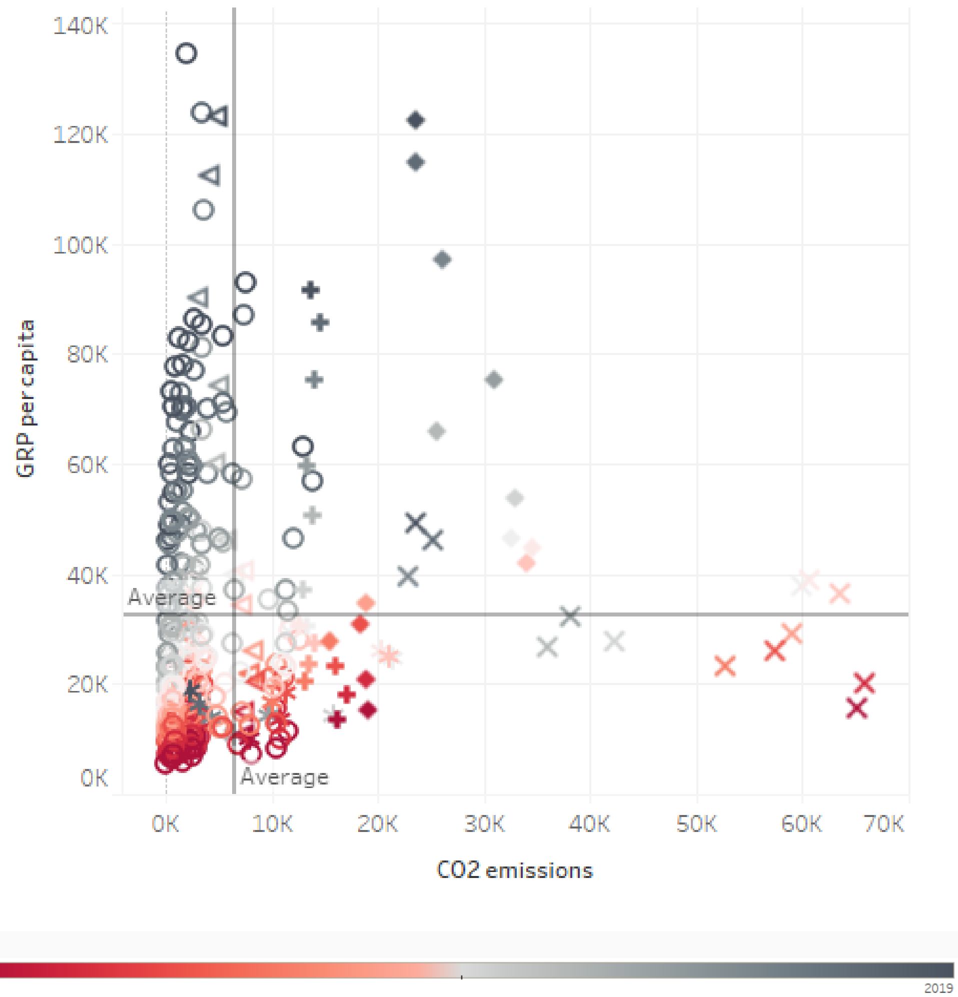

Figure 4. Correlation between CO2 emissions and GRP per capita
Source: own estimates based on SSSU data
Note: X – Donetska oblast; Ӽ - Luganska oblast; Δ - Kyivska oblast; ○ – other regions;

Two largest outliers in Figure 4 are connected with Donetsk. This is 2011-2013. It can be assumed that the distribution would have been approximately the same had it not started the Armed Conflict in Donbas in 2014. But what is interesting is that the red dots are concentrated in bottom part of graph, their concentration is not so dense and is gradually distributed from left to the right side. In turn, the dark blue dots are more concentrated in the upper left corner. This suggests that GDP has grown, but emissions have not grown as much as GDP, which indicates the potential presence of a quadratic relationship between those two variables. Importantly, we have highlighted Donetsk and Luhansk in order to avoid visual confusion associated with the drop in emissions after 2014.

If we look at the second factor – electricity generation, we can see that the generation per capita decreases over time and CO_2 emissions decrease respectively (Figure 5).

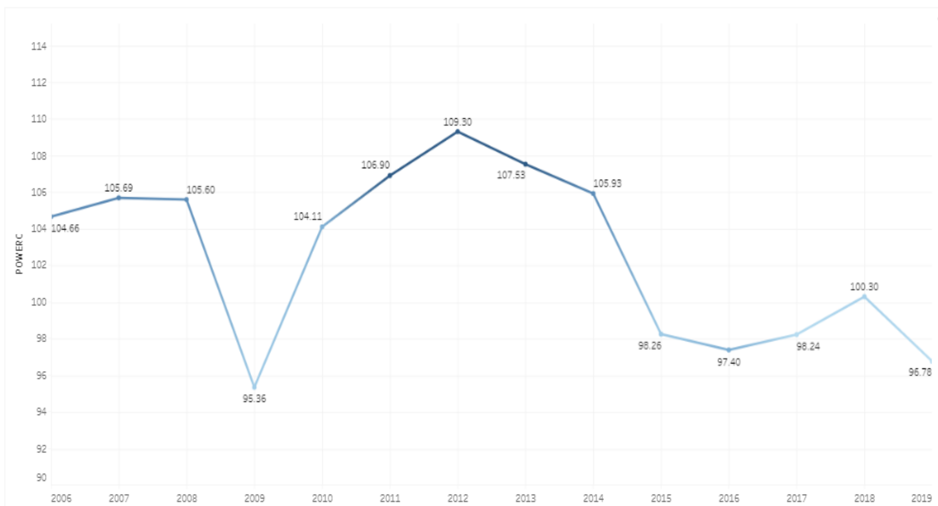

Figure 5. Correlation between CO2 emissions per capita and GRP per capita
Source: own estimates based on SSSU data

In general, the decrease in generation volumes is associated with the beginning of the Armed conflict in Donbas, which can be seen on the Figure 6. There are still a large number of power plants on the territory of Donetsk region. Considering that the region is a key producer of coal, which is a raw material for thermal power plants, thermal generation prevails here. However, this type of generation is a major pollutant with a high emission factor.

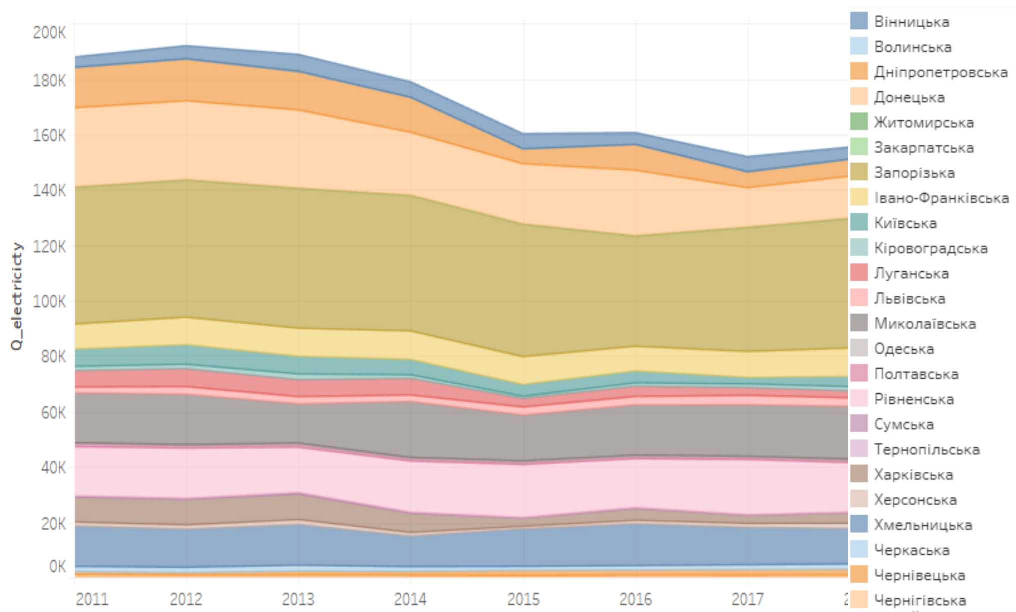

Figure 6. CO_2 emissions by 24 Ukrainian regions during 2011-2019

Source: own estimates based on SSSU data

4.2. Data description

Description statistic of variables that were selected for the following estimation presented in table 5.

Table 5. Descriptive statistics

	CO2C	GRPC	IND	URBPOP	INVESTC	INDC	POWERC
Mean	2 815	32	28	1 123	0,1	35	4 274
Sd	3 069	24	27	844	0,4	29	6 462
Median	1 570	24	19	751	0,0	26	1 498
Max	14 384	134	159	4 144	4,8	159	28 974
Min	26	6	2	374	0,0	4	8

Source: own estimates

Table 5 and figure 7 show that the distribution of most variables is right-skewed. This means that to avoid bias in the estimates, the data needs to be transformed and logarithm transformation best suit for this. A significant deviation in capital investment in green technologies is also striking. This is an outlier that related to double growth of investments in green technologies in Kiev, in 2016. Capital investment grew up to UAH 8 million, and then returned to UAH 4 million and continued to fall slowly. Probably, we are not interested in amount of investment made in particular year, because capital investment should have lagged effect on emissions, it is better to take a growth rate of investment.

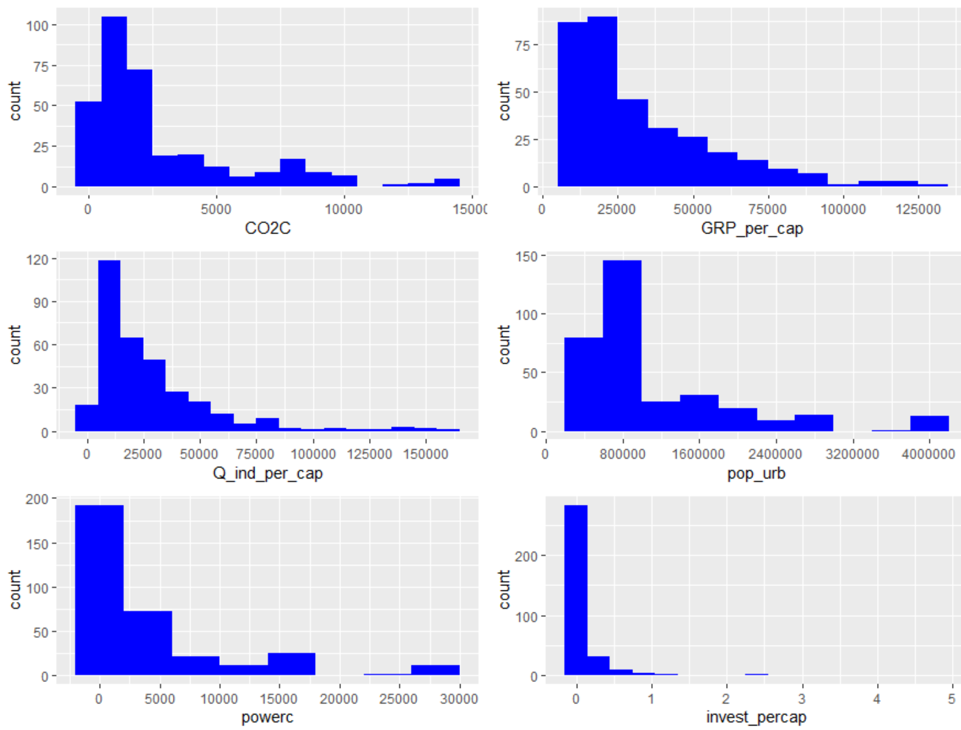

Figure 7. Key variables distribution
Source: own estimates based on SSSU data

Chapter 5

ESTIMATION RESULTS

Using the methodology described in Section 3 author estimated three fixed effect models controlling for both individual and time effect testing for the following relationship between emissions and income:

1) Squared relationship (classic EKC proposed);
2) Cubic relationship (applicable for many developing and emerging countries);
3) Linear relationship.

Table 6. Estimation results

CO2C	Squared relationship	Cubic relationship	Linear relationship
lnGRPC	-2.068**	0.259	-8.654
	(0.939)	(0.199)	(12.708)
slnGRPC	0.110**	0.751	
	(0.043)	(1.234)	
clnGRPC		-0.021	
		(0.040)	
lnINDC	0.370**	0.307**	0.374**
	(0.145)	(0.144)	(0.145)
lnPOWERC	0.241***	0.222***	0.232***
	(0.058)	(0.059)	(0.061)
lnURBPOP	-3.206***	-4.142***	-3.028**
	(1.149)	(1.097)	(1.200)
lnINVESTC	-0.015	0.002	-0.018
	(0.021)	(0.020)	(0.021)
Observations	336	336	366
R2	0.244	0.228	0.245

Note: *p<0.1; **p<0.05; ***p<0.01

We are fail to confirm the hypothesis of a square relationship between CO2 pollution and the income growth of Ukraine. However, we found a statistically significant U-shaped relationship, means Ukraine is not yet on the stable path and GHG emissions still increase with countries income growth. In general, we can accept the Kuznetsov Model as a specification and benchmark for tracking the effects of different parameters - the development of industry, energy, investments in the environment, population changes. Our conclusion also consistent with Soberon and D'Hers (2020), they are also reject the hypothesis for for Denmark, France, Ireland, Italy, Turkey and come to similar results. Authors explain such effect by a large agricultural sector dominated in country, which doesn't have such a large effect on environment (for Ukraine is around 12% of CO2) and quick transition to industry which creates higher income growth and corresponding growth of GHG. It is also could be implemented for Ukraine as it has a share of agriculture in GDP around 10% and 45% of total export in 2020.

Based on estimation results, we can also identify turning point and use the model to estimate the effects of the underlying variables. The turning point is 12 578 UAH, which correspond to the GRP per capita level up to 2009. Since 2009, no region, except the Luhansk in 2010, had such a low GRP. After this point was turned out the CO2 emissions start to depend from GRP per capita exponentially.

Very important variables for GHG emission analysis is industry growth and power generation. Estimated effects for these variables are robust and represent expected signs. Considering that according to the Ministry of Energy of Ukraine, electricity production in 2020 decreased by 3.3% (by 5 billion 157.3 million kWh) compared to 2019, which is around 123 kWh per person, we could estimate the effect of such reduction for 2020. Keeping all other factors constant, the reduction in electricity generation in 2020 by 3.3% led to a decrease in CO_2 emissions per capita by 0.24%. Taking into account that total amount of CO_2 emissions in Ukraine in 2019 was 2.89 ton per capita. We receive that decay in power generation in 2020 reduce CO_2 emissions approximately by 6.93 kg per capita caused by power generation reduction.

Urban population share doesn't show expected sign. This can probably be caused by a large outflow of human capital from Ukraine every year. People spend most of their lives abroad, but large share of them counts in statistic among the population of Ukraine. As a result, the model shows that with an increase of 1% of the urban population, pollution is reduced by 3.2%. We believe it is not objective to interpret this result as faithful, despite the fact that it is statistically significant at a reliability level of less than 0.01%. However, we have found a similar conclusion in reviewed literature for Canada, Denmark, Finland (Soberon and D'Hers 2020). The variable that was used as a proxy to reflect the investment in reducing CO_2 emissions does not describe the variation well enough, but in the face of limited data, this is the best we could use.

Another important observation is the effect of industry gross product growth. It is obvious that in Ukraine the industry is one of the main pollutants. Eastern and Central regions, mainly Zaporizhzhia, Dnipropetrovsk, Kryvyi Rik, Kharkiv are regions with a high industry intensity, they are also the main pollutants in the country. The model shows that keeping all other variables constant with an increase in industry GDP by 1%, CO_2 emissions increase by 0.37%. Let's take a closer look at this. If we take into account that average year-to-year growth in industry gross product per capita is ~ 16%, but sometimes its rich even 30% we could expect sufficiently higher effect (Figure 9).

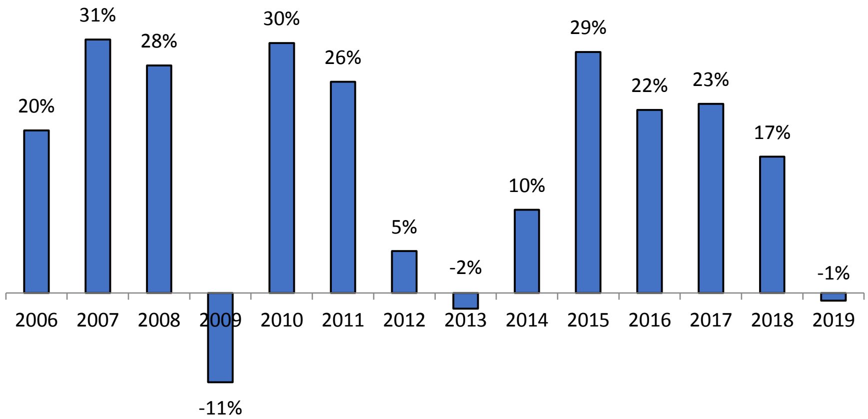

Figure 9. Gross industry product changes during 2010-2019
Source: own estimates based on SSSU data

More interesting analysis appear by region (APPENDIX H). We see how much the effect differs across regions. Moreover, the difference is not only in the strength of the influence of a particular region on CO2 emissions, but even in signs. As expected, Zaporizhzhya, Luhansk, Kharkov, Donetsk, Dnepropetrovsk, Odessa have the most significant positive influence. This is the most industrial and energy-intensive regions. However, despite the fact that one of the largest pollutants is Kyiv, it has significant positive but twice lower effect. It is could be explained that most of the investments in the environment are concentrated in Kyiv. Moreover, one of the significant pollution factors in the Kyiv region is transport, which is not included in our model. Interesting that almost all Western region (Volyn, Zakarpatska oblast, Ternopil, Rivne, Chernivtsi) has a negative effect. (Figure 10).

Figure 10. Difference in CO2 emissions effect contributed by each Ukrainian regions
Source: own estimates based on SSSU data

Chapter 6

CONCLUSIONS AND POLICY RECOMENDATIONS

Unfortunately we are fail to prove hypothesis that GHG relationship to country income in Ukraine has an inverted U-shaped form, means that currently Ukraine is not on the sustainable path. From a macroeconomic point of view, it is not strange that we have come to such results. The two largest pollutants in the world are energy and industry. The industry represents a significant share in Ukraine's GDP, with a huge part of it being mining, metallurgy and other energy-intensive spheres. In the power generation sector, since 2015, have begun shifts towards green energy, but the regulation of green technologies in Ukraine is still at a development level, not even in transition. In the merit order, renewable energy sources are far from being in the first place in generation, but are inferior to a large pollutant - coal. However, one should not forget that a significant share of generation in Ukraine is made up of the atom, which by its nature does not belong to air pollutants.

Of course, companies are making installations to reduce emissions, but so far there are not enough incentives in Ukraine to force the industry and power sectors to abandon emission-intensive production. The CO_2 tax is 10 UAH now (around $ 0,30), which is the lowest tax in Europe. For comparison, carbon tax rates in developed countries range from $ 1 / CO_2e (Poland) up to $ 139 / CO_2e (Sweden). According to a Report of the High-Level Commission on Carbon Prices (2017), there was calculated that in order to achieve the goals of the Paris Agreement, the carbon tax rate should be $ 40-80 / tCO_2 by 2020 and $ 50-100 / tCO_2 by 2030. Today there are active discussions touching the rate countries should implement. For example, the IMF recently proposed that in order to decrease emissions more than 100%, that committed by countries under the Paris Agreement, G20 countries should introduce a tax on CO_2 emissions with a gradual increase to $ 75 per ton until 2030, and the developing countries - up to $ 25 per ton.

The second main instrument is emissions trading systems. Emissions trading programs are presented in the countries all around the World as EU ETS (Europe), RGGI (America), Korean ETS and 8 pilots (China), Australian ETS. In most countries, such programs are still not very effective and are rather supports limiting the growth of emissions (since about 100% of quotas are distributed to agents free and there is no trade). However, in the EU, this topic indeed forces economy to transform the industry and energy sectors. Futures prices on CO_2 jumped to 50 Euros per ton at the May 2021. This makes the operation of the coal industry and the generation of energy from coal inefficient. As a result, the sector is shrinking sharply and energy sector transform to less pollution intensive. Another way to reduce CO_2 emissions is by switching to renewable energy. European countries continue to found out new sources to make energy as "green" as it is possible. EU Agencies provide specific grants and other incentives for research in the alternative energy field.

One more important problem is that revenue collected from CO_2 tax in Ukraine go to the general treasury and have no specific purpose. This issue has recently been raised for consideration by the Department of Energy. They proposed to create a Decarbonization Fund. The Fund's money is planned to be directed exclusively to combat with CO_2 emissions. This is a small step towards sustainability, but there are still many difficult steps ahead. For the Fund to work, it is necessary to have precise and well-reasoned legislation. Money distribution also should be justified. The Ministry's strategy should clearly define the priority sectors of support to be sure that the budget money will not be wasted. The Fund plans to raise the tax rate to 30 UAH/ton. In

2019, the budget received 0.9 UAH bln from the CO_2 tax (for comparison, in 2018 - 50 UAH mln). With an increased rate, the Fund's expectations are 2.9 UAH bln, 50% of which is planned to be spent on projects to reduce emissions.

We show in our analysis that CO_2 emissions as well as regions development is very largely. This suggests that the government must act in the context of at least partial decentralization in the issue of charges for CO_2 emissions. After all, the largest polluted regions are most in need of investments to improve the quality of the region ecology. Our proxy for environmental investments is not indicative enough, as it only takes into account capital investments made by enterprises. But in general, the ecology of the region can be influenced by both investments in purification systems and the replacement of public transport with electric cars, modernization of the transport system, landscaping or "green" zones where public places operate due to alternative energy, for example, parks with solar lighting and other environmental programs to be carried out locally, taking into account local problems.

Therefore, in general, our analysis confirms that in Ukraine the policy aimed at reducing emissions into the environment is not effective, while the European Union is actively developing tools to combat them. This is both a tax on emissions and the EU ETS. Building close relations with the European Union in any case will entail the obligation of Ukraine to accept the cap and trade systems and raise the tax. Moreover, from 2023, the European Union will introduce CBAM - a duty on the import of energy intensive products and electricity into the EU. As the result, Ukrainian producers - large exporters one way or another will have to improve technologies in order to reduce the size of the duty.

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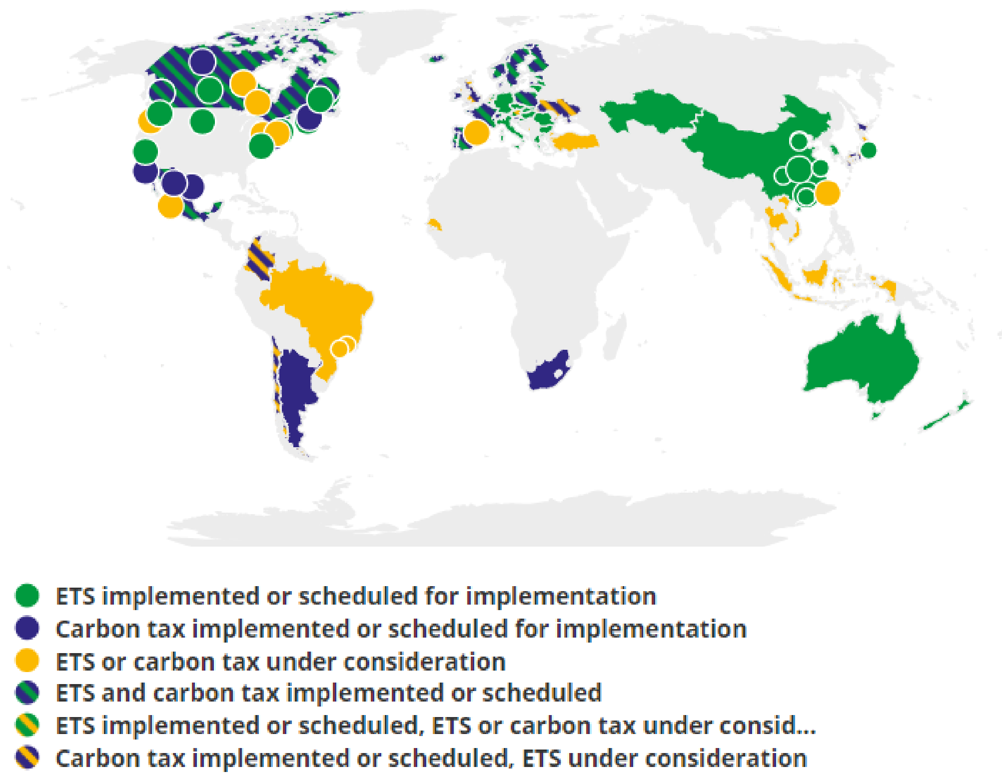
APPENDIX A



Source: World Bank: https://carbonpricingdashboard.worldbank.org/

APPENDIX B

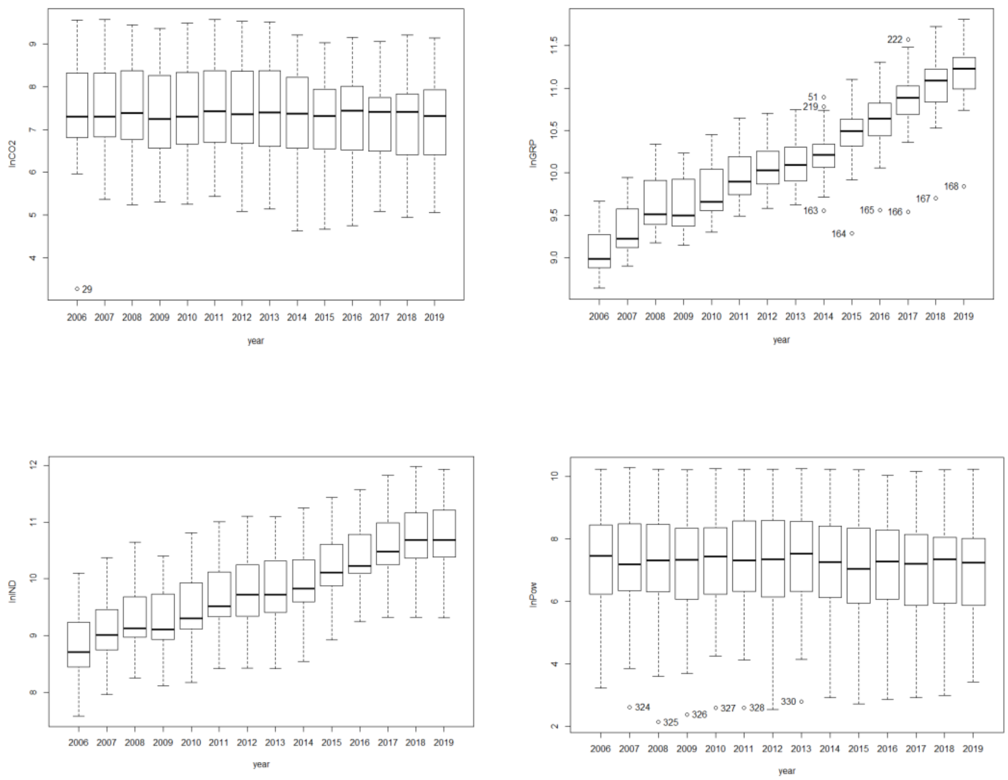


Figure B. Visual data analysis

APPENDIX C

Test	H1	p-value
Wooldridge's test for unobserved individual effects	unobserved individual effects	0.01625
F test for individual effects	significant effects	<0.001
Bera, Sosa-Escudero and Yoon locally robust test (one-sided) - balanced panel	random effects sub AR(1) errors	<0.001
Wooldridge's first-difference test for serial correlation in panels	serial correlation in differenced errors	0.09962
Durbin-Watson test for serial correlation in panel models	Serial correlation in idiosyncratic errors	<0.001
Studentized Breusch-Pagan test	Heteroscedasticity residuals	<0.001
Pesaran CD test for cross-sectional dependence in panels	cross-sectional dependence	0.07798

APPENDIX D

Maddala-Wu Unit-Root Test

Table D.1 Unit-root test for levels

Variable	Chisq	P-value
CO2C	180.88	<0.001
GRPC	48.196	0.4649
INDC	19.792	0.9999
POWERC	175.7	<0.001
INVESTC	73.923	0.009517
URBPOP	82.748	0.001356

*H1: stationarity

Table D.2 Unit-root test for logs

Variable	Chisq	P-value
CO2C	243.36	<0.001
GRPC	9.5688	1
INDC	42.422	0.6999
POWERC	190.37	<0.001
INVESTC	148.53	<0.001
URBPOP	82.003	0.001614

*H1: stationarity

APPENDIX E

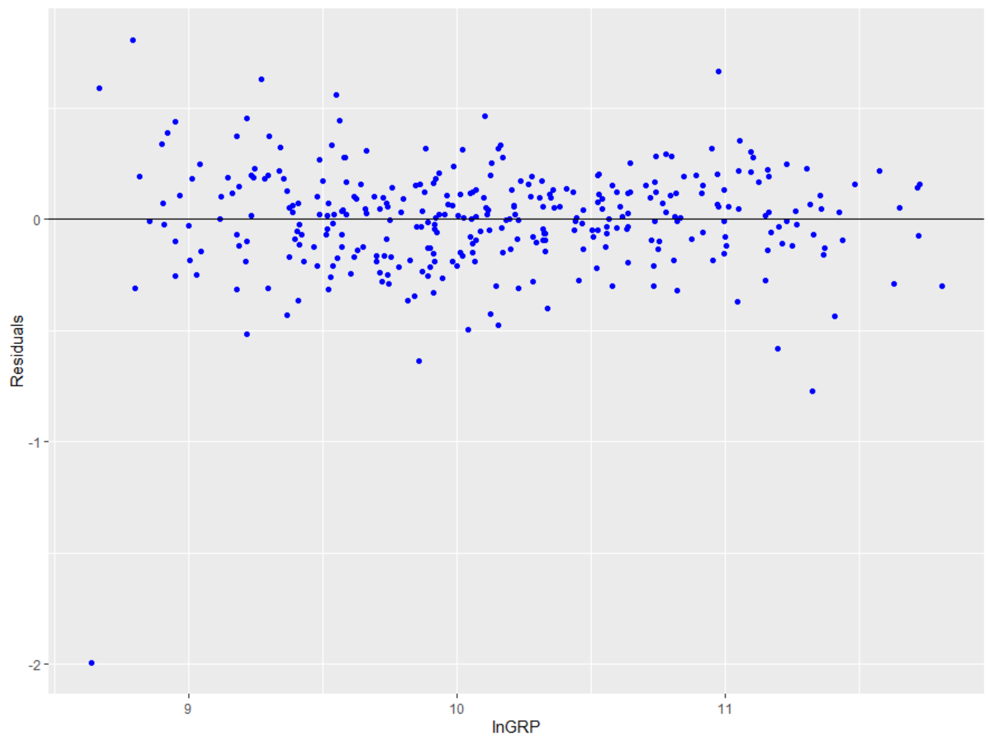


Figure H. Heteroscedasticity test for fixed effect model controlling for time and individual effect

APPENDIX F

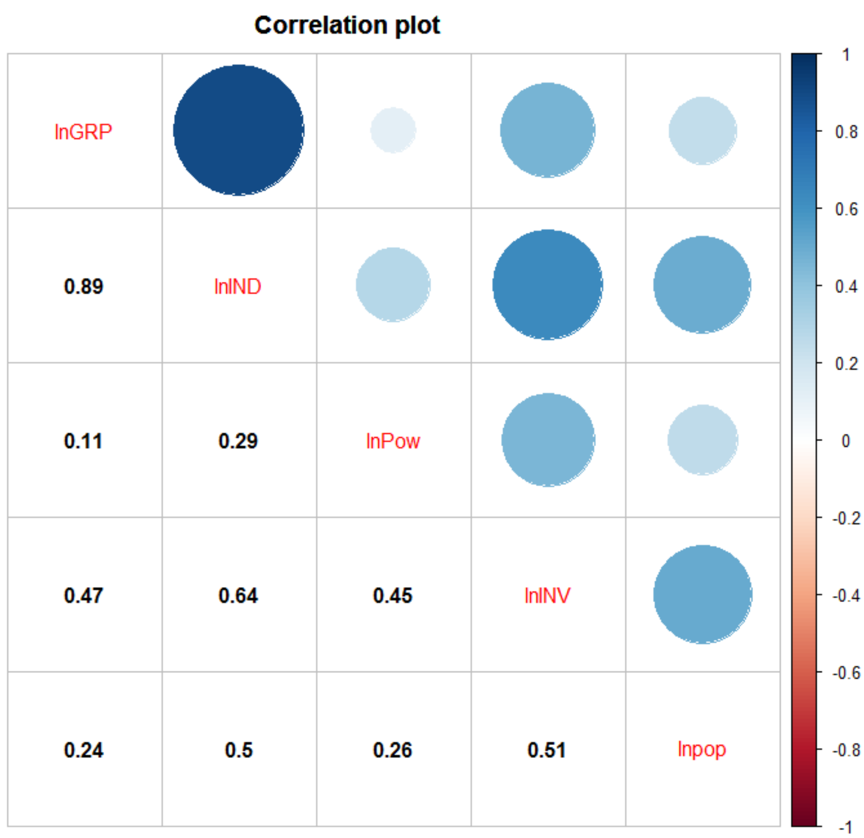


Figure F. Correlation matrix between variables

APPENDIX G

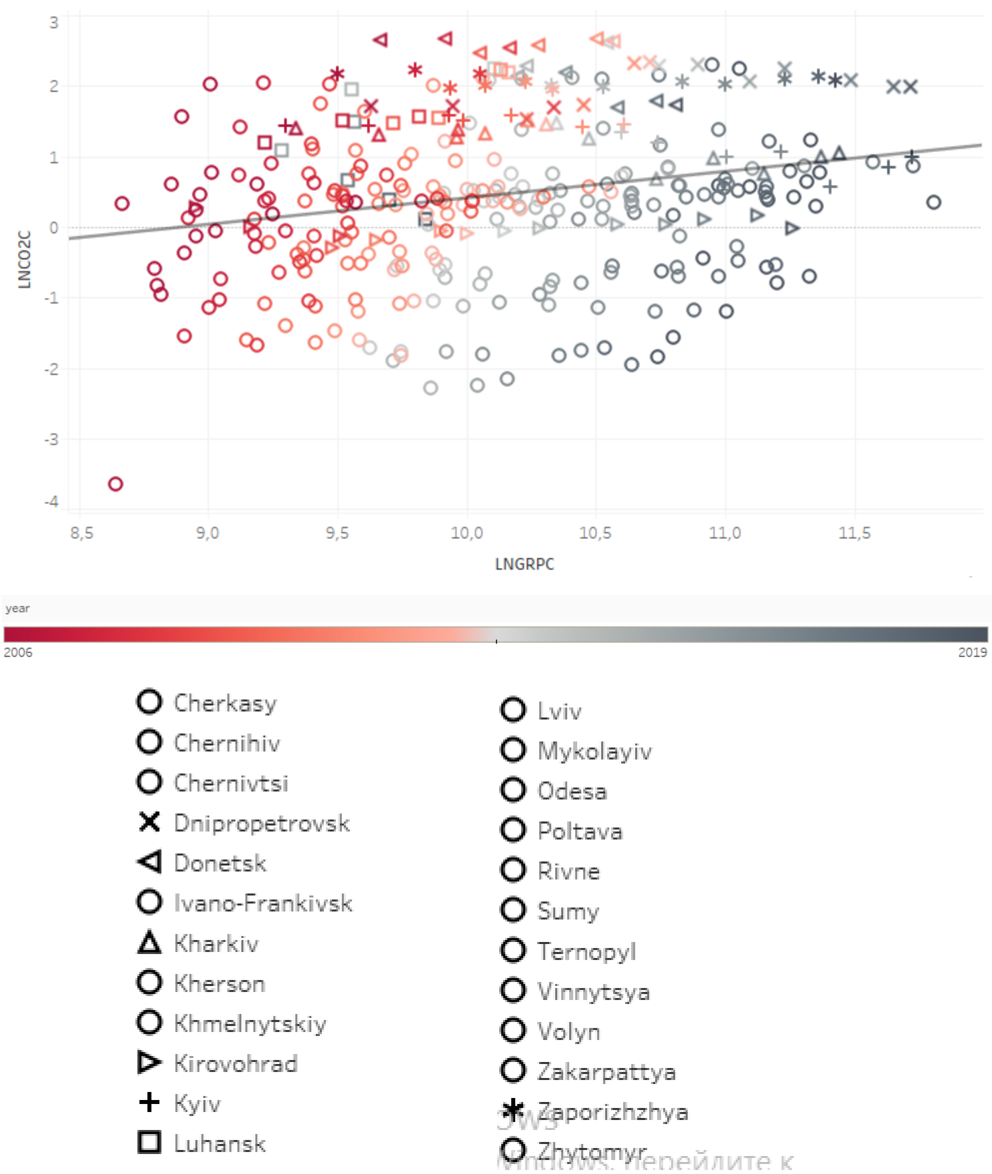


Figure G. logarithmic dependence between GRP per capita and CO2 per capita

APPENDIX H

Table H. Estimation results for fixed-effect estimator controlling for time and individual effect (factor by region)

	lnCO2
lnGRP	-2.068**
	(0.939)
slnGRP	0.110**
	(0.043)
lnIND	0.370**
	(0.145)
lnPow	0.241***
	(0.058)
Lnpop	-3.206***
	(1.149)
lnINV	-0.015
	(0.021)
factor(region)Chernihiv	-0.243**
	(0.117)
factor(region)Chernivtsi	-4.031***
	(0.731)
factor(region)Dnipropetrovsk	4.910***
	(1.535)
factor(region)Donetsk	6.519***
	(1.950)
factor(region)Ivano-Frankivsk	0.485*
	(0.269)
factor(region)Kharkiv	3.804***
	(1.281)
factor(region)Kherson	-1.851***
	(0.149)
factor(region)Khmelnytskiy	-0.444***
	(0.162)
factor(region)Kirovohrad	-1.072***
	(0.202)
factor(region)Kyiv	1.413***
	(0.447)
factor(region)Luhansk	3.923***
	(1.175)

Table H. - Continued

factor(region)Lviv	2.134**
	(0.889)
factor(region)Mykolayiv	-0.408**
	(0.196)
factor(region)Odesa	2.656***
	(0.959)
factor(region)Poltava	0.306
	(0.289)
factor(region)Rivne	-1.915***
	(0.371)
factor(region)Sumy	0.290*
	(0.171)
factor(region)Ternopyl	-1.357***
	(0.480)
factor(region)Vinnytsya	0.849***
	(0.179)
factor(region)Volyn	-1.345***
	(0.351)
factor(region)Zakarpattya	-2.710***
	(0.496)
factor(region)Zaporizhzhya	2.354***
	(0.735)
factor(region)Zhytomyr	0.013
	(0.287)
Observations	336
R2	0.957
Adjusted R2	0.951
F Statistic	225.294*** (df = 29; 293)
Note:	*p<0.1; **p<0.05; ***p<0.01