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The Role of the Key Components of Renewable Energy (Combustible Renewables and Waste) in the Context of CO₂ Emissions and Economic Growth of Selected Countries in Europe

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Abstract: In the case of developing countries, it is not clear which crisis management tools will ensure sustainable development in a sustainable and environmentally friendly way, as well as reducing CO₂ emissions in addition to ensuring GDP growth. The next analysis discusses the details of this issue. The study explores the connection between per capita GDP, emission of CO₂, combustible energy, and waste consumption. The Hausman test ratifies that the regression model with the fixed effect is the proper method for the panel balanced data from 1990 to 2019 in the selected 13 countries of the EU. This study ordered the data into three categories (for 13 selected countries, the top nine EU countries (in GDP), and Visegrad countries (Hungary, Slovakia, Czech Republic and Poland)). The study found a significant positive effect of combustible energy and waste consumption and the negative impact of CO₂ emission on GDP per capita. The cointegration test confirms that all three variables are cointegrated. This implies a long-term link among all three variables in the context of all three types of the selected panel. The Granger causality results ensure that there is a two-way cause–effect relation between the variables. The study strongly recommends that developed European Union countries (the top nine EU countries) increase energy production from biomass-based renewable energy and waste to stimulate economic growth. The same strategy was not recommended in the Visegrad countries because of the much lower GDP growth due to the N-shaped Kuznets curve. In these countries, it is advisable to avoid unexpected increases in CO₂ emissions from biomass and fossil fuel-burning, to achieve greenhouse gas reductions using other circular, platform-based models instead of simple biomass energy production. Due to the low level of energy efficiency and the lack of application of technological innovation, the energy use of biomass can significantly slow down GDP growth in less developed EU countries (such as the V4 countries).

Keywords: GDP growth; combustible energy; renewable energy; bio-waste; CO₂ emission; Visegrad countries; Environmental Kuznets Curve (EKC); N-shaped curve



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1. Introduction

Renewable energy consumption is expanding significantly worldwide. More than 71% of the total electricity capacity in Europe consisted of renewable energy during the year 2011, while the industries and market for renewable energy extended to all end-use sectors experienced substantial growth in new regions and countries [1]. The key components of renewable energy are combustible renewables and waste (CRW) and comprise liquid biomass, municipal waste, solid biomass, biogas, and waste from industrial activities. Many countries concerned about (greenhouse gas) GHG emissions and energy security have adopted the goal of biofuels. They have agreed to give incentives to the sector of

biofuels. The source biomass includes feed for livestock, fiber, and food [2]. Biomass is the fourth largest energy resource worldwide after natural gas, oil, and coal, contributing to over 10% of the global supply of primary energy. Biomass feedstocks are made of solid, gaseous, and liquid types and transform into heat, transport fuels, and electricity through various technologies [3]. The average percentage share of the annual international production of liquid biofuels is 17%. The ethanol production rate was 17% and 27% for biodiesel during 2007 and 2013, respectively [4]. For example, over the last few decades, Brazil has seen steady, significant economic development, redistributing the fruits and elevating poverty for millions of Brazilians by utilizing sufficient natural resources. In this transition, the agricultural bioethanol sector played a crucial role, and the government policies of Brazil were influential. The secure agricultural status of Brazil is because of said choices [5]. The government took a hands-on approach years ago on rural development and agriculture across high infrastructure spending, and R&D. The agricultural sector productivity has dramatically improved and GDP has grown significantly, changing Brazil into one of the largest global agricultural goods exporters from a net food importer [6]. Atici investigated the effect of different factors, for example, energy utilization per capita, GDP per capita, and CO₂ emission per capita in Hungary, Bulgaria, Turkey, and Romania [6]. The study found an EKC (environmental Kuznets curve) for the locale with the end goal that CO₂ emanation per capita diminishes over the long run as the per capita GDP increments. The GHG emissions of Brazil are the fourth biggest in the world. Brazil is, however, among the five nations with the highest pollution reduction perspective. Agriculture provides about half of the total supply of energy in Brazil. Agricultural renewables consist of 42% of sugarcane biomass, 28% of hydraulic power, 20% of firewood, and 10% of other sources [7]. By stimulating nature-friendly and agricultural practices with low-carbon initiatives, Brazil is promoting the production of biofuels.

The projection of agriculture has a growing influence on environmental sustainability [8]. Consequently, there is a close correlation between emissions of CO₂, combustible renewables and waste for energy and GDP per capita. Results show that it is worth looking at the EU context, and similar programs have been running in the EU over the past year. It may also be interesting to note that the economic development (GDP levels) of the EU Member States concerned vary significantly. Energy demand is facing a substantial growth rate due to population and economic growth. Several reports indicate that emissions of CO₂ are rising increasingly due to the significant rise of fossil fuel usage and inefficiency (natural gas, coal, and petroleum). The efficient usage of these energies is essential to promote the use of compatible energies [9–15]. Simultaneously, the current economic and political question is what kind of renewable energy a country should use to cope with the declining use of fossil fuel resources and prevent the significant problems caused by CO₂ emissions. At present, it is not clear whether, among the crisis management tools, increasing the use of renewable biomass energy or bad practices can have a negative impact on GDP growth.

2. Literature Review

The use of renewable energy sources is increasingly prevalent, primarily due to political and environmental concerns. The projection of renewable energy plays an essential role in increasing GDP per capita and boosting air quality. Combustible renewables and waste comprise biomass [16–18]. According to the World Bank, biomass composition is liquid gas, reliable biogas, and municipal and industrial waste [19]. These renewable energy sources are not clean compared to renewable energy (geothermal, solar, wind, etc.) from other sources. However, it was found that they contaminate less than fossil fuel sources [20].

2.1. Relationships between GDP Growth and Combustible Renewables in Developing Countries

The cause–effect association concerning renewable energy consumption and economic growth has been investigated in a number of empirical studies [21,22]. The cause–effect relation direction outcomes differ in countries' trial methods, selection of countries, the time counted, the methodology of empirical study used, and the variables used in the models described. The cause–effect relation path between the GDP growth and renewable energy consumption, therefore, develops four hypotheses: (1) the assumption of feedback claims that there is a two-way cause–effect link between the growth of GDP and renewable energy consumption [23–25]. Al-Mulali et al. found that GDP Granger causes the use of renewable energy consumption. (2) The hypothesis of neutrality indicates that there is no cause–effect correlation in any direction between the two variables. (3) The hypothesis of growth entails that renewable energy consumption drives a vital role in justifying GDP growth; (4) the hypothesis indicates that energy consumption plays an essential role in clarifying GDP growth. In this case, any rise in renewable energy use does not change GDP [26].

Al-Mulali discusses the impact of non-renewable and renewable energy on GDP growth in 18 countries of Latin America. The analysis findings showed that economic development, non-renewable and renewable energy use, resources, labor, and trade have long-term bidirectional connections. They also reveal that the consumption of renewable electricity is more important than the consumption of non-renewable electricity in fostering short- and long-term GDP growth for this country's community. The Granger causality test findings indicate short- and long-term two-way correlations between green energy and economic development [27,28]. Sadorsky employed a cointegration model for a panel of 18 countries of emerging markets and illustrated a long-term one-way correlation that stretches from the growth of GDP to renewable energy consumption. Additionally, projections of the long-term investigation recommend that GDP growth has a decisive impact on renewable resources [29]. The investigation of cointegration strategies on 11 African nations determined the cause–effect relationship between the growth of GDP per capita, combustible energy, and trade. The panel of error correction model findings shows a bidirectional cause–effect link between trade (net export) and economic growth.

There is a one-way cause–effect link between the short- and long-term consumption of renewable energy towards GDP growth. There is a cause–effect correlation between economic growth and the consumption of renewable energy [30]. Their observational findings recommend that the consumption of renewable energy has a detrimental consequence on GDP growth. The cause–effect relation of one-way runs from the growth of GDP to renewable energy consumption. As its influence on CO₂ emissions is one of the most critical consequences of renewable energy, it is of great importance to research the complex cause–effect connection between emissions of CO₂, growth of GDP and the use of renewable energy [31]. Apergis et al. investigated the panel data of 19 emerging countries. They found a cause–effect correlation between the emission of CO₂, clean energy, nuclear energy, and GDP growth. According to the findings of long-term projections, nuclear energy generation harms pollution. However, consumption of renewable energy has a significant positive impact on the emissions of CO₂. The study also highlights bidirectional short- and long-term connections between renewable energy use, emissions of CO₂, and GDP [32]. Apergis and Payne investigated data of seven countries of Central America on a panel. The study found the determinants of consumption involving per capita renewable energy. They also studied a long-term cointegration between GDP growth, emissions of CO₂, real oil prices and actual coal prices, and per capita renewable energy consumption [33].

Ben Jebli et al. investigated 24 countries in sub-Saharan Africa. The study found the complex correlative relation between variables taken in this study of panel data—economic growth, emission of CO₂, trade, and renewable energy consumption. A short-term bidirectional correlation was established between the emission of CO₂ and the growth of GDP. There was a long-term two-way correlation between CO₂ emission and GDP growth. This does not support the environmental Kuznets curve theory (EKC) [34]. Another study

by Farhani and Shahbaz looked at panel data from 10 North African and Middle Eastern countries. Researchers have noted the cause–effect correlation between non-renewable and renewable energy use, output, and CO₂ emissions. The hypothesis of EKC certifies that its long-term calculations indicate that CO₂ emissions increased by non-renewable and renewable energy use. The study also found a long-term correlation between the consumption of non-renewable and renewable energy and the CO₂ emission [35]. The relationship between renewable energy and agricultural value added has been the subject of several studies. The studies evaluate the short- and long-term links between GDP growth, CO₂ emissions, resources of non-renewable and renewable energy, agricultural value added (AVA) and foreign trade access [36]. Granger causality checks demonstrated the presence of a short-term two-way correlation between emissions of CO₂, agricultural value added and transparency of trade. Long-term bidirectional correlations were observed between all the variables considered. Long-term forecasts confirm that CO₂ emissions are boosted by non-renewable electricity, commerce, and agriculture and that renewable energy decreases emissions. These scholars suggest that the usage of green resources in the agriculture sector being subsidized will enable the industry to become more competitive in export markets, although at the same time becoming less polluting. Jebli and Youssef emphasized panel data of five countries from North Africa. They used cointegration panel strategies to estimate the complex cause–effect connections between the consumption of clean energies, emission of CO₂, agricultural value added, and GDP growth. The study observed that there are short- and long-term correlations between AVA pollution and the emission of CO₂. There was also a one-way cause–effect relation with the consumption of renewable energy to AVA (agricultural value added). The study proposes that North African countries promote solar or wind power, clean, renewable energy because it increases productivity in the agricultural sector and supports reducing the emission of CO₂ [37]. Over the period 1981 to 2000, energy use in the Middle East and north African countries (MENA) has substantially affected CO₂ emissions. Furthermore, for the field, real GDP has a quadratic relationship with CO₂ emissions. Though the calculated coefficients of income in the long-run and their square support the hypothesis of EKC in most countries examined, the turning points are deficient in some cases and extremely large in others, supporting insufficient evidence to satisfy the EKC hypothesis [38].

2.2. Kuznets Curve Hypothesis and CO₂ Emission Correlation in Different Countries

The consumption of energy has a substantial effect on growth. A bidirectional cause–effect correlation exists between energy consumption and economic growth. Energy consumption is a crucial factor in the growth of GDP in MENA countries, and, thus, a high level of economic growth contributes to a high level of energy demand. The research ensures that countries use more resources due to production growth, which puts pressure on the atmosphere, leading to more pollution [39]. According to the environmental Kuznets curve (EKC) hypothesis, the relationship between per capita emissions of pollutants and per-capita GDP has an inverted-U form. This means that economic development will be profitable for environmental quality beyond a particular stage [40]. Richard investigated the presence of an EKC for emissions of CO₂ in Canada for 57 years.

The study found that the slope of the function changes monotonically over time [41]. In Spain, for the period of 1857 to 2007, there was a long-term relationship between per capita income and CO₂. The study also supports the EKC hypothesis [42]. In Turkey, 40-year time series data support the EKC hypothesis [43]. The EKC hypothesis was not confirmed for the period of 1996 to 2012 in Cambodia, however. The study demonstrates that GDP, energy consumption, and urbanization are responsible for increasing CO₂, while government policy and control of corruption can reduce CO₂ [44]. In Pakistan, between 1971 and 2009, there was a long-term relationship between trade openness, energy consumption, CO₂ emissions, and economic growth. The EKC hypothesis confirms the country's significant effort to reduce emissions of CO₂. The study suggests that research can ensue on the provincial level to find the effect of emissions of CO₂ on economic growth [45].

There was a connection between per capita GDP and CO₂ emissions by the EKC hypothesis from the EU-27 panel. The study found that among the 27 countries, only four (Greece, Spain, Cyprus, and Slovenia) have an inverted U-shaped curve. The research suggests that further development should include econometric analysis to test the long-term relationship between CO₂ emissions and GDP [46].

North Africa is facing a substantial rise in energy demand of six to eight percent per year. According to a report prepared by the UNECA, fossil fuels control energy fusion through a more significant contribution to natural gas. These countries' energy policies are updated considering the very high volatility of gas and oil prices. The diversification of their energy mix is giving the highest priority to renewable energy. Moreover, the benefit of renewable energy is that it can serve remote areas far from the national power grid. Energy-saving capacity and renewable energy are still primarily under-utilized. There is potential efficiency of using natural energy for these countries, as a 10% gain in energy usage in the region could be achieved by enhanced energy initiatives by 2030, an SDGs goal (Sustainable Development Goals). The contribution of renewable energy sources is inadequate within the mix of energy. It accounted for just eight percent in 2006, with gas (67%), oil (19%) and coal (19%) making up the remainder (six percent). Effective changes have been introduced in the governing environment to promote more private sector involvement in developing renewable energy sources [47]. These countries have set impressive, organized targets. They have implemented large-scale incorporated initiatives to reduce greenhouse gas (GHG), industrial growth, economic development, and human capital to promote direct and indirect job-creation improvement. Several current programs, for example, the Mediterranean solar plan (MSP) or the present deals between individual countries in North Africa and the EU, will strengthen financial and technical cooperation and extend the regional renewable energy markets [48–50]. Estimates of biofuel output impacts often rely on models with an inadequate capacity to integrate economic and environmental effects, ignoring the generation of co-products. Early evaluation of the biofuel effect neglected co-product generation, resulting in an overestimation of GHG emissions and land requirements. Due to the large shares of grains used in the production of ethanol with high feed-yields, the performance of feed co-products is relatively high in the United States, the European Union, and China [51].

We must also distinguish between developed and less developed Member States within the European Union. For central and eastern European countries, the EKC curve shows a different relationship between GDP and emissions, including GHG emissions. Lazăr et al. (2019) [52], in their research, narrowed to eastern and central Europe; the EKC showed a turning point at \$ 21,000 GDP in terms of carbon emissions and economic growth. Kasman and Duman's (2015) [53] study of 15 European countries found a long-term cause–effect relationship between energy consumption, trade openness, economic growth, and carbon emissions. Armeanu et al. (2018) [54] confirmed, in addition to economic growth and energy consumption, the EKC hypothesis for greenhouse gases and sulphur dioxide emissions. They found a short-term effect between the variables, but no cause–effect relationship, thus proving that economic growth has a role in the evolution of emissions. According to Nemet-Durkó's (2020) studies, which cover the period 1982 to 2016, the relationship between economic growth and CO₂ emissions does not take an inverted U-shaped curve but an inverted N-shape in the case of Hungary, Slovakia, and Poland. In an early stage of the economy, CO₂ emissions started to decline, but as soon as they reached the first income turning point, they started to increase until the second turning point, after which they fell again. The increase in CO₂ emissions was, therefore, only temporary. But the growth of the global renewable energy industry is providing at an increasing rate [55,56]. Nemet-Durkó (2020) believes that to reduce CO₂, it is worth emphasizing energy-saving and efficiency-oriented technical solutions and preferring business solutions that benefit modern financial development [57].

To our knowledge, there is a cause–effect link between CRW consumption, growth of GDP per capita, and emission of CO₂. This study's main objective is to examine the

association between per capita GDP, combustible energy, waste consumption and emissions of CO₂. The main research question is: “Does combustible energy, and waste consumption and emissions of CO₂ affect GDP per capita?” These are some objectives of this study:

(1) To find out the link concerning GDP per capita, combustible energy, and waste consumption and emissions of CO₂ in 13 countries in Europe. Among the 13 countries, the situation is different in the top nine countries (Austria, Belgium, Denmark, Germany, France, Ireland, Liechtenstein, the Netherlands, Luxembourg, Switzerland, United Kingdom) and the four less developed Visegrad countries (V4/Hungary, Slovakia, Czech Republic, and Poland).

(2) To test the correlation between GDP per capita, combustible energy, and waste consumption and emissions of CO₂ in selected countries in Europe. Among the 13 countries, the correlation is different in the top nine countries and Visegrad 4 (V4) countries.

3. Materials and Methods

The following methodological process was used to test the hypotheses. The stationary test identifies whether the series is stationary or not [58]. In a regression model, the Hausman test identifies endogenous regressors. The Hausman test is also referred to as a model misspecification test. The Hausman test helps us to decide the appropriate model to use, a fixed-effects model or a random-effects model, when working with panel data. The regression model with random effects is the suitable model when the null hypothesis is true. The regression model with fixed effects is the appropriate model when the alternative hypothesis is true [59–61]. The Pedroni cointegration test shows the long-term relationship [62]. Then, panel cointegration is performed. Granger causality also checks for cause–effect relationships [63]. This study is structured as follows: materials and method in Section 2. In Section 3, we will portray the result and discussion. Finally, the conclusion and policy suggestions are presented. The study uses secondary data from 13 (1) countries from Europe. The set is a balanced panel with three main variables: per capita GDP at constant USD, emission of CO₂ and combustible energy and waste consumption. The dependent variable is the GDP per capita as a proxy of economic growth. The main source of the data is the World Bank, 2020. The independent variables are combustible energy and waste consumption (CEWC), and CO₂ emissions. For the analysis, the study uses Stata 14, ArcGIS 10.8.1, and Eviews 10.

Data and Sample

The study area is 13 selected countries in Europe. The 15 countries comprising this sub-region are the Czech Republic, Austria, Belgium, Denmark, Germany, Hungary, France, Ireland, Slovakia, the Netherlands, Poland, Luxembourg, Switzerland, United Kingdom, and Liechtenstein (Figure A1 in Appendix A). Due to data unavailability, the study dropped Liechtenstein, and the United Kingdom is no longer part of the EU. All the data were collected from the World Development Indicator (WDI), 2020.

The study aims to see the impact of CO₂ emissions and combustible energy and waste consumption on GDP per capita. The study will investigate three models. These are (1) a panel regression model (Pooled OLS), (2) a regression model with fixed effect, and (3) a regression model with random effect. The fixed effect is appropriate based on the structure of the data. All the models are listed below:

$$\text{GDP}_{it} = \alpha_0 + \beta_1 C_{it} + \beta_2 \text{CEWC}_{it} + \varepsilon_{it} \quad (1)$$

$$\text{GDP}_{it} = (\alpha_0 + v_i) + \beta_1 C_{it} + \beta_2 \text{CEWC}_{it} + \mu_{it} \varepsilon_{it} = v_i + \mu_{it} \quad (2)$$

$$\text{GDP}_{it} = \alpha_0 + \beta_1 C_{it} + \beta_2 \text{CEWC}_{it} + (v_i + \mu_{it}) \quad (3)$$

where GDP_{it} is the dependent variable of country i at time t .

C_{it} is the CO₂ emission of country i at time t .

CEWC_{it} is the combustible energy and waste consumption of country i at time t .

α_0 is the constant term and intercept.

β_1 and β_2 are the coefficients of the variables C_{it} and $CEWC_{it}$.
 ε_{it} is the error term, v_i is the individual effect and μ_{it} is the time effect.

4. Results and Discussion

4.1. Descriptive Statistics

For the chosen countries in Europe, the average GDP per capita is \$34,233.62, with a standard deviation of \$24,102.14 from 1990 to 2019. In 2014, Luxembourg was responsible for a maximum GDP per capita of \$118,823.6.

The minimum per capita GDP is \$1731.209, which belonged to Poland in 1990. In Europe, the average consumption of combustible energy and waste among the selected countries is 3.94%. The maximum consumption of combustible energy and waste is 18.21% in Denmark. In selected European countries, the average CO₂ emission is 9.25%. In 2016, Switzerland was the country with the lowest CO₂ emissions. The gross emission of CO₂ in 1991 was 27.43% in Luxembourg. The average GDP per capita of the top nine countries is \$44,796.43, which is around 23.58% higher than the average of 13 selected countries and more than four times higher than any of the Visegrad countries during the last 30 years. The average GDP per capita of Visegrad countries is \$10,467.29. The average combustible energy and waste consumption of the top nine and Visegrad countries is 3.88% and 4.09%, respectively, during 1990 to 2019. The average emission of CO₂ of the top nine and Visegrad countries is 9.83 and 7.97, respectively. Table 1a illustrates the descriptive statistics of the selected 13 countries in Europe. Table 1b,c show the top nine and Visegrad countries' descriptive statistics, respectively. Figure 1 shows that the per capita GDP trend for the selected countries in central Europe rose from 1990 to 2019. Luxemburg has the most important pattern.

Table 1. Descriptive Statistics.

(a) Descriptive Statistics for the Selected 13 Countries of Europe					
Variable	Observation	Mean	Std. Dev.	Min	Max
GDP per Capita (GDP)	390	34,233.62	24,104.14	1731.209	118,823.6
Combustible Energy and Waste Consumption (CEWC)	390	3.94	3.46	0.38	18.21
CO ₂ Emission	390	9.25	4.12	4.11	27.43
(b) Descriptive Statistics for the Selected Nine Developed Countries of Europe					
GDP per Capita (GDP)	270	44,796.43	21,443.26	14,048.11	118,823.60
Combustible Energy and Waste Consumption (CEWC)	270	3.88	3.85	0.39	18.21
CO ₂ Emission	270	9.83	4.59	4.12	27.43
(c) Descriptive Statistics for Selected Visegrad 4 (V4) Countries of Europe					
GDP per Capita (GDP)	120	10,467.29	6092.94	1731.21	23,494.60
Combustible Energy and Waste Consumption (CEWC)	120	4.09	2.38	0.40	11.25
CO ₂ Emission	120	7.97	2.38	4.19	13.89

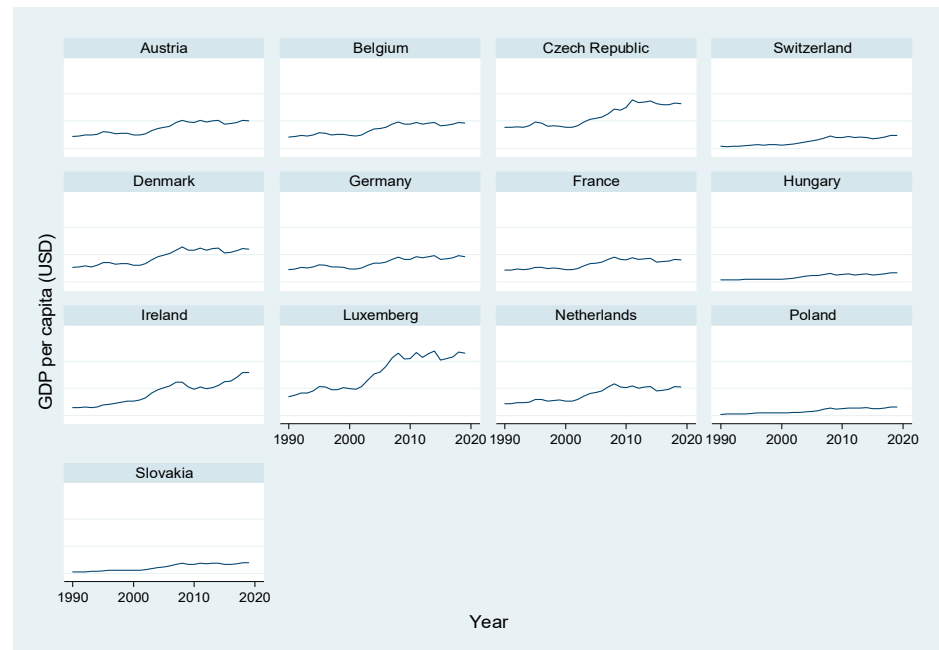


Figure 1. The trend of GDP per capita in the selected country during 1990 to 2019.

Figure 2 shows that combustible energy and waste consumption patterns are growing over time. According to the curve trend, Denmark plays an essential role in combustible energy and waste consumption.

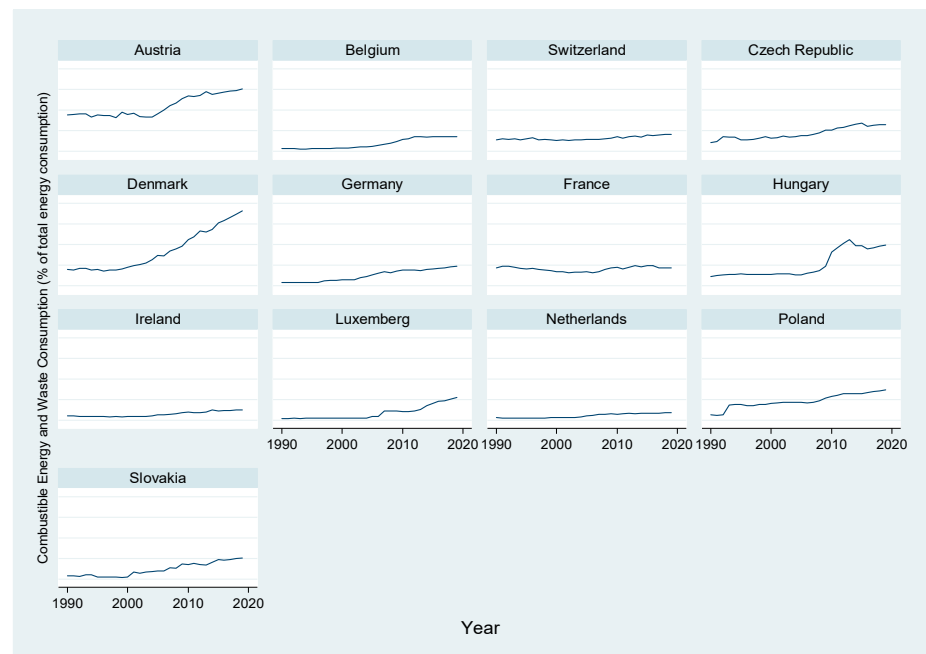


Figure 2. The trend of CEW consumption in the selected country during 1990 to 2019.

Figure 3 shows that CO₂ emissions are declining over time. In the sense of CO₂ emissions, every European Union country selected has a negative trend.

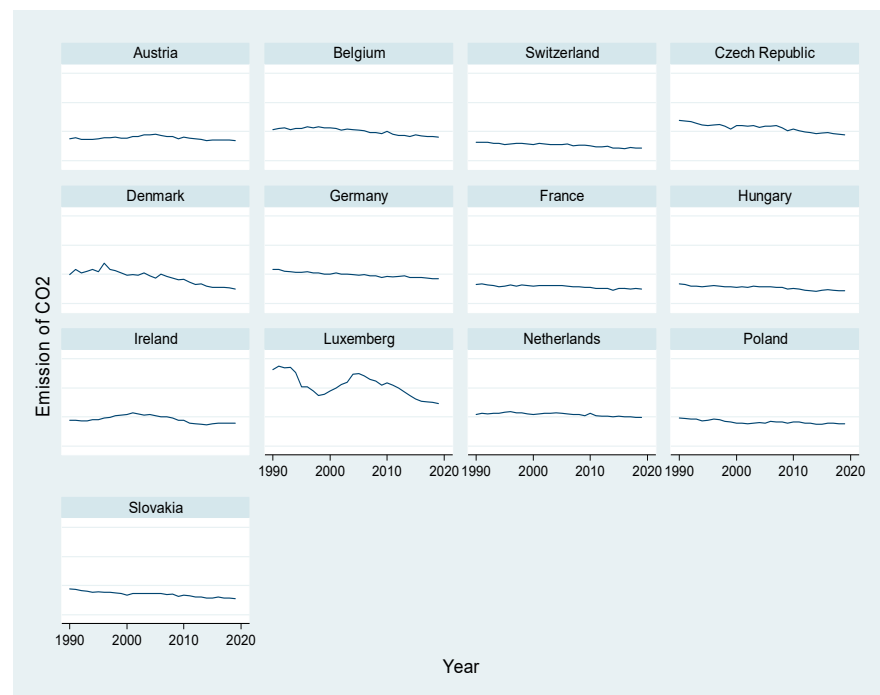


Figure 3. The trend of CO₂ emission in the selected country during 1990 to 2019.

4.2. Correlation

The combustible energy and waste consumption and GDP per capita have a weak positive relationship. A positive relationship also exists between emissions of CO₂ and per capita GDP. The most significant argument is that there is a negative correlation between emissions of CO₂ and combustible energy and waste consumption. There is a weak positive link between the variable CEWC and GDP per in the top nine countries, but there is a strong positive correlation between these two in the Visegrad countries. There is a negative correlation between CEWC and emissions of CO₂ in leading countries, but there is a positive correlation between these variables in the Visegrad countries (Table 2). The correlation is explained by the fact that the energy efficiency of the top nine countries is much better than that of the V4 countries. The differences in the related technological background and the use of biomass forms (energy density) should be highlighted. In the V4 countries, the Kuznets curve shows a fundamentally inverted N-shape, because the economy is entering a new stage of production (after the financial crisis) with very intensive energy demand, so the pollution indicators (CO₂) are also jumping [40,54,55].

Table 2. Correlation Matrix.

(a) Correlation Matrix for the 13 Selected Countries of Europe			
	GDP	CEWC	CO ₂
GDP	1		
CEWC	0.10	1	
CO ₂	0.31	−0.37	1
(b) Correlation Matrix for the Nine Selected Developed Countries of Europe			
	GDP	CEWC	CO ₂
GDP	1		
CEWC	0.12	1	
CO ₂	0.25	−0.38	1

Table 2. Cont.

(c) Correlation Matrix for Selected Visegrad 4 (V4) Countries of Europe			
	GDP	CEWC	CO ₂
GDP	1		
CEWC	0.59	1	
CO ₂	−0.15	0.26	1

4.3. Stationary Test

The most general model of the panel data, the Hardi LM test, and the Levin–Lin–Chu (LLC) unit-root test can be applied to check whether panel data is stationary or not. To do so, we have carried out the following:

Hardi LM Test	LLC unit-root test
Ho: All panels are stationary Ha: Some panels contain unit roots	Ho: Panels contain unit roots Ha: Panels are stationary

4.4. Regression Analysis

Since all the data are stationary at the first difference (Table 3), we can apply the regression. The Hausman test suggested that the fixed effect regression model is considered the appropriate model for this study's panel data. The results of the Hausman test are given in Appendix B.

Table 3. Results of Stationary Test.

(a) Unit Root Test for Selected 13 Countries of Europe								
Hardi LM Test					Levin–Lin–Chu (LLC) Unit-Root Test			
Variables	Level		First Difference		Level		First Difference	
	Statistic	<i>p</i> -value	Statistic	<i>p</i> -value	Statistic	<i>p</i> -value	Statistics	<i>p</i> -value
GDP	60.22	0.00	−1.46 *	0.92	−0.86	0.19	−10.61 *	0.00
CO ₂	40.65	0.00	−0.51 *	0.69	−0.36	0.35	−8.18 *	0.00
CEWC	58.4382	0.00	4.75 *	0.52	4.14	1.00	−6.35 *	0.00
(b) Unit Root Test for the Nine Selected Developed Countries of Europe								
GDP	50.01	0.00	−1.21 *	0.88	−0.96	0.17	−8.80 *	0.00
CO ₂	32.01	0.00	−0.23 *	0.59	0.47	0.68	−5.65 *	0.00
CEWC	49.91	0.00	8.79 *	0.23	4.53	1.00	−4.59 *	0.00
(c) Unit Root Test for the Selected Visegrad 4 (V4) Countries of Europe								
GDP	34.6	0.00	−0.89 *	0.81	−0.18	0.42	−5.94 *	0.00
CO ₂	30.63	0.00	0.03 *	0.48	−1.36	0.08	−6.48 *	0.00
CEWC	30.87	0.00	−1.35 *	0.91	0.15	0.56	−4.56 *	0.00

* All panels are stationary at the first difference at a 5% level of significance.

Since (Prob > chi2 = 0.0000), we reject the null hypothesis, and the fixed effect is appropriate for discussion. According to the regression result with fixed effect, there was a positive relationship between GDP per capita and combustible energy and waste consumption in all the selected 13 countries and top nine countries and Visegrad countries. The coefficients are different. Table 4 shows results of the Pooled Regression.

The value of the coefficient of combustible energy and waste consumption (CEWC) for the 13 selected and top nine countries are 2161.94 and 2920.23, respectively. This means that if the usage of CEWC increases by one unit, GDP per capita increases by \$2161.94 and \$2920.23 in the selected 13 countries and top nine countries of Europe, respectively. The coefficient of the Visegrad countries is 842.09. When the usage of CEWC increases by one unit, the GDP per capita for the Visegrad countries will increase by \$842.09. All three

coefficients are statistically significant at a 1% level of significance (Table 5). There was a negative relationship between the emission of CO₂ and GDP per capita for all three categories of country. The value of the coefficients of CO₂ emission is −3312.11 (for the selected 13 countries), −2984.81 (for the top nine countries), and −3640.77 (for the Visegrad countries). This means that if the emission of CO₂ increases by one unit, the GDP per capita will decrease by \$2161.94. According to the regression analysis results, it is clear that in the V4 countries, the increase in CO₂ emissions is a relevant impediment to GDP growth (The main reason for this is that for the V4 countries, the share of renewable energy in the energy mix comes mainly from conventional biomass (wood) combustion, basically, without any technological innovation [55–57]). These coefficients are also statistically significant at a 1% level of significance. The value of the F statistics implies that the model is appropriate for the analysis. The results of the random effect are given in Appendix A.

Table 4. Results of the Pooled Regression.

Dependent Variables: GDP per Capita			
Independent Variables/Constant	Selected 13 Countries of Europe	Selected 9 Developed Countries of Europe	Selected Visegrad Four Countries of Europe
CEWC	2390.21 * (6.58)	3184.13 * (6.37)	1388.49 * (6.76)
CO ₂	−2606.14 * (−5.28)	−1652.49 * (−2.86)	−1917.51 * (−4.78)
Constant	48,921.77 * (6.34)	48,669.54 * (5.85)	20,073.17 * (4.99)
Wald	190.45	109.99	189.10
Probability>	0.0000	0.0000	0.0000
Hausman Test ()	−22.87	−57.68	48.70
Probability>	0.0000	0.0000	0.0000

* All coefficients are significant at a 5% level of significance.

Table 5. The Results of Fixed Regression Output.

Dependent Variables: GDP per Capita			
Independent Variables/Constant	Selected 13 Countries of Europe	Selected Nine Developed Countries of Europe	Selected Four Visegrad Countries of Europe
CEWC	2161.94 * (5.91)	2920.23 * (5.60)	842.09 * (4.00)
CO ₂	−3312.11 * (−6.47)	−2984.81 * (−4.66)	−3640.77 * (−7.74)
Constant	56,356.35 * (9.70)	62,786.70 * (8.04)	36,038.80 * (8.12)
F-Statistics	109.57	74.84	140.84
Probability>F	0.0000	0.0000	0.0000
Hausman Test ()	−22.87	−57.58	48.70
Probability>	0.0000	0.0000	0.0000

* All coefficients are significant at a 5% level of significance.

4.5. Results of Panel Cointegration Test

Pedroni proposed the method of cointegration testing panel data. The test spectates the long-term relationship among the variables for the selected panel. Variables should have a unit root on the label but be stationary at the first difference to conduct a cointegration test. In the unit root analysis, all the data are not stationary at the level of the results. However, all are stationary at the first difference. The result of the panel cointegration test confirms three statistics (Panel Rho-statistic; Panel PP-statistics and group PP statistic) with intercept and reject the null hypothesis for selected 13-EU countries at 1% level of significance. There are five statistics (Panel Rho-statistic, PP-statistics and ADF statistic, group PP statistic

and ADF statistic) with intercept and trends are significant at a 1% level of significance. Consequently, GDP per capita, CEWC and CO₂ are cointegrated for the selected panel of 13 European countries.

For the top nine European countries, the panel cointegration test outcome confirms four statistics (Panel PP and ADF statistic and group PP and ADF statistic) are significant with both intercepts and intercept and trend. This implies rejecting the null hypothesis for the selected top nine countries of the EU at a 1% level of significance. Therefore, GDP per capita, CEWC and CO₂ are cointegrated for the top nine European countries' selected panel. The same result is valid for the Visegrad countries. This means that the GDP per capita, CEWC and CO₂ are cointegrated for the selected panel of Visegrad countries. Therefore, the study confirms a long-term relationship among three variables: GDP per capita, CEWC and CO₂ emission (Table 6).

Table 6. The results of Pedroni Cointegration Test.

(a) For the Selected 13 EU Countries				
Test Statistics	Intercept	<i>p</i>-Value	Intercept and Trend	<i>p</i>-Value
Panel				
v-statistic	−3.1570	0.9992	−5.9458	1.00
Rho-statistic	−4.4331	0.0000	−2.6498	0.0040
PP-statistic	−13.5673	0.0000	−44.7171	0.0000
ADF-statistic	−0.7798	0.2183	−4.3979	0.0000
Group				
Rho-statistic	−1.2343	0.1085	−0.8057	0.7898
PP-statistic	−14.3352	0.0000	−52.9561	0.0000
ADF-statistic	−0.4155	0.3389	−3.9998	0.0000
(b) For the Top Nine EU Countries				
Test Statistics	Intercept	<i>p</i>-value	Intercept and Trend	<i>p</i>-value
Panel				
v-statistic	−3.9734	1.00	−7.2609	1.0000
Rho-statistic	1.8880	0.9699	4.9396	1.0000
PP-statistic	−11.5733	0.0000	−14.2050	0.0000
ADF-statistic	−12.1343	0.0000	−13.2731	0.0000
Group				
Rho-statistic	4.0401	1.0000	6.7310	1.0000
PP-statistic	−14.9022	0.0000	−15.9056	0.0000
ADF-statistic	−11.7890	0.0000	−11.2203	0.0000
(c) For Selected Visegrad 4 (V4) Countries				
Test Statistics	Intercept	<i>p</i>-value	Intercept and Trend	<i>p</i>-value
Panel				
v-statistic	−3.9734	1.0000	−7.2609	1.0000
Rho-statistic	1.8800	0.9699	4.9396	1.0000
PP-statistic	−11.5733	0.0000	−14.2050	0.0000
ADF-statistic	−12.1343	0.0000	−13.2731	0.0000
Group				
Rho-statistic	4.0401	1.0000	6.7310	1.0000
PP-statistic	−14.9022	0.0000	−15.9056	0.0000
ADF-statistic	−11.7890	0.0000	−11.2203	0.0000

4.6. Granger Causality Test

Table 7 shows that all null hypotheses reject a significance level of 5%, which means a bidirectional cause–effect relationship between GDP and CO₂ emissions for all selected 13 countries, top nine EU countries, and four Visegrad countries. There is also a two-way cause–effect relation of CO₂ emissions and combustible energy and waste consumption (CEWC) for all three country categories. There is also a two-way correlation of per capita GDP and combustible energy and waste consumption (CEWC) for all selected 13 countries, top nine countries, and Visegrad countries.

The regression model with the fixed effect is given below:

Table 7. Results of the Granger Causality Test.

(a) Selected 13 Countries of Europe			
Null Hypothesis	Observation	F-Statistics	p-Value
GDP does not Granger Cause CO ₂	330	46.7732	0.00
CO ₂ does not Granger Cause GDP		104.230	0.00
CEWC does not Granger Cause CO ₂	330	33.5861	0.00
CO ₂ does not Granger Cause CEWC		3.02688	0.04
CEWC does not Granger Cause GDP	330	88.8860	0.00
GDP does not Granger Cause CEWC		95.4284	0.00
(b) Selected Nine Developed Countries of Europe			
GDP does not Granger Cause CO ₂	210	43.76	0.00
CO ₂ does not Granger Cause GDP		55.12	0.00
CEWC does not Granger Cause CO ₂	210	145.88	0.00
CO ₂ does not Granger Cause CEWC		20.90	0.00
CEWC does not Granger Cause GDP	210	19.99	0.00
GDP does not Granger Cause CEWC		25.73	0.00
(c) Selected Visegrad 4 (V4) Countries of Europe			
GDP does not Granger Cause CO ₂	60	50.12	0.00
CO ₂ does not Granger Cause GDP		48.57	0.00
CEWC does not Granger Cause CO ₂	60	30.99	0.00
CO ₂ does not Granger Cause CEWC		95.68	0.00
CEWC does not Granger Cause GDP	60	3.79	0.02
GDP does not Granger Cause CEWC		20.50	0.00

5. Conclusions

At the end of the discussion, we conclude that the panel-balanced data regression with the fixed-effect model is appropriate. We tested the cointegration and Granger causality. There was a positive relationship between GDP per capita and combustible energy and waste consumption. GDP per capita and the emission of CO₂ have a negative relationship. In the results of regression, all the coefficients are statistically significant at a 1% level of significance. The results of the cointegration test confirm that all three variables are cointegrated. This implies a long-term relationship among all three variables in the context of all three types of the selected panel. There is a bidirectional cause–effect relation between GDP and CO₂ emissions. There is also a two-way cause–effect relation of CO₂ emissions and combustible energy and waste consumption (CEWC) and per capita GDP and combustible energy and waste consumption (CEWC). The study recommends that promoting combustible energy and waste consumption for the selected country can be a powerful policy instrument. However, this policy will be more useful for the top nine

countries than for the Visegrad countries. One unit of CEWC growth showed 3.4 times higher GDP growth for the top nine countries than for the V4 countries. Based on the results, it is also clear that if CO₂ reduction and economic growth are joint economic development goals, then in the case of the Visegrad countries, the focus should not be on increasing the CEWC area in the GHG reduction strategy.

In the case of the V4 countries, the share of renewable energy in the energy mix comes mainly from the combustion of conventional biomass (wood), basically, without any technological innovation. There is no significant technological innovation behind this form of energy utilization, so it has no positive effect on either energy efficiency or GDP growth. Among the conclusions, it should be pointed out that in countries where the Kuznets curve shows a fundamentally inverted N-shape, after a deep period, economic growth enters a new, energy-intensive phase, resulting in a sudden jump in pollution emission indicators, including CO₂ emissions.

In the Visegrad countries, when the GDP is lower, economic growth is strong in the short term and there is a need to consider extra high energy requirements; the low efficiency of biomass and waste incineration and the moderately advanced technological level have an adverse effect on CO₂ emissions and for GDP growth. In the post-crisis stage of rapid economic development, it is therefore more appropriate to choose another GHG reduction strategy instead of biomass and waste energy recovery. A suitable solution framework can be provided by circular business solutions (up-cycling, down-cycling, reusing, remanufacturing, refurbishing), which implement business solutions for the material cycle. These are often viable models in normal business practice and GHG reduction solutions without any subsidies. In contrast to the V4 countries, for the Top 9 countries studied, combustible renewables and waste for energy utilization could be efficient tool for CO₂ reduction.

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Appendix A



Figure A1. Selected Countries for Study in Europe. Source: based on worldatlasbook.com (accessed on 23 December 2020).

Appendix B

Table A1. The regression model with random effect.

Independent Variables/Constant	Dependent Variables: GDP per Capita		
	Selected 13 Countries of Europe	Selected 9 Developed Countries of Europe	Selected Visegrad Four Countries of Central Europe
CEWC	2390.21 * (6.58)	3184.13 * (6.37)	1388.49 * (6.76)
CO2	−2606.14 * (−5.28)	−1652.49 * (−2.86)	−1917.51 * (−4.78)
Constant	48,921.77 * (6.34)	48,669.54 * (5.85)	20,073.17 * (4.99)
Wald	190.45	109.99	189.10
Probability>	0.0000	0.0000	0.0000
Hausman Test ()	−22.87	−57.68	48.70
Probability>	0.0000	0.0000	0.0000

* denotes that all the coefficients and constants are significant at a 5% level of significance.

Table A2. Result of Hausman Test.

(a) Selected 13 Countries of Europe				
Variables	Coefficients		(b-B)	Standard Error (SE)
	(b) fe	(B) re	Difference	
CEWC	2161.94	2390.21	−228.26	41.10
CO2	−3312.11	−2606.14	−705.97	133.94
Hausman Test	22.87		Probability>	0.0000
Decision	Reject the null hypothesis and fixed effect is appropriate			
(b) Selected 9 Developed Countries of Europe				
CEWC	2920.23	3184.13	146.86	146.86
CO2	−2984.81	−1652.49	−1332.31	279.04
Hausman Test	−57.68		Probability>	0.0000
Decision	Reject the null hypothesis and fixed effect is appropriate			
(c) Selected Visegrad Four Countries of Europe				
CEWC	842.09	1388.49	−546.39	45.01
CO2	−3640.78	−1917.52	−1723.26	245.36
Hausman Test	48.70		Hausman Test	48.70
Decision	Reject the null hypothesis and fixed effect is appropriate			

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