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The CO_2 Emissions Drivers of Post-Communist Economies in Eastern Europe and Central Asia

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Abstract: CO_2 emissions have become a key environmental contaminant that is responsible for climate change in general and global warming in particular. Two geographical groups of countries that previously belonged to the former bloc of socialist countries are used for the estimations of CO_2 emissions drivers. The research covers such Eastern European countries as Bulgaria, Czech Republic, Hungary, Russian Federation, Poland, Romania, Slovak Republic, and Ukraine and such Central Asian states as Kazakhstan and Uzbekistan during the period 1996–2018. The main goal of the research is to identify common drivers that determine carbon dioxide emissions in selected states. To control for the time fixed effects (like EU membership), random effect model was used for the analysis of the panel data set. Results: It is found that energy efficiency progress reduces per capita CO_2 emissions. Thus, an increase in GDP by 100 USD per one ton of oil equivalent decreases per capita CO_2 emissions by 17–64 kg. That is, the more energy-efficient the economy becomes, the less CO_2 emissions per capita it produces in a group of selected post-communist economies. Unlike energy efficiency, an increase in GDP per capita by 1000 USD raises CO_2 emissions by 260 kg per capita, and the richer the economy becomes, the more CO_2 emissions per capita it generates. The increase in life expectancy by one year leads to an increase in CO_2 emissions per capita by 200−370 kg, with average values of 260 kg per capita. It was found that an increase in agriculture, forestry, and fishing sector share (as a % of GDP) by one percentage point leads to the decrease in CO_2 emissions by 67–200 kg per capita, while an increase in industrial sector share by one percentage point leads to the increase in CO_2 per capita emissions by 37–110 kg. Oil prices and foreign direct investment appeared to be statistically insignificant factors in a group of selected post-communist economies. Conclusions: The main policy recommendation is the promotion of energy efficiency policy and the development of green economy sectors. The other measures are the promotion of a less energy-intensive service sector and the modernization of the industrial sector, which is still characterized by high energy and carbon intensity.

Keywords: CO_2 emissions; energy efficiency; electricity consumption; economic development; decarbonization; environmental economics; institutional changes; post-communist countries

1. Introduction

Environmental aspects of economic growth and development of national economies are closely intertwined with economic and social problems. All of the above-mentioned problems can be addressed using the framework of sustainable development (SD). The SD concept has received significant attention during the last 40 years and is now recognized by the world-leading countries as a means to reach the harmonious co-existence of human society and natural systems. The SD concept involves an analysis of environmental performance in all key processes of international and national development. It turns out that the combustion of fossil fuels for energy production is the largest contemporary source of environmental pollution. It produces carbon dioxide, CO_2, water, and energy. For example, according to [1], "the total annual quantity of water formed from the combustion of hydrocarbon fuels exceeds the water sequestered from the hydrologic cycle through deep well injection in the US, but is substantially less than water volumes generated through evaporation and irrigation each year. However, this water is not currently widely harvested at the site of production. Instead, it is added to the hydrologic cycle, often in a different location from the fuel production site". Therefore, the water formed from the combustion of fossil fuels significantly contributes to climate change and environmental pollution.

Problems of rational energy use have been given considerable attention by politicians and scientists in different countries in the context of sustainable development. Over the past decades, many researchers focused on studying the range of factors that influence CO_2 emissions. Climate change mitigation is gradually gaining momentum in the global economy. However, to ensure that environmental projects are realized with maximum efficiency, it is necessary to clarify the nature, directions, and strength of certain impacts from CO_2 emissions.

Despite a significant number of scientific studies devoted to the study of CO_2 emission drivers, there is no consensus among researchers regarding all determinants of these processes. Many scientists have empirically tested the impact of greenhouse gas (GHG) emissions on national economies as well as a proper relationship between various factors that cause those emissions. According to their findings, economic growth [1–11], energy prices [4,12–16], electricity consumption [2,3,8,9,11,17–20] energy efficiency [11,21–23], institutional reforms and structural changes [16,21–27], investment and trade openness [6,8,9,11,19,20,28–30], and population dynamics and urbanization [2,9,19,23,29,31,32] are recognized as the most important factors influencing CO_2 emissions. These research results are based on empirical studies conducted in various countries over different periods of time.

A large number of papers treat the analysis of factors that cause CO_2 emissions in emerging economies, particularly in post-communist states [3,6,8,9,16,17,20,23,27,29,30,33–39]. Decarbonization and greening of national economies became urgent issues for post-communist states, which have historically inherited highly energy-intensive economies. In this regard, the identification of factors associated with CO_2 emissions and policy recommendations for environmental improvement is of great importance. However, the research outcomes of empirical studies are quite different, which complicates the formation of recommendations for local environmental policies.

This study focuses on the main drivers of carbon dioxide emissions using a panel of 10 post-communist states in Eastern Europe as well as Central Asia during 1996–2018. A particular feature of the research is the analysis of three different geographical groups of countries (as defined by the United Nations [40]), which belonged to the former bloc of socialist countries. These groups include countries of Eastern European states (Bulgaria, Czech Republic, Hungary, Russian Federation, Poland, Romania, Slovak Republic, and Ukrainian territory as treated by international law) and Central Asian countries (Kazakhstan and Uzbekistan). Over our study period, some of the analyzed states have made great progress in terms of environmental sustainability through the reduction of CO_2 emissions per capita (for example, Slovak Republic) or just preserved their positions (like Hungary, Romania, Ukraine and Uzbekistan). The other states like Kazakhstan and the Russian Federation were not very successful in the reduction of their CO_2 emissions over our study period. The contribution of the research is the key drivers' identification that influenced CO_2 per capita emissions in the countries mentioned above, as well as the formulation of policy recommendations for efficient energy use and environmental improvements. To achieve the comparability of results, we have chosen the 1996–2018 period. The chosen period is also characterized by data availability provided by the World Bank and the European Bank for Reconstruction and Development (EBRD).

The main hypotheses tested in this study can be specified as follows:

- CO_2 emissions in post-communist countries depend on economic progress, which means better economic achievements are related to higher per capita levels of CO_2 emissions.
- An increase in natural gas and crude oil prices improves energy efficiency, and therefore reduces per capita CO_2 emissions.
- Foreign direct investment (FDI) has an ambiguous influence: (a) if foreign direct investment in post-communist countries is associated with the so-called "pollution haven industries", then such investment increases the level of pollution and per capita CO_2 emissions levels; however, (b) if the foreign direct investment is associated with financial or service sphere, then such investment decreases CO_2 emissions per capita.
- The structural changes in the gross domestic product (GDP) should have a significant influence on CO_2 emission per capita. It expected that an increase in industry sector share (including construction) as % of GDP should increase the CO_2 emission per capita, while the increase in cleaner industries and service sector shares should reduce the CO_2 emission per capita.
- Energy efficiency improvements are negatively correlated with per capita levels of CO_2 emissions indicators.
- Higher values of population growth rates are correlated with higher rates of CO_2 per capita emissions.
- Institutional changes, such as related to European Union (EU) accession, increase energy efficiency, and reduce per capita levels of CO_2 emissions.

The rest of the paper has the following structure. Section 2 critically reviews recent literature with regard to the existing factors that influence CO_2 emissions in national economies. Section 3 presents the methodological contribution to our analysis and describes data sources. Section 4 discusses the results of our empirical estimation. Section 5 summarizes our findings and policy implications.

2. Literature Review

As proclaimed in Agenda 21 [41], sustainable development goals' achievements involve a systematic reduction of the carbon intensity of national economies. The latter includes measures on rationalizing energy consumption, declining fossil fuel utilization, switching to renewable energy, activating macro- and microeconomic mechanisms of CO_2 reduction. A basic measure for assessing the degree of national economies decarbonization is the CO_2 emissions indicator, which is applied in a number of international environmental documents. For instance, the United Nations uses variations of this indicator to evaluate the current state and formation of global plans on decreasing the carbon intensity of countries and regions [42]. The Intergovernmental Panel on Climate Change and the United Nations Environment Programme (UNEP) use indicators related to CO_2 emissions and carbon intensity in reports [43] as well. Organization for Economic Cooperation and Development (OECD) analyses energy issues in close connection with CO_2 problems that are reflected in the titles and contents of relevant reports (for example, [44]). The International Energy Agency (IEA) considers carbon intensity as one of the key indicators to measure the efficiency of economic and energy development and includes it to annual documents such as IEA World Energy Balances, reports on World Energy Statistics, and others [45]. Various carbon intensity indicators are included in internationally recognized economic and environmental ratings and form a separate international and regional ranking (for example, ET Carbon Rankings, Global Carbon Atlas, Ranking Global Warming Contributions by Country) [46–49].

Along with documents and reports of international organizations, the reason for including carbon intensity index in international rankings is a number of scientific studies that confirm a close relationship between energy development, economic growth, and the dynamics of CO_2 emissions. Given the importance of CO_2 intensity tracking to prevent global climate change, a significant number of papers are devoted to studying factors affecting the CO_2 emissions volume.

Several studies (e.g., [7,10,50,51]) use decoupling and decomposition methods to estimate CO_2 emissions in national and sectoral economies such as industry, power, and transportation sectors. The authors conclude that fast economic development is the key driver of increasing CO_2 emission for all considered countries.

The report [52] is based on the top 25 emitting countries data for 1990−2002 and suggests that CO_2 intensity is not related to economy size or a number of inhabitants. A large state may have lower GHG intensity and another way round. Thus, carbon intensity is affected by two fundamental drivers—energy intensity and sort of fuel. The authors concluded that relative indicators of CO_2 efficiency are similar for developing and developed economies. Everett et al. [24] have examined the link between economic growth and environment (concerning CO_2 emissions) as well as the role of eco-policy of renewable and non-renewable resource usage. The authors have proved that the links between economic achievements and environmental quality are at a high level of complexity. They distinguished some CO_2 factors, e.g., the economy's scale and structure. Changes in technological efficiency and innovations reduce environmental impacts while promoting economic growth.

Koengkan et al. (2020) [32] approached the relationship between CO_2 emissions, renewable and non-renewable energy consumption, economic growth, and urbanization in the Southern Common Market in 1980–2014. The authors found the existence of bi-directional causality between the consumption of fossil fuels, economic growth, consumption of renewable energy, and carbon dioxide emissions. In addition, it was revealed that there was a uni-directional relationship between the consumption of renewable energy and urbanization. The research also proves that the countries from Southern Common Market are dependent on fossil fuel consumption and that the urbanization process is highly linked with the consumption of this type of energy. One of the reasons for these dependencies is that these countries have low renewable energy participation in their energy mix.

Grubb et al. (2004) [5] have studied the attitude between CO_2 emissions and economic achievements for different types of economic systems during 1950−2002. The research result is that beyond initial industrialization the relationships between per capita incomes and CO_2 are not vivid. Moreover, there is no strong link between GDP and progressive CO_2 increasing since some developed economies have shown a divergence between GDP and emissions. As of transition economies, they have grown with little or no emissions increase in the "post-transition" period, and resumed economic growth has been accompanied by continued emission reductions.

The ambiguous influence of economic and energy development on CO_2 intransitive economies raises many scientific discussions regarding key drivers of CO_2 emissions in these states. In general, recent publications on carbon emissions drivers in post-communist and developing countries, have determined the following essential factors affecting the dynamics of CO_2 emissions:

- Energy consumption, whose influence was discovered for 15 European states (EU states and candidate states) over the period 1992–2010, 5 countries from the Association of Southeast Asian Nations over the period 1980–2008 [17]; Indonesia over the period 1975–2011 [8]; the Baltic states over the period 1990–2012 [36]; Brazil, China, India, and Indonesia over the period 1970–2012 [2]; 14 Latin American states in 1980–2010 [19]; the United Arab Emirates over the period 1975–2011 [20]; 69 states over the period 1985–2005 [9]; and Saudi Arabia over the period 1971–2010 [3];
- Trade openness, whose influence was discovered for Indonesia over the period 1975–2011 [8]; Malaysia over the period 1970–2008 [6]; 69 states over the period 1985–2005 [9]; and 28 European and Central Asian transitive economies over the period 1990–2012 [27];
- Economic growth, whose influence was discovered for 5 countries from Association of Southeast Asian Nations over the period 1980–2008 [17]; Indonesia over the period 1975–2011 [8]; Brazil, China, India, and Indonesia over the period 1970–2012 [2]; Malaysia over the period 1970–2008 [6]; 69 states over the period 1985–2005 [9]; and Saudi Arabia in 1971–2010 [3];
- Financial development and foreign direct investment, whose influences were discovered for Malaysia over the period 1970–2008 [6]; the United Arab Emirates over the period 1975–2011 [20];

54 states in 1990–2011 [30]; Malaysia over the period 1965–2010 [29]; and Indonesia over the period 1975–2011 [8];

- Population growth, population density, and urbanization, whose influences were discovered for India and Brazil over the period 1970–2012 [2]; 88 developing states in 1975–2005 [31]; 69 states over the period 1985–2005 [9]; Malaysia over the period 1965–2010 [29]; and 5 African states (Egypt, Kenia, Nigeria, DR Congo, and South Africa) over the period 1980–2010 [23];
- Energy efficiency and relevant encouraging energy policy, whose influences were discovered for the Baltic states over the period 1990–2012 [36]; 5 African states (Egypt, Kenia, Nigeria, DR Congo, and South Africa) over the period 1980–2010 [23]; Asia Pacific Economic Cooperation members over the period 2001–2010 [53]; 99 countries over the period 1971–2010 [11]; and 28 European and Central Asian transitive economies over the period 1990–2012 [27];
- Institutional reforms and structural changes, whose influences were discovered for 28 European and Central Asian transition economies over the period 1990–2010 [27]; Brazil over the period 2004–2009 [25]; Malaysia over the period 1971–2013 [16]; and the Baltic states over the period 1990–2012 [36];
- Energy prices, whose influence was discovered for Saudi Arabia over the period 1971–2010 [3]; Malaysia over the period 1971–2013 [16]; and OECD countries [12].

However, while the influence of the abovementioned determinants of CO_2 emissions is confirmed for some countries and periods, it seems to be ambiguous for other states and time series. The reason is that scientists consider mixed groups of national economies that are on different stages of their market transformation. In this regard, the drivers affecting carbon emissions for transitive economies require further research.

3. Methodology

Based on the World Bank and EBRD's data [54,55] on countries' economic and energy development, it is estimated the impact of key drivers for the dynamics of CO_2 emissions per capita for 10 selected post-communist states of Eastern Europe and Central Asia during 1996–2018. To choose a number of states, we considered the following arguments. Firstly, our research focuses on studying tendencies of CO_2 emissions per capita for post-communist states in order to investigate how these countries have coped with environmental problems through processes of their economic transformations and recent reforms. Thus, all selected countries belong to the former communist bloc, which finally ceased to exist with the Soviet Union collapsed in 1991. Secondly, we have considered three different geographical regions, which represent the largest number of post-communist countries, and the majority of them share European values and environmental goals in particular. Thirdly, all selected states were characterized by centrally planned economies with close economic relations for several decades. Therefore, studying long-run environmental transformations in these countries accompanied by radical changes in their economic models allows us to understand the successes of some countries and failures of the other ones in decarbonizing their economies. To see the dynamic changes in CO_2 emissions per capita for 10 selected countries, we have calculated a normal distribution within the two standard deviations (a range from $-\sigma$ to $+2\sigma$ from the mean value) in the sample for 1996 and 2018 (Table 1). Definitely, it is clear that COVID-19 has reduced the economic activity and CO_2 emissions per capita in 2019–2020, but we have limited the study period up to 2018 due to the availability of the majority of indicators. Based on this analysis, it is possible to form policy recommendations to make post-communist and former economies in transition more environmentally friendly.

Table 1. The distribution of the studied countries according to levels of per capita CO_2 emissions in 1996 and 2018.

CO_2 Emissions Per Capita/Year	1996	2018
The lowest levels among the set of the studied countries (range between −2σ and −1σ).	Uzbekistan	Uzbekistan
The low levels among the set of the studied countries (range between − 1σ and mean value).	Bulgaria, Hungary, Romania, Ukraine	Bulgaria, Hungary, Romania, Slovak Republic, Ukraine
The higher levels among the set of the studied countries (range between the mean value and +1σ).	Kazakhstan, Poland, Slovak Republic	Czech Republic, Poland, Russian Federation
The highest levels among the set of the studied countries (range between +1σ and +2σ).	Czech Republic, Russian Federation	Kazakhstan

Calculations based on [54,55].

Fourthly, in order to construct an adequate econometric model, we needed a comprehensive database for each country. Therefore, an important reason for choosing the presented states was the availability of data for each country from the list of post-communist countries in the World Bank and EBRD databases. That is why we have excluded some countries from consideration if their data were missing or incomplete.

The study span period was chosen according to the following arguments:

- The end of the 1980s and early 1990s were marked by the communist bloc collapse in Europe. Those are the countries such as Eastern European countries (Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovak Republic, and Ukraine) and Central Asian states (Kazakhstan, Russian Federation, and Uzbekistan). In addition, in 1993 the Czech-Slovak republic split into two states: The Czech Republic and Slovakia. Therefore, statistics for a number of countries were available only after the 1991−1993 period;
- Till 1991, all analyzed countries had subsidized energy prices because the Soviet Union had large reserves of energy resources and shared them at low prices in exchange for political and economic benefits. After the Eastern bloc of socialist economies and the Soviet Union collapsed, most of the newly-formed states had been in deep economic crisis over the next few years because of the loss of economic ties and transition to world energy prices. Since 1996, a tendency to stabilize economies appeared in the majority of states. It led to economic development and an increase in their CO_2 per capita emissions. For such reason, we did not consider the 1991−1995 period in this study because this period does not reflect steady economic trends and cannot be used to obtain reliable statistical results;
- Comprehensive sets of data for the selected countries and indicators in the World Bank and EBRD databases were found for the period 1996−2018;
- The method of random-effect generalized least squares (GLS) estimations was used for panel data analysis. To identify key factors that should be included in the econometric model, we have analyzed the main determinants that influence per capita CO_2 emissions according to the research results described in the Literature Review section.

The focus on the service sector in the post-industrial era should reduce CO_2 emissions. One more reason is the development of housing and communal services. It was associated with the widespread use of centralized heating systems in cities instead of individual ones, which was applied mainly in rural areas. Compared to individual heating systems, centralized heating systems produce lower CO_2 emissions per capita. It is mostly due to the use of more advanced equipment and technologies.

Thus, because of the multidirectional influence of the urbanization trends on CO_2 emissions, it requires a more detailed empirical analysis.

We have added a dummy variable (1, 0) for states that are linked to the common EU energy policy. EU energy policy dummy is null for all non-EU countries and one for EU members since the year of accession. It is expected that the Common European energy policy and EU 2020 Energy Strategy are strong political reasons for energy efficiency improvements. To be more specific, according to the EU 2020 Energy Strategy [56], the EU has to reduce its GHG to at least 20% of consumption. If the EU dummy variable in terms of common EU energy policy is statistically significant, it means that being within the EU under influence of common EU energy policy is more fruitful for CO_2 emission reduction.

Given the above discussion, the following model was specified:

$$CO_{2it} = F\,(LE_{it};\, Y_{it};\, GDP\_E_{it};\, FA_{it};\, EC_{it};\, AFF_{it};\, IN_{it};\, EXP_{it};MS_{it};\, FDI_{it};\, MT_{it};\, GF_{it};\, EU;\, PG_{it};\, Op_{it};\, T_t) \quad (1)$$

where

LE_{it}—Life expectancy (years at birth);
Y_{it}—GDP per capita (USD);
GDP_E_{it}—GDP per unit of energy (USD per 1 ton);
FA_{it}—Forest area (percentage);
EC_{it}—Energy consumption (toe) per capita;
AFF_{it}—Agriculture, forestry, and fishing (% of GDP);
IN_{it}—Industry (including construction) (% of GDP);
EXP_{it}—Exports of goods and services (% of GDP);
MS_{it}—Mobile cellular subscriptions (per 100 people);
FDI_{it}—FDI per capita;
MT_{it}—Merchandise trade (% of GDP);
GF_{it}—Gross fixed capital formation (% of GDP);
EU—European Union dummy (1 EU member, 0—otherwise);
PG_{it}—Population growth (annual %);
Op_{it}—Oil price ($/bbl); and
T_t—time dummy (annual 1996–2013).

4. Results

Using our random effect model, we have obtained the following results (Table 2). Energy efficiency has a negative influence on per capita CO_2 emissions and it is one of the most important factors to reduce CO_2 pollutions. Thus, an increase in energy efficiency by 100 USD per 1 ton of oil decreases per capita CO_2 emissions by 17−64 kg (Models 1, 3). It means that the more energy-efficient the economy becomes, the less CO_2 emissions per capita it produces. Thus, energy efficiency improvement is a powerful driver for environmentally-friendly changes in post-communist economies. This conclusion is also confirmed by other theoretical and empirical studies [11,27,36].

Table 2. The random-effects generalized least squares (GLS) regression of CO_2 emissions (metric tons per capita) for the panel of 10 countries during 1996−2018.

	CO_2 Emissions (Metric Tons per Capita)			
VARIABLES	***Model 1***	***Model 2***	***Model 3***	***Model 4***
Life Expectancy	0.203 *** (0.0456)	0.374 *** (0.0958)	0.241 *** (0.0450)	0.280 *** (0.0419)
GDP Per Unit of Energy (USD per 1 ton of oil)	−0.00064 ** (0.000247)		−0.000176 ** (6.91×10^{-5})	−0.00021 *** (6.22×10^{-5})
Forest Area (percent)	−0.0842 *** (0.00636)	−0.0296 *** (0.0108)	−0.0903 *** (0.00589)	−0.0919 *** (0.00538)

Table 2. *Cont.*

	CO_2 Emissions (Metric Tons per Capita)			
VARIABLES	***Model 1***	***Model 2***	***Model 3***	***Model 4***
Energy Consumption (toe) per capita	2.849 *** (0.131)		3.019 *** (0.114)	3.073 *** (0.106)
Agriculture, Forestry, and Fishing (% of GDP)	−0.134 *** (0.0182)	−0.202 *** (0.0301)	−0.0999*** (0.0155)	−0.0677 *** (0.0144)
GDP Per Capita (USD)		0.00026 *** (4.80×10^{-5})		
Industry (including construction) (% of GDP)	0.0373 ** (0.0165)	0.110 *** (0.0336)	0.0378 ** (0.0169)	0.0692 *** (0.0161)
Exports of Goods and Services (% of GDP)	−0.0401 *** (0.00421)	−0.0402 *** (0.00878)	−0.0395 *** (0.00405)	
GDP Per Unit of Energy Squared (USD per 1 ton)	5.35×10^{-8} * (2.89×10^{-8})			
Mobile Cellular Subscriptions (per 100 people)	−0.00650 * (0.00379)	0.0210 *** (0.00697)	−0.0105 *** (0.00365)	−0.00839 *** (0.00325)
FDI Per Capita	-1.36×10^{-5} (5.99×10^{-5})	6.90×10^{-6} (0.000124)	-1.33×10^{-5} (6.12×10^{-5})	
Merchandise Trade (% of GDP)				−0.0239 *** (0.00205)
Gross Fixed Capital Formation (% of GDP)				−0.0553 *** (0.0141)
EU	1.082 *** (0.410)	−5.499 *** (0.573)	0.721 (0.377)	1.318 *** (0.355)
Oil Price ($/bbl)	0.00627 (0.0142)	−0.159 *** (0.0252)	0.0124 (0.0143)	0.0127 (0.0130)
Population Growth (annual %)	0.365 *** (0.112)			
Y1997	0.221 (0.370)	0.216 (0.371)	0.212 (0.370)	0.232 (0.340)
Rest Time Year Dummies 1998–2017				
Y2018	−0.142 (0.414)	−0.171 (0.413)	−0.105 (0.411)	−0.216 (0.379)
Constant	−14.17 *** (2.870)	−11.03 * (6.475)	−14.14 *** (2.866)	−17.32 *** (2.665)
Observations	230	230	230	230
Number of Id	10	10	10	10

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Similar to the previous factor, GDP per capita plays a significant role in per capita CO_2 emissions. However, unlike energy efficiency, per capita GDP growth has a positive effect: An increase in GDP per capita by 1000 USD increases CO_2 emissions by 260 kg per capita. The richer the economy becomes, the more CO_2 emissions per capita it generates. All these activities increase energy consumption and cause higher levels of CO_2 emissions. These results are similar to the studies [9,11,27,57].

The increase in life expectancy by one year leads on average to an increase in CO_2 emissions from 200 to 370 kg per capita, with average values of 260 kg per capita. Thus, it is not the life expectancy itself that rises CO_2 emissions per capita, it is the way of life that is more common to more developed economies (e.g. elderly people may have more traveling during retirements).

Countries with larger forest areas (percentage of the territory) tend to have smaller CO_2 emissions per capita. This is a rather policy important result, since countries with smaller forest areas (percentage of the territory) do not have always reasonable instruments to compensate for their CO_2 emissions.

Energy consumption (toe) per capita is a factor that positively adds to the CO_2 emissions per capita, and in the group of selected economics one additional ton of energy consumption in terms of oil equivalent leads to the 3 tons increase in carbon dioxide.

It appears that structure of the economy has a significant influence on carbon dioxide emissions. Thus, the industrial share growth (% of GDP) increases the CO_2 emissions per capita while the growth of agriculture, forestry, and fishing (% of GDP) reduces it. It was found that an increase in agriculture, forestry, and fishing sector share by one percentage point leads to the decrease in CO_2 emissions per capita by 67–200 kg. An increase in industrial sector share (as a % of GDP) by one percentage point leads to the increase in CO_2 emissions by 37–110 kg per capita (depending on the model), with average values of 63 kg per capita.

An increase in merchandise trade (as a % of GDP) by one percentage point leads to the decrease in CO_2 emissions by 23 kg per capita. An increase in gross fixed capital formation share (as a % of GDP) by one percentage point leads to the decrease in CO_2 emissions by 55 kg per capita. Exports of goods and services (% of GDP) increase by one percentage point leads to a decrease in CO_2 emissions per capita by 40 kg. That is the development of green and service economy is an important factor in carbon dioxide reduction in a selected set of countries.

Mobile cellular subscriptions (per 100 people) is an indicator of the digital economy and an increase in mobile cellular subscriptions by 10 people per 100 people, leads to a decrease in CO_2 emissions by 37–110 kg per capita.

The next factor influencing CO_2 emissions is the EU energy policy. The countries that became members of the EU are characterized by lower CO_2 emissions as stated by model 2. However, the first and third models show different results. Thus, more research should be done in this direction concerning the comparison of the whole set of EU states with non-EU members.

Results in Table 2 show an insignificant influence of gas and oil prices on CO_2 per capita emissions. This outcome can be explained that world energy prices did not affect considerably the selected countries [27,34,58]. Definitely, it is reasonable to study the impact of energy prices on CO_2 emissions in an individual country based on the criteria of the presence or absence of subsidized energy prices (for example, subsidized prices in the Russian Federation, Kazakhstan, and Uzbekistan and market prices in Poland, Slovak Republic, Hungary, etc.). However, the abolition of subsidized prices in the countries was carried out gradually and over different periods of time. Therefore, it is not possible to group countries into separate groups that clearly meet the criteria of the presence or absence of subsidized prices.

Foreign direct investment is another statistically insignificant factor for CO_2 emissions in our model. The reason is its dual effect on those emissions. On the one hand, investment in a national economy is responsible for faster economic growth and, as a rule, for an increase in fossil fuel consumption that causes an increase in CO_2 emissions. On the other hand, investment in energy efficiency, development of environmentally friendly technologies, and service sector deployment may significantly contribute to a reduction in per capita CO_2 emissions. Those are two mutually exclusive trends affecting the dynamics of CO_2 per capita emissions. The dominance of one of these tendencies at a particular stage of development determines the direction of impact on CO_2 emissions. These results are in accordance with other papers [27,30,59]. However, the survey by Bae J.H. et al. (2016) [60] on post-Soviet Union independent states proves a positive influence of foreign direct investment on CO_2 emissions.

The increase in population for the panel of 10 countries has no statistically significant impact on the decarbonization of national economies. Its multidirectional influence on CO_2 emissions can explain this result as it had been discussed in the Methodology and data section, which is consistent with other studies [23,31].

To sum up, the obtained results support the majority of hypotheses concerning the influence of various factors on CO_2 emissions in pre-selected post-communist countries. Among confirmed hypotheses are:

(1) The positive impact of GDP per capita, the share of industry (including construction) (% of GDP), life expectancy, and population growth on per capita CO_2 emissions.

(2) The negative impact of energy efficiency, the share of agriculture, forestry and fishing (% of GDP), and progress in the digital economy (mobile cellular subscriptions) on per capita CO_2 emissions.

(3) The ambiguous impact from FDI as well as oil prices, EU energy policy access, on per capita CO_2 emissions. Contrary to other views, our study shows the insignificant influence of these factors on CO_2 emissions due to their ambiguous consequences.

5. Conclusions

This paper considers the key drivers of per capita CO_2 emissions for the panel of 10 post-communist countries in Eastern Europe and Central Asia. Significant findings of our study can be summarized as follows:

1. Economic growth, increase in energy consumption per capita, and population growth is the main determinants that positively affect per capita CO_2 emissions. These outcomes are quite logical because economic development requires additional resources as well as primary energy. Since fossil fuels are basic energy resources for the selected countries, their use in the production of various goods and services leads to an increase in carbon dioxide emissions. Energy efficiency; share of agriculture, forestry, and fishing; share of exports of goods and services; and progress in the digital economy (mobile cellular subscriptions) appear to be significant factors for decarbonizing in selected countries. Positive changes in these determinants lead to a reduction in CO_2 pollution due to a decrease in energy use through energy-efficient innovations, development of less energy-intensive service sector, and relevant national energy efficiency programs.

2. Oil prices, foreign direct investment came as statistically insignificant factors. These results are explained by the ambiguity of their effects on the selected set of countries. During our study period, investments in some countries have been made in the development of energy-efficient industries (for example, Czech Republic and Poland) while in other countries (in particular, Russia, Ukraine and Uzbekistan) they have been aimed at energy-intensive industries rebuilding. The presence of contradictory tendencies in those countries led to the leveling of the investment factor's impact on CO_2 emissions per capita.

3. It was found that the increase in life expectancy by one year leads to an increase in CO_2 emissions per capita by 200–370 kg, with average values of 260 kg per capita.

4. The empirical evidence proves that an increase in agriculture, forestry, and fishing sector share (as a % of GDP) by one percentage point leads to the decrease in CO_2 emissions by 67–200 kg per capita (depending on the model), with average values of 125 kg per capita. An increase in merchandise trade (as a % of GDP) by one percentage point leads to the decrease in CO_2 emissions by 23 kg per capita. An increase in gross fixed capital formation share (as a % of GDP) by one percentage point leads to the decrease in CO_2 emissions by 55 kg per capita. That is the development of green and service economy is an important factor of carbon dioxide reduction in a selected set of countries.

5. An increase in industrial sector share (as a % of GDP) by one percentage point leads to the increase in CO_2 emissions by 37–110 kg per capita (depending on the model), with average values of 63 kg per capita.

6. In terms of policy implications, energy and environmental policy in post-communist countries of Eastern Europe and Central Asia should be aimed at decarbonization and green economy development with the help of the following measures:

- Promotion of energy efficiency policy in accordance with EU policies and programs that stimulate a reduction in energy consumption and consequently CO_2 emissions per capita.

- Promotion of the predominant development of less energy-intensive service sector instead of building up an industrial sector characterized by high energy and carbon intensity. Moreover, it requires a well-balanced investment policy that directs investment into innovative technologies with lower CO_2 emissions.
- Most of the studied countries have switched to world prices for oil and natural gas over the last 5–7 years. Thus, we expect an increase in energy efficiency with a reduction in CO_2 emissions. In this regard, state policy in the energy sector of these countries should include the formation of higher prices for fossil fuels due to the adverse impact of their use on the environment as well as the introduction of preferential policies for renewable energy to ensure a smooth transition to a green economy with lower CO_2 emissions.

The policy recommendations require further research to identify optimal policy instruments and to assess their effectiveness for all post-communist countries concerning their national specifics.

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Abbreviations

CO_2: Carbon dioxide; EBRD: European Bank for Reconstruction and Development; EU: European Union; FDI: Foreign direct investment; GDP: Gross domestic product; GHG: Greenhouse gas; GLS: Generalized least squares; IEA: International Energy Agency; OECD: Organization for Economic Cooperation and Development; SD: Sustainable development; UNEP: United Nations Environment Programme.

References

1. Belmont, E.L.; Davidson, F.T.; Glazer, Y.R.; Beagle, E.A.; Webber, M.E. Accounting for water formation from hydrocarbon fuel combustion in life cycle analyses. *Environ. Res. Lett.* **2017**, *12*. [CrossRef]
2. Alam, M.; Murad, M.W.; Noman, A.H.M.; Ozturk, I. Relationships among carbon emissions, economic growth, energy consumption, and population growth: Testing Environmental Kuznets Curve hypothesis for Brazil, China, India and Indonesia. *Ecol. Indic.* **2016**, *70*, 466–479. [CrossRef]
3. Alshehry, A.; Belloumi, M. Energy consumption, carbon dioxide emissions and economic growth: The case of Saudi Arabia. *Renew. Sustain. Energy Rev.* **2015**, *41*, 237–247. [CrossRef]
4. Bilan, Y.; Streimikiene, D.; Vasylieva, T.; Lyulyov, O.; Pimonenko, T.; Pavlyk, A. Linking between renewable energy, CO_2 emissions, and economic growth: Challenges for candidates and potential candidates for the EU membership. *Sustainability* **2019**, *11*, 1528. [CrossRef]
5. Grubb, M.; Muller, B.; Butler, L. The Relationship between Carbon Dioxide Emissions and Economic Growth. Oxbridge Study on CO_2–GDP Relatsh. 2004. Available online: https://www.oxfordenergy.org/wpcms/wp-content/uploads/2011/02/Presentation19-The-RelationshipBetweenCarbonDioxideEmissionsandEconomicGrowth-MGrubbBMullerLButler-2004.pdf (accessed on 28 October 2017).

6. Lau, L.-S.; Choong, C.K.; Eng, Y.K. Investigation of the environmental Kuznets curve for carbon emissions in Malaysia: Do foreign direct investment and trade matter? *Energy Policy* **2014**, *68*, 490–497. [CrossRef]
7. Muangthai, I.; Lewis, C.; Lin, S.J. Decoupling effects and decomposition analysis of CO_2 emissions from Thailand's thermal power sector. *Aerosol Air Qual. Res.* **2014**, *14*, 1929–1938. [CrossRef]
8. Shahbaz, M.; Hye, Q.M.A.; Tiwari, A.K.; Leitão, N.C. Economic growth, energy consumption, financial development, international trade and CO_2 emissions in Indonesia. *Renew. Sustain. Energy Rev.* **2013**, *40*, 109–121. [CrossRef]
9. Sharma, S.S. Determinants of carbon dioxide emissions: Empirical evidence from 69 countries. *Appl. Energy* **2011**, *88*, 376–382. [CrossRef]
10. Shrestha, R.M.; Anandarajah, G.; Liyanage, M.H. Factors affecting CO_2 emission from the power sector of selected countries in Asia and the Pacific. *Energy Policy* **2009**, *37*, 2375–2384. [CrossRef]
11. Chiu, Y. Carbon dioxide, income and energy: Evidence from a non-linear model. *Energy Econ.* **2017**, *61*, 279–288. [CrossRef]
12. Julia, R. CO_2 Allowance and Electricity Price Interaction. Executive Summary. 2018. Available online: https://www.iea.org/textbase/npsum/price_interaction07sum.pdf (accessed on 15 March 2019).
13. Allaire, M.; Brown, S.U.S. Energy Subsidies Effects on Energy Markets and Carbon Dioxide Emissions. 2012. Available online: http://www.pewtrusts.org/~{}/media/legacy/uploadedfiles/wwwpewtrustsorg/reports/fiscal_and_budget_policy/energysubsidiesfinalpdf.pdf (accessed on 12 September 2020).
14. McCollum, D.L.; Jewell, J.; Krey, V.; Bazilian, M.; Fay, M.; Riahi, K. Quantifying Uncertainties Influencing the Long-Term Impacts of Oil Prices on 2 Energy Markets and Carbon Emissions. 2018. Available online: http://pure.iiasa.ac.at/id/eprint/13293/1/NEnergy_oil_prices_pre.pdf (accessed on 12 September 2020).
15. Rapanos, V.T.; Polemis, M.L. Energy demand and environmental taxes: The case of Greece. *Energy Policy* **2005**, *33*, 1781–1788. [CrossRef]
16. Yiia, K.-J.; Geethab, C. The nexus between technology innovation and CO_2 emissions in Malaysia: Evidence from granger causality test. The 8th Int. Conf. on Appl. Energy–ICAE2016. *Energy Procedia* **2017**, *105*, 3118–3124. [CrossRef]
17. Heidari, H.; Katircioglu, S.T.; Saeidpour, L. Economic growth, CO_2 emissions, and energy consumption in the five ASEAN countries. *Electr. Power Energy Syst.* **2015**, *64*, 785–791. [CrossRef]
18. Kurbatova, T.; Khlyap, H. GHG emissions and economic measures for low carbon growth in Ukraine. *Carbon Manag.* **2015**, *6*, 7–17. [CrossRef]
19. Sapkota, P.; Bastola, U. Foreign direct investment, income, and environmental pollution in developing countries: Panel data analysis of Latin America. *Energy Econ.* **2017**, *64*, 206–212. [CrossRef]
20. Sbia, R.; Shahbaz, M.; Hamdi, H. A contribution of foreign direct investment, clean energy, trade openness, carbon emissions and economic growth to energy demand in UAE. *Econ. Model.* **2014**, *36*, 191–197. [CrossRef]
21. Auffhammer, M. Carbon vs. Energy Intensity. Research that Informs Business Public Policy. 2013. Available online: https://energyathaas.wordpress.com/2013/01/14/carbon-vs-energy-intensity/ (accessed on 12 September 2020).
22. Baumert, K.; Herzog, T. *Pershing, Navigating the Numbers Greenhouse Gas Data and International Climate Policy*; World Resources Institute: Washington, DC, USA, 2005.
23. Lin, B.; Omoju, O.E.; Nwakeze, N.M.; Okonkwo, J.U.; Megbowon, E.T. Is the environmental Kuznets curve hypothesis a sound basis for environmental policy in Africa? *J. Clean. Prod.* **2016**, *133*, 712–724. [CrossRef]
24. Everett, T.; Ishwaran, M.; Ansaloni, G.P.; Rubin, A. Economic Growth and the Environment. Defra Evidence Analysis Series. 2010. Available online: https://mpra.ub.uni-muenchen.de/23585/1/economic-growth-environment.pdf (accessed on 12 September 2020).
25. Freitas, L.C.; Kaneko, S. Decomposing the decoupling of CO_2 emissions and economic growth in Brazil. *Ecol. Econ.* **2011**, *70*, 1459–1469. [CrossRef]
26. Lyulyov, O.; Shvindina, H. Stabilization pentagon model: Application in the management at macro- and micro-levels. *Probl. Perspect. Manag.* **2017**, *15*, 42–52. [CrossRef]
27. Nepal, R.; Jamasb, T.; Tisdell, C.A. On environmental impacts of market-based reforms: Evidence from the European and Central Asian transition economies. *Renew. Sustain. Energy Rev.* **2017**, *73*, 44–52. [CrossRef]
28. Chygryn, O.; Pimonenko, T.; Luylyov, O.; Goncharova, A. Green bonds like the incentive instrument for cleaner production at the government and corporate levels: Experience from EU to Ukraine. *J. Environ. Manag. Tour.* **2018**, *9*, 1443–1456. [CrossRef]

29. Hitam, M.B.; Borhan, H.B. FDI, growth and the environment: Impact on quality of life in Malaysia. *Procedia-Soc. Behav. Sci.* **2012**, *50*, 333–342. [CrossRef]
30. Omri, A.; Nguyen, D.K.; Rault, C. Causal interactions between CO_2 emissions, FDI, and economic growth: Evidence from dynamic simultaneous-equation models. *Econ. Model.* **2014**, *42*, 382–389. [CrossRef]
31. Martínez-Zarzoso, I.; Maruotti, A. The impact of urbanization on CO_2 emissions: Evidence from developing countries. *Ecol. Econ.* **2011**, *70*, 1344–1353. [CrossRef]
32. Koengkan, M.; Fuinhas, J.A.; Santiago, R. The relationship between CO_2 emissions, renewable and non-renewable energy consumption, economic growth, and urbanisation in the Southern Common Market. *J. Environ. Econ. Policy* **2020**. [CrossRef]
33. Vasylieva, T.; Lyulyov, O.; Bilan, Y.; Streimikiene, D. Sustainable economic development and greenhouse gas emissions: The dynamic impact of renewable energy consumption, GDP, and corruption. *Energies* **2019**, *12*, 3289. [CrossRef]
34. Sineviciene, L.; Sotnyk, I.; Kubatko, O. Determinants of energy efficiency and energy consumption of Eastern Europe post-communist economies. *Energy Environ.* **2017**, *28*, 870–884. [CrossRef]
35. Lyeonov, S.; Pimonenko, T.; Bilan, Y.; Štreimikiene, D.; Mentel, G. Assessment of green investments' impact on sustainable development: Linking gross domestic product per capita, greenhouse gas emissions and renewable energy. *Energies* **2019**, *12*, 3891. [CrossRef]
36. Liobikiene, G.; Butkus, M.; Bernatonienė, J. Drivers of greenhouse gas emissions in the Baltic States: Decomposition analysis related to the implementation of Europe 2020 strategy. *Renew. Sustain. Energy Rev.* **2016**, *54*, 309–317. [CrossRef]
37. Karintsheva, O.I. Economic restructuring in Ukraine in view of destructive effect of enterprises on environment. *Int. J. Ecol. Econ. Stat.* **2017**, *38*, 1–11.
38. Yevdokimov, Y.; Chygryn, O.; Pimonenko, T.; Lyulyov, O. Biogas as an alternative energy resource for ukrainian companies: EU experience. *Innov. Mark.* **2018**, *14*, 7–15. [CrossRef]
39. Sineviciene, L.; Kubatko, O.V.; Sotnyk, I.M.; Lakstutiene, A. Economic and environmental performance of post-communist transition economies. *Eurasian Econ. Perspect.* **2019**. [CrossRef]
40. *Standard Country or Area Codes for Statistical Use*; United Nations, Statistical Office: New York, NY, USA, 1999; Volume 49. Available online: https://unstats.un.org/unsd/methodology/m49/ (accessed on 20 September 2020).
41. United Nations Conference on Environment & Development, Rio de Janerio, Brazil, 3 to 14 June 1992. Agenda 21. 1992. Available online: https://sustainabledevelopment.un.org/content/documents/Agenda21 (accessed on 12 September 2020).
42. CLP's Climate Vision 2050. #SDGAction809. United Nations. 2016. Available online: https://sustainabledevelopment.un.org/partnership/?p=809 (accessed on 12 September 2020).
43. Intergovernmental Panel on Climate Change Reports. 2017. Available online: https://www.ipcc.ch/ (accessed on 12 September 2020).
44. Recent trends in the OECD: Energy and CO_2 Emissions OECD/IEA. 2017. Available online: http://www.iea.org/media/statistics/Recent_Trends_in_the_OECD.pdf (accessed on 12 September 2020).
45. International Energy Agency Publications. 2017. Available online: http://www.iea.org/publications (accessed on 12 September 2020).
46. Carbon Rankings. ET Index Ltd. 2017. Available online: https://environmental-tracking.etindex.com/#!/et-carbon-rankings (accessed on 12 September 2020).
47. CO_2 Emissions–Country Ranking Index Mundi. 2020. Available online: http://www.indexmundi.com/facts/indicators/EN.ATM.CO2E.PC/rankings (accessed on 12 September 2020).
48. Global Carbon Atlas. CO_2 Emissions. 2016. Available online: http://www.globalcarbonatlas.org/en/ (accessed on 12 September 2020).
49. Our World in Data. CO_2 and Greenhouse Gas Emissions Country Profiles. Available online: https://ourworldindata.org/CO2-and-other-greenhouse-gas-emissions (accessed on 20 September 2020).
50. Lin, S.J.; Chang, T.C. Decomposition of SO_2, NO_x and CO_2 emissions from energy use of major economic sectors in Taiwan. *Energy J.* **1996**, *17*, 1–17. [CrossRef]
51. Nag, B.; Parikh, J. Indicators of carbon emission intensity from commercial energy use in India. *Energy Econ.* **2000**, *22*, 441–461. [CrossRef]

52. Emissions Intensity. Chapter 5. In book: Navigating the Numbers: Greenhouse Gas Data and International Climate Policy, 2004, Part 1. Available online: http://pdf.wri.org/navigating_numbers_chapter5.pdf (accessed on 20 September 2020).
53. Wang, Z.; He, W.; Chen, K. The integrated efficiency of economic development and CO_2 emissions among Asia Pacific Economic Cooperation members. *J. Clean. Prod.* **2016**, *131*, 765–772. [CrossRef]
54. European Bank for Reconstruction and Development. Transition Data. 2020. Available online: http://www.ebrd.com/ (accessed on 12 September 2020).
55. The World Bank. World Development Indicators Database. 2020. Available online: http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators (accessed on 12 September 2020).
56. European Commission. 2020 Energy Strategy. Available online: https://ec.europa.eu/energy/energy-strategy/2020-energy-strategy_en?redir=1 (accessed on 12 September 2020).
57. Melnyk, L.G.; Kubatko, O. The EU experience for economic systems adaptation to resource fluctuations through green industries innovations. *Actual Probl. Econ.* **2013**, *12*, 36–42.
58. Carvalho, A. Energy efficiency in transition economies: A stochastic frontier approach. *Econ. Transit.* **2018**, *26*, 553–578. [CrossRef]
59. Melnyk, L.; Kubatko, O.; Pysarenko, S. The impact of foreign direct investment on economic growth: Case of post communism transition economies. *Probl. Perspect. Manag.* **2014**, *12*, 17–24.
60. Bae, J.H.; Li, D.D.; Meenakshi, R. Determinants of CO_2 emission for post-Soviet Union independent countries. *Clim. Policy* **2016**. [CrossRef]