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CO_2 Emissions in the Visegrad Group Countries and the European Union Climate Policy

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Abstract

Climate change is one of the most pressing challenges of our time and several policies trying to mitigate this negative phenomenon have been implemented. The reduction of GHG emissions along with the improvement in energy efficiency and the increase in the share of energy consumption from renewable sources also constitute the European Union policy priority. In this context, the aim of this article is to explore factors that affect changes in CO_2 emissions in the four EU member states that form the Visegrad Group, during the period 1993–2016. The analysis was conducted using the Logarithmic Mean Divisia Index (LMDI) decomposition method and the Kaya identity, which enables the factors contributing most to the CO_2 emissions changes to be identified. It also allows the results to be discussed in relation to the European Union's climate policy.

According to the decomposition analysis results, energy intensity and economic growth measured in terms of GDP per capita were the main factors driving changes in CO_2 emissions across all countries considered. The emissions decrease resulted mainly from an improvement in energy efficiency and to a lesser extent from the change in the energy mix towards renewables.

Keywords: carbon dioxide emissions, LMDI decomposition analysis, the European Union climate policy, Visegrad Group countries

JEL: Q50, Q54

Introduction

Climate change due to global warming has become a vital subject of debate among environmental economists, environmentalists and politicians at national and international levels. Excessive greenhouse gas (GHG) emissions are claimed to be the major reason for this environmental problem, and carbon dioxide (CO_2) is considered the primary greenhouse gas contributing to global warming (Pao and Tsai 2011, p. 685; Tang and Tan 2015, p. 447). The potential consequences of global warming are so severe that the reduction of GHG emissions has become an important policy objective. Therefore, some initiatives have been put in place in order to regulate and reduce emissions. For example, in accordance with the 1997 Kyoto protocol, countries are required to reduce their emissions of six greenhouse gases: CO_2 (the most important one), methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride. The European Union ratified the Kyoto protocol in 2002, and it came into force in 2005. According to the European Union's Europe 2020 strategy, one of the priorities, alongside smart and inclusive growth, is sustainable growth defined as "promoting a more resource efficient, greener and more competitive economy" (*Europe 2020: A strategy…*, p. 10). As emphasised in the document, "these three priorities are mutually reinforcing" (*Europe 2020: A strategy…*, p. 10). This strategy established three, so-called "20–20–20" climate/energy targets: the reduction of greenhouse gas emissions by at least 20% compared to 1990 levels, increase the share of energy from renewable sources in final energy consumption to 20%, and increase energy efficiency by 20%. Furthermore, in 2014, the European Council adopted the 2030 climate and energy framework for the European Union. The 2030 targets are:[1] at least a 40% reduction in GHG emissions compared to 1990 levels, increase the share of renewable energy consumption to at least 32%, and an improvement of at least 32.5% in energy efficiency (*Conclusions on 2030…*, pp. 2, 5–6*; Directive (EU) 2018/2001…*, pp. 82, 105; *Directive (EU) 2018/2002…*, p. 216). It should be noted that establishing a binding target for GHG emissions cuts implements the EU's commitments under the 2015 Paris Agreement.

In this context, the purpose of this article is to explore factors that affect changes in CO_2 emissions in Visegrad Group (V4) countries using the decomposition method and to analyse the results in relation to the European Union's climate policy. The results are expected to demonstrate which factors contributed most to the CO_2 emissions changes between 1993 and 2016, both in the V4 as a whole and at country level.

The Visegrad Group is a regional cooperation comprising (after the dissolution of Czechoslovakia in 1993) four Central European countries – the Czech Republic, Slovakia, Hungary and Poland. The V4 was formed in February 1991 after the collapse of the Soviet bloc with the aim of coordinating the process of post-communist transformation; consequently, the collaboration focused on mutual support in the joint "return to Europe" (see Pakulski (ed.) 2016, p. 7). Since the beginning of the economic

1 The targets initially set for renewables and energy efficiency were revised upwards in 2018.

transition roughly two decades ago, the group has undergone tremendous adjustments. The transition from centrally planned to market-oriented systems was crowned with the accession of the V4 to the European Union. On 1 May 2004, all Visegrad countries became member states of the EU.

All the Visegrad countries experienced a reduction in CO_2 emissions during the 1993–2016 period (see Figure 1). Total emissions decreased by 20%; the biggest decline was reported for Hungary (26%) and the smallest for Poland (only 18%). Due to its size, among other things, Poland is the largest emitter of CO_2 in the analysed group of countries.

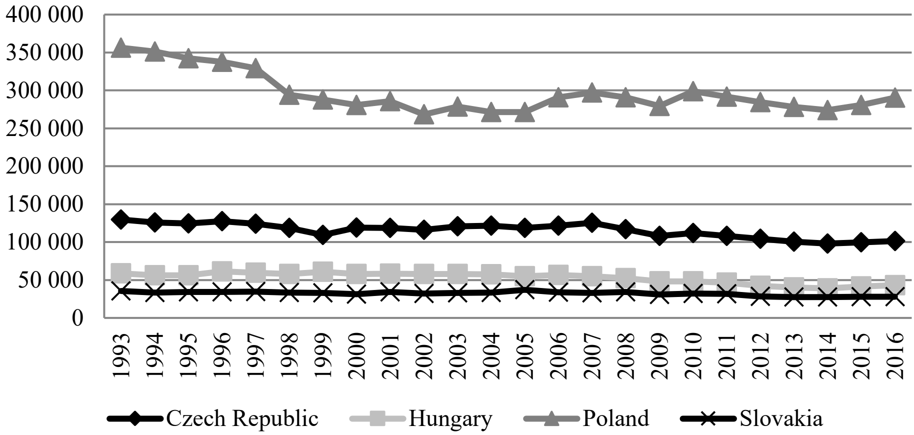

Figure 1. CO_2 emissions in 1000 tons in the Visegrad countries[2]
Source: Eurostat database.

Although many studies have applied decomposition analysis in order to better understand factors that affect changes in CO_2 emissions, there is only a limited number of studies for European countries, despite the fact that these economies are large polluters (González, Landajo and Presno 2014a, p. 12). Moreover, very few are relevant to the Visegrad countries. Several of these studies subsume the V4 countries as part of the European Union or other groups (e.g. OECD), and thus do not explore the role of various factors affecting the emissions at country level – see, for example, Chen et al. (2018), Madaleno and Moutinho (2017), and Moutinho, Moreira and Silva (2015). Some scholars have reported country analysis results alongside the ones for the whole group examined. Examples include González, Landajo and Presno (2014a, b) and Karmellos, Kopidou and Diakoulaki (2016). This paper addresses this gap in the literature and allows us not only to identify the factors that contribute most to changes in CO_2 emissions in the Visegrad countries, but also to assess differences across the economies analysed. Furthermore, it makes it possible to formulate some policy recommendation concerning actions aimed at emissions mitigation. The results of the

2 CO_2 emissions from the combustion of biomass fuels are not included.

research conducted in this paper cover the decomposition of CO_2 emissions for each of the countries concerned, as well as for the V4 countries overall. Additionally, the decomposition results on a year-by-year basis are reported.

Studies explaining the changes in emissions with the use of decomposition analysis differ in terms of the data and methodology (and thus factors) utilised. Many of them employ some form of the Kaya identity, e.g. Fatima et al. (2019), Köne and Büke (2019), Chapman, Fujii and Managi (2018), Chen et al. (2018), Engo (2018), Feng, Huang and Wang (2018), Madaleno and Moutinho (2017), Lima et al. (2016), Mavromatidis et al. (2016), Štreimikienė and Balezentis (2016), Moutinho, Moreira and Silva (2015), Remuzgo and Sarabia (2015), Li, Ou and Chen (2014), O'Mahony (2013), and Kumbaroğlu (2011). In its initial version, the Kaya equation decomposes emissions into four factors: population, GDP per capita, energy per unit of GDP (energy intensity of the economy), and emissions per unit of energy (emissions intensity of energy) (Madaleno and Moutinho 2017, p. 10240; Mavromatidis et al. 2016, p. 344; Shahiduzzaman and Layton 2015, p. 28). Moreover, the Kaya identity is a concrete form of the more general IPAT (I=PAT) framework (Wang and Li 2016, p. 955), which employs three factors to explain emissions: population (P), affluence (A, GDP per capita), and technology (T, emissions per unit of GDP) (Remuzgo and Sarabia 2015, p. 15; Shahiduzzaman and Layton 2015, p. 28; Calbick and Gunton 2014, p. 896). Modifications to the formulae have enabled further investigation of various other driving factors of changes in emissions. For example, Moutinho, Moreira and Silva (2015) analyse six effects: the carbon intensity, the energy mix, the energy intensity, the average renewable capacity productivity, the change in the capacity of renewable energy per capita, and the change in population effect. Additionally, Kumbaroğlu (2011) uses the extended version of the Kaya identity in order to account for effects at the subsectoral level, i.e. the output effect, the carbon intensity of energy use effect, the energy intensity of production effect, and the subsectoral composition effect. Following Moutinho, Moreira and Silva (2015, p. 1488), the most common components analysed are the output, the energy mix, the energy intensity, and the structural effect.

This analysis also utilises the Kaya identity in order to identify which factors are crucial in the reduction of CO_2 emissions. Using this formula enables CO_2 emissions changes to be assessed in relation to changes in energy intensity, which is broadly the inverse of energy efficiency (Shahiduzzaman and Layton 2015, p. 29), and in the carbon intensity of energy use (the emission factor), which reflects the share of renewables in final energy consumption (Štreimikienė and Balezentis 2016, p. 1108). Thus, the analysis facilitates the investigation of the CO_2 emissions drivers which are referenced in the European Union's climate policy. As this issue is underexplored in the literature, especially in the case of the Visegrad Group countries, an examination of the abovementioned factors' impact on CO_2 emissions is evidently important. The decomposition analysis covering the V4 countries between 1993 and 2016 is conducted with the use of the Logarithmic Mean Divisia Index (LMDI) decomposition method.

The structure of the article is as follows. The next section introduces the LMDI decomposition method and describes the data used in the analysis, while the subsequent section presents and discusses the results. The last section concludes.

Methodology and data

In order to explore factors that affected changes in CO_2 emissions in Visegrad Group countries during the 1993–2016 period, this study uses the LMDI decomposition method proposed by Ang, Zhang and Choi (1998). This approach was selected as the decomposition technique for the analysis due to the many advantages it provides; it is easy to apply, can handle zero values and the decomposition formulae hold the same, irrespective of the number of factors considered. The approach gives perfect decomposition, i.e. it does not leave a residual term, which would complicate the interpretation of the results (Ang 2004, p. 1135; Ang 2015, p. 237). It is also consistent in aggregation, which means that effects estimates at the sub-group level can be aggregated to give the corresponding effect at the group level (Ang 2005, p. 870). The LMDI decomposition can be conducted either additively or multiplicatively, and the choice between the two is arbitrary (Ang 2004, p. 1134). The additive and multiplicative results are linked and can be easily converted to each other (Ang 2015, p. 237). This paper uses the additive LMDI approach, which is recommended when an aggregate is a quantity indicator[3] (Ang 2015, p. 237). In such an analysis, the difference change of an aggregate indicator is decomposed (Ang 2004, p. 1134; Ang 2015, p. 234). According to Ang (2015, p. 236) and Ang and Goh (2019, p. 75), the additive decomposition analysis is more popular among researchers in comparison to the multiplicative one, and its popularity has increased over time.

This study also employs the abovementioned Kaya identity to assess the drivers of energy-related CO_2 emissions. Therefore, the decomposition for *k* countries in year *t* is given by:

$$
\begin{aligned}
CO2 &= \sum_{i=1}^{k} CO2_i = \sum_{i=1}^{k} \frac{CO2_i}{fec_i} \times \frac{fec_i}{gdp_i} \times \frac{gdp_i}{pop_i} \times pop_i = \\
&= \sum_{i=1}^{k} e\_fct_i \times e\_int_i \times gdp\_pc_i \times pop_i
\end{aligned}
\tag{1}
$$

where

$CO2_i$ – CO_2 emissions in 1000 tons in country *i*,[4]

fec_i – final energy consumption in million tonnes of oil equivalent in country *i*,

gdp_i – GDP in constant 2010 US$ in country *i*,

[3] Multiplicative decomposition is recommended when an aggregate is an intensity indicator (Ang 2015, p. 237).

[4] See footnote 2.

pop_i – total population in country *i*,
e_fct_i – carbon intensity of energy use (the emission factor) in country *i* calculated as $CO2_i$ and fec_i ratio,
e_int_i – energy intensity in country *i* calculated as fec_i and gdp_i ratio,
gdp_pc_i – GDP per capita in country *i* calculated as gdp_i and pop_i ratio,
k – the number of countries.

In the presented identity, the changes in CO_2 emissions are decomposed into four factors: (i) the carbon intensity/the emission factor, (ii) the energy intensity, (iii) GDP per capita, and (iv) the population size. The first component considered – the carbon intensity of energy use, also referred to as the emission factor (*e_fct*) – shows CO_2 emissions per unit of final energy consumed. It represents the quality of energy mix consumed in the economy (Freitas and Kaneko 2011, p. 1499; Cansino, Sánchez-Braza and Rodríguez-Arévalo 2015, p. 750) and thus reflects the share of renewables in final energy consumption (Štreimikienė and Balezentis 2016, p. 1109). Changing the energy mix towards renewables contributes to the mitigation of CO_2 emissions. The energy intensity (*e_int*) represents the energy consumption per unit of GDP; it is broadly the inverse of energy efficiency (Shahiduzzaman and Layton 2015, p. 29) and is often utilised as a measure of energy efficiency (see González, Landajo and Presno 2014b, p. 741; Cansino, Sánchez-Braza and Rodríguez-Arévalo 2015, p. 750). This paper follows this practice. The decrease in energy intensity is associated with an increase in energy efficiency and thus leads to a decline in CO_2 emissions. The next factor – GDP per capita (*gdp_pc*) – captures the affluence effect originally considered in the IPAT equation, i.e. it represents the contribution to changes in CO_2 emissions resulting from changes in affluence (wealth) (Shahiduzzaman and Layton 2015, p. 30). Finally, an increase in population size (*pop*) is expected to produce increased energy consumption, resulting in higher CO_2 emissions (see Chen et al. 2018, p. 939).

The analysis covers the Visegrad Group countries (the Czech Republic, Hungary, Poland and Slovakia) from 1993–2016. The data on GDP and population are sourced from the World Development Indicators (WDI) database of the World Bank. CO_2 emissions and final energy consumption series have been obtained from the Eurostat database.

According to the additive LMDI method, changes in CO_2 emissions between a base year 0 and year T can be expressed as:

$$\Delta CO2 = CO2^T - CO2^0 = \Delta e\_fct + \Delta e\_int + \Delta gdp\_pc + \Delta pop \quad (2)$$

The components of change in Eq. 2 are given by Eq. 3–6:

$$\Delta e\_fct = \sum_{i=1}^{k} L\left(CO2_i^T, CO2_i^0\right) \times \ln\left(\frac{e\_fct_i^T}{e\_fct_i^0}\right) \quad (3)$$

$$\Delta e\_int = \sum_{i=1}^{k} L\left(CO2_i^T, CO2_i^0\right) \times \ln\left(\frac{e\_int_i^T}{e\_int_i^0}\right) \tag{4}$$

$$\Delta gdp\_pc = \sum_{i=1}^{k} L\left(CO2_i^T, CO2_i^0\right) \times \ln\left(\frac{gdp\_pc_i^T}{gdp\_pc_i^0}\right) \tag{5}$$

$$\Delta pop = \sum_{i=1}^{k} L\left(CO2_i^T, CO2_i^0\right) \times \ln\left(\frac{pop_i^T}{pop_i^0}\right) \tag{6}$$

where the logarithmic mean is defined as:

$$L\left(CO2_i^T, CO2_i^0\right) = \frac{CO2_i^T - CO2_i^0}{\ln CO2_i^T - \ln CO2_i^0} \tag{7}$$

Research results

The additive decomposition results of CO_2 emissions in the Visegrad Group countries for the sub-periods 1993–2004, 2004–2008, 2008–2009 and 2009–2016 are shown in Table 1 below. The analysis comprises countries which have undergone a transition process from centrally planned economies to market economies following the collapse of the Soviet bloc. Therefore, the first sub-period (1993–2004) covers the transformation period until joining the European Union in 2004. The second period applies to the years 2004–2008. Following Vehmas, Kaivo-oja and Luukkanen (2018) and Wang, Ang and Su (2017), the period of economic crisis covers the years 2008–2009. Due to data availability, the post-crisis period (2009–2016) is limited to the year 2016. Table A1 in the Appendix reports the results between 1993 and 2016 on a year-by-year basis.

Table 1. Decomposition results of changes in CO_2 emissions in the Visegrad countries – sub-periods

Period	Δe_fct	Δe_int	Δgdp_pc	Δpop	ΔCO_2
1993–2004	–65,251.1	–260,163.9	234,238.9	–5,010.8	–96,186.9
2004–2008	–7,382.7	–79,902.7	96,402.6	1,425.6	10,542.8
2008–2009	–15,744.6	–9,212.6	–3,641.9	800.0	–27,799.0
2009–2016	–26,957.5	–63,223.2	87,471.6	–855.1	–3,564.2
1993–2016	–119,944.4	–423,462.4	430,035.4	–3,635.9	–117,007.3

Source: own calculations based on Eurostat and World Development Indicators data.

Globally, the Visegrad countries experienced a 20% drop in CO_2 emissions between 1993 and 2016, which corresponds to an emissions reduction of 117,007.3 kt. Energy intensity and GDP per capita were the main factors driving the abovementioned change. The increase in CO_2 emissions caused by the growth of GDP per capita (430,035.4 kt) was largely compensated for by the emissions fall resulting from the decrease in energy intensity (423,462.4 kt), which is associated with an increase in energy efficiency. The carbon intensity decline reflecting the higher share of renewables in final energy consumption also made a significant contribution to the reduction of CO_2 emissions. The impact of population size changes was negligible. A similar pattern was detected for the 2009–2016 sub-period. Between 1993 and 2004, the decrease in CO_2 emissions owing to energy efficiency improvement individually outweighed the emissions increase arising from GDP per capita growth. During the economic crisis (2008–2009), the GDP per capita fall in all V4 countries (except Poland) also contributed, next to the change in energy intensity and carbon intensity, to the drop in CO_2 emissions. In contrast to the other analysed sub-periods, in the years 2004–2008 CO_2 emissions rose. The changes in energy intensity and carbon intensity were not able to offset the negative impact, from a CO_2 mitigation perspective, of GDP per capita increase.

The decomposition analysis conducted for the whole Visegrad Group revealed that energy intensity and economic growth measured in terms of GDP per capita played the key role in the CO_2 emissions changes. The emissions decline was predominantly caused by the energy efficiency improvement and, to a much lesser extent, the change of the energy mix towards renewables. These two emissions-reducing factors coincide with the European Union's climate/energy targets, but the impact of the first one is much more significant. This is an important outcome from the EU climate policy perspective.

Turning to the country-level analysis, it should be noted that, although CO_2 emissions decreased considerably in the Visegrad Group as a whole, the scale of the changes varied substantially among the countries considered. In the years 1993–2016, emissions declined by 26% in Hungary, 22% in the Czech Republic, 21% in Slovakia, and only 18% in Poland, which corresponds to drops of 15,456.9 kt, 28,309.7 kt, 7,429.8 kt, and 65,810.9 kt, respectively. Although the percentage reduction is the lowest in Poland, it is the highest in kilotonnes. This is related to the fact that Poland is the largest country in the V4 and the largest emitter.

Tables 2–5 present the decomposition results separately for each of the countries considered. The year-by-year results are presented in Tables A2–A5 of the Appendix.

Table 2. Decomposition results of changes in CO_2 emissions in the Czech Republic – sub-periods

Period	Δe_fct	Δe_int	Δgdp_pc	Δpop	ΔCO_2
1993–2004	−1,332.3	−45,218.0	39,979.7	−1,623.9	−8,194.6
2004–2008	−1,755.5	−27,819.5	22936.3	2,172.8	−4,465.8
2008–2009	−4,410.1	1,142.5	−6,181.7	641.3	−8,807.9
2009–2016	−5,581.7	−15,020.0	12,539.7	1,220.6	−6,841.4
1993–2016	−13,540.5	−83,534.8	66,163.5	2,602.0	−28,309.7

Source: see Table 1.

Table 3. Decomposition results of changes in CO_2 emissions in Hungary – sub-periods

Period	Δe_fct	Δe_int	Δgdp_pc	Δpop	ΔCO_2
1993–2004	–5,593.1	–16,385.4	22,250.0	–1,418.0	–1,146.5
2004–2008	–4,437.8	–5,755.8	5,504.7	–375.2	–5,064.2
2008–2009	–3,351.3	2,553.1	–3,347.9	–77.7	–4,223.9
2009–2016	–7,104.2	–3,558.2	6,597.8	–957.8	–5,022.4
1993–2016	–20,176.3	–20,918.3	28,354.3	–2,716.7	–15,456.9

Source: see Table 1.

Table 4. Decomposition results of changes in CO_2 emissions in Poland – sub-periods

Period	Δe_fct	Δe_int	Δgdp_pc	Δpop	ΔCO_2
1993–2004	–56,657.8	–181,961.7	156,023.6	–2,272.3	–84,868.1
2004–2008	–624.6	–37,232.7	57,711.2	–415.8	19,438.1
2008–2009	–7,100.2	–12,073.9	7,737.8	193.2	–11,243.1
2009–2016	–12,268.6	–38,037.9	62,527.8	–1,359.1	10,862.2
1993–2016	–81,146.2	–287,339.2	306,817.2	–4,142.8	–65,810.9

Source: see Table 1.

Table 5. Decomposition results of changes in CO_2 emissions in Slovakia – sub-periods

Period	Δe_fct	Δe_int	Δgdp_pc	Δpop	ΔCO_2
1993–2004	–1,668.0	–16,598.8	15,985.6	303.4	–1,977.8
2004–2008	–564.9	–9,094.6	10,250.4	43.8	634.7
2008–2009	–882.9	–834.3	–1850.1	43.2	–3,524.1
2009–2016	–2,002.9	–6,607.0	5806.3	241.1	–2,562.6
1993–2016	–5,081.5	–31,670.1	28,700.3	621.6	–7,429.8

Source: see Table 1.

The general pattern of the results obtained for the Visegrad Group as a whole also holds at the country-level analysis. In the years 1993–2016, the main drivers of CO_2 emissions changes across all analysed countries were energy intensity and economic growth expressed in terms of GDP per capita. The decrease in CO_2 emissions owing to the decline in energy intensity (and thus energy efficiency improvement) and, to a much lesser extent, to the drop in carbon intensity exceeded the increase in emissions due to the growth of GDP per capita. The impact of population size changes was negligible.

The decomposition results comprising the years 2004–2008 show that Hungary and the Czech Republic reduced CO_2 emissions during this period, while Poland and Slovakia recorded the increase in CO_2 emissions. In the last two countries, the negative effect, from a CO_2 mitigation perspective, of GDP per capita growth outweighed the positive impact of energy intensity and carbon intensity decrease.

Another sub-period requiring in-depth discussion is the economic crisis (2008–2009). Among the V4 countries, only Poland experienced a GDP per capita growth during this period. It had consequences with regards to CO_2 emissions changes. In the Czech Republic, Hungary and Slovakia, the decline of GDP per capita led to a decrease in CO_2 emissions, while in Poland it contributed to an increase in emissions. In turn, in the Czech Republic and Hungary, in contrast to the other sub-periods, energy intensity increased, thus inducing CO_2 emissions growth. Overall, CO_2 emissions declined between 2008 and 2009 in all Visegrad Group states as the positive impacts of some factors on emissions reduction outweighed the negative ones.

The energy intensity factor, showing changes in energy efficiency, contributed most to the CO_2 emissions decline in all V4 states during the analysed period (1993–2016), but its impact differed among countries. In relation to the second emission-reducing factor – carbon intensity, which reflects the share of renewables in final energy consumption – energy intensity played the most important role in Slovakia and the Czech Republic, where it led to a decrease in emissions approximately six times greater compared to the second factor. On the other hand, in Hungary, its impact was only slightly bigger than that of carbon intensity. It is, however, important to mention that between 1993 and 2015, the share of renewable energy consumption in total final energy consumption increased the most in Hungary (from 5.0 to 15.6%) and the least in Poland (from 6.1 to 11.9%).[5]

Conclusion

Climate change and its possible consequences for mankind have made greenhouse gas emissions reduction a pressing issue. The European Union policy addresses this problem and treats climate change mitigation as an integral element of sustainable development policy. In this context, the purpose of this article was to explore factors that affect changes in CO_2 emissions in four member states of the EU (the Visegrad Group countries) during the period 1993–2016. The analysis conducted with the use of the LMDI decomposition method was expected to indicate the most influencing factors and to enable a discussion of the results in relation to the European Union's climate policy.

The reduction of greenhouse gas emissions, the improvement in energy efficiency and the increase in the share of energy from renewable sources in final energy consumption constitute a priority of the EU policy. During the research period, emissions of the main GHG that contribute to global warming – CO_2 – declined in all V4 countries. The largest decrease was recorded for Hungary (26%) and the smallest for Poland (18%), while as a whole the Visegrad Group reduced emissions by 20%. The decomposition results show that in terms of CO_2 emissions mitigation, the energy intensity factor was more influential than the carbon intensity factor, both for the Visegrad Group countries overall and for individual economies. This means that an increase in energy efficiency contributed more to the CO_2 decrease than the change of energy mix towards renewables. Taking this into account, more emphasis should be put

5 Source: World Development Indicators database (EG.FEC.RNEW.ZS series). The year 2015 is the last year for which data is available.

on improving the quality of the energy mix consumed in the economy as this factor may be an important means of bringing about a reduction in CO_2 emissions. This recommendation is of particular importance for Poland, as among the V4 countries it reported the least progress in this area and the smallest percentage drop in CO_2 emissions, while simultaneously being the largest emitter. The share of renewable energy consumption in the total final energy consumption increased the most in Hungary; however, the share in 2015 did not exceed 16% in any of the Visegrad countries.[6]

In view of international pressure to reduce CO_2 emissions and European Union climate policy targets, further efforts to improve energy efficiency, and especially to increase the share of energy consumption from renewable sources, can be recommended in order to overcome the influence of GDP per capita growth, which has been revealed in the analysis to be one of the main drivers of changes in CO_2 emissions.

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6 Source: World Development Indicators database (EG.FEC.RNEW.ZS series).

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Appendix A

Results of changes in CO_2 emissions by year for each of the Visegrad countries, period 1993–2016

Table A1. Decomposition results of changes in CO_2 emissions in the Visegrad countries, period 1993–2016

Period	Δe_fct	Δe_int	Δgdp_pc	Δpop	ΔCO_2
1993–1994	6,617.0	–45,950.1	24,792.2	849.9	–13,691.0
1994–1995	–15,583.9	–27,219.4	33,186.0	414.8	–9,202.5
1995–1996	–20,173.4	–3,275.2	27,375.6	83.7	4,010.7
1996–1997	–1,783.0	–35,914.5	24,116.9	24.4	–13,556.2
1997–1998	–13,336.4	–47,742.4	17,513.7	–94.9	–43,660.0
1998–1999	267.8	–29,511.2	16,892.7	–274.6	–12,625.4
1999–2000	10,624.5	–32,945.6	23,775.9	–3,488.3	–2,033.5
2000–2001	–827.3	–1,983.0	10,894.5	–717.8	7,366.3
2001–2002	–17,165.7	–16,754.8	12,084.6	–531.5	–22,367.5
2002–2003	1,164.6	–2,594.8	18,075.9	–405.6	16,240.1
2003–2004	–15,525.5	–15,242.1	24,358.1	–258.5	–6,668.0
2004–2005	–6,836.0	–16,620.7	21,695.1	–61.6	–1,823.2
2005–2006	7,934.8	–16,526.2	29,740.1	61.5	21,210.3
2006–2007	11,872.9	–34,830.0	29,912.7	484.3	7,439.9
2007–2008	–20,499.9	–13,522.6	16,757.8	980.5	–16,284.2
2008–2009	–15,744.6	–9,212.6	–3,641.9	800.0	–27,799.0
2009–2010	–2,089.2	11,841.0	15,175.1	–584.3	24,342.5
2010–2011	–593.1	–30,515.0	17,760.3	293.0	–13,054.8
2011–2012	–12,720.2	–9,304.3	3,527.5	–30.8	–18,527.7
2012–2013	–8,510.2	–9,293.0	4,881.8	–219.6	–13,140.9
2013–2014	5,368.3	–27,038.3	14,239.1	–182.4	–7,613.3
2014–2015	1,982.5	–9,176.9	17,992.5	–59.6	10,738.4
2015–2016	–10,266.4	10,935.1	13,041.1	–18.0	13,691.8
1993–2016	–119,944.4	–423,462.4	430,035.4	–3,635.9	–117,007.3

Source: own calculations based on Eurostat and World Development Indicators data.

Table A2. Decomposition results of changes in CO_2 emissions in the Czech Republic, period 1993–2016

Period	Δe_fct	Δe_int	Δgdp_pc	Δpop	ΔCO_2
1993–1994	3,536.4	–11,122.8	3,616.6	46.1	–3,923.7
1994–1995	189.8	–8,973.0	7,630.3	–76.7	–1,229.7
1995–1996	1,244.4	–3,312.3	5,362.6	–146.8	3,147.9
1996–1997	–2,162.0	–671.6	–615.2	–135.7	–3,584.5
1997–1998	–794.4	–4,286.0	–284.6	–115.0	–5,479.9
1998–1999	–3,604.1	–7,139.0	1,738.3	–116.5	–9,121.2
1999–2000	5,426.5	–601.7	5,093.2	–320.3	9,597.7
2000–2001	–2,328.2	–1,528.9	3,855.0	–446.6	–448.7
2001–2002	–378.6	–4,245.1	2,148.7	–226.3	–2,701.3
2002–2003	–575.2	1,360.3	4,225.4	–33.9	4,976.7
2003–2004	–1,719.1	–3,514.6	5,769.0	36.9	572.2
2004–2005	–1,138.7	–9,407.2	7,429.6	166.0	–2,950.3
2005–2006	1,153.7	–6,144.4	7,631.1	325.0	2,965.4
2006–2007	6,382.2	–9,068.8	6,012.9	720.8	4,047.1
2007–2008	–8,064.3	–3,672.9	2,203.6	1,005.6	–8,528.0
2008–2009	–4,410.1	1,142.5	–6,181.7	641.3	–8,807.9
2009–2010	2,291.7	–1,165.9	2,152.5	320.5	3,598.8
2010–2011	–197.4	–5,456.4	1,710.3	227.3	–3,716.2
2011–2012	–3,512.1	419.9	–1,000.7	148.5	–3,944.4
2012–2013	–2,968.7	–342.4	–529.6	33.9	–3,806.7
2013–2014	585.6	–5,556.6	2,552.8	104.4	–2,313.7
2014–2015	–876.1	–2,631.6	4,918.8	194.3	1,605.4
2015–2016	–726.2	–111.7	2,380.3	193.0	1,735.4
1993–2016	–13,540.5	–83,534.8	66,163.5	2,602.0	–28,309.7

Source: see Table A1.

Table A3. Decomposition results of changes in CO_2 emissions in Hungary, period 1993–2016

Period	Δe_fct	Δe_int	Δgdp_pc	Δpop	ΔCO_2
1993–1994	–2,114.5	–2,016.3	1,742.2	–78.4	–2,467.0
1994–1995	22.7	–829.0	907.1	–78.1	22.7
1995–1996	3,148.6	2,125.8	109.1	–100.8	5,282.7
1996–1997	1,210.4	–4,938.6	2,109.2	–121.9	–1,740.8
1997–1998	–2,062.7	–2,071.9	2,574.8	–136.7	–1,696.5
1998–1999	1,604.7	–765.1	2,027.1	–167.9	2,698.9
1999–2000	–1,471.5	–3,541.6	2,600.3	–154.1	–2,566.9
2000–2001	–2,773.8	627.7	2,322.0	–133.2	42.6
2001–2002	–723.5	–2,222.9	2,729.5	–164.9	–381.8
2002–2003	–2,069.1	149.7	2,350.4	–165.7	265.3
2003–2004	–278.8	–3,143.7	2,944.6	–127.7	–605.6
2004–2005	–5,725.7	993.7	2,525.8	–111.8	–2,318.0
2005–2006	2,217.6	–2,711.7	2,198.0	–87.0	1,616.9
2006–2007	1,768.8	–3,665.6	328.8	–86.5	–1,654.5
2007–2008	–2,708.6	–457.1	551.0	–94.0	–2,708.6
2008–2009	–3,351.3	2,553.1	–3,347.9	–77.7	–4,223.9
2009–2010	–865.2	509.2	435.6	–108.7	–29.1
2010–2011	–1,677.3	–509.1	914.7	–134.2	–1,405.9
2011–2012	–1,705.5	–1,879.1	–507.3	–229.6	–4,321.4
2012–2013	–2,247.1	–607.6	971.1	–113.8	–1,997.4
2013–2014	–385.5	–2,609.3	1,748.9	–106.8	–1,352.7
2014–2015	–605.7	1,537.6	1,423.5	–95.4	2,260.0
2015–2016	630.1	271.4	1,047.0	–124.4	1,824.1
1993–2016	–20,176.3	–20,918.3	28,354.3	–2,716.7	–15,456.9

Source: see Table A1.

Table A4. Decomposition results of changes in CO_2 emissions in Poland, period 1993–2016

Period	Δe_fct	Δe_int	Δgdp_pc	Δpop	ΔCO_2
1993–1994	6,654.9	–30,112.5	17,492.5	746.2	–5,218.9
1994–1995	–16,695.8	–15,491.4	22,821.9	470.4	–8,894.9
1995–1996	–23,299.2	–1,069.7	19,730.9	258.6	–4,379.4
1996–1997	–1,376.5	–27,971.8	20,657.4	218.3	–8,472.7
1997–1998	–9,857.1	–39,442.9	13,933.7	111.3	–35,255.1
1998–1999	1,851.0	–21,071.0	13,229.4	–24.2	–6,014.7
1999–2000	8,860.7	–28,709.1	15,651.6	–2,970.3	–7,167.1
2000–2001	2,844.4	–1,468.2	3,591.7	–78.2	4,889.8
2001–2002	–13,971.4	–9,104.8	5,724.7	–128.3	–17,479.8
2002–2003	1,939.4	–1,232.7	9,753.6	–184.5	10,275.8
2003–2004	–14,342.9	–6,577.9	13,930.4	–160.9	–7,151.2
2004–2005	–1,914.4	–7,456.7	9,437.7	–119.3	–52.6
2005–2006	7,024.5	–4,171.5	17,031.6	–178.1	19,706.5
2006–2007	4,334.0	–18,081.3	20,157.3	–159.7	6,250.3
2007–2008	–10,260.2	–8,443.6	12,197.7	40.1	–6,466.0
2008–2009	–7,100.2	–12,073.9	7,737.8	193.2	–11,243.1
2009–2010	–2,574.1	11,480.6	11,067.7	–825.5	19,148.7
2010–2011	36.7	–21,657.3	14,289.0	158.7	–7,172.8
2011–2012	–5,845.9	–5,931.4	4,593.8	–0.7	–7,184.1
2012–2013	–1,458.2	–8,731.8	4,056.9	–169.7	–6,302.9
2013–2014	3,535.7	–16,528.3	9,219.2	–206.6	–3,979.9
2014–2015	3,414.7	–7,314.1	10,632.8	–184.8	6,548.6
2015–2016	–9,679.5	10,871.4	8,735.6	–122.7	9,804.7
1993–2016	–81,146.2	–287,339.2	306,817.2	–4,142.8	–65,810.9

Source: see Table A1.

Table A5. Decomposition results of changes in CO_2 emissions in Slovakia, period 1993–2016

Period	Δe_fct	Δe_int	Δgdp_pc	Δpop	ΔCO_2
1993–1994	–1,459.8	–2,698.4	1,940.9	135.9	–2,081.4
1994–1995	899.5	–1,926.0	1,826.7	99.2	899.5
1995–1996	–1,267.3	–1,018.9	2,173.0	72.7	–40.5
1996–1997	545.2	–2,332.5	1,965.4	63.6	241.7
1997–1998	–622.3	–1,941.6	1,289.8	45.5	–1,228.5
1998–1999	416.1	–536.2	–102.2	33.9	–188.4
1999–2000	–2,191.2	–93.2	430.8	–43.6	–1,897.2
2000–2001	1,430.3	386.4	1,125.8	–59.8	2,882.7
2001–2002	–2,092.2	–1,182.0	1,481.7	–12.1	–1,804.6
2002–2003	1,869.5	–2,872.2	1,746.6	–21.5	722.3
2003–2004	815.3	–2,006.0	1,714.0	–6.8	516.6
2004–2005	1,942.8	–750.5	2,301.9	3.5	3,497.6
2005–2006	–2,460.9	–3,498.6	2,879.4	1.6	–3,078.4
2006–2007	–612.0	–4,014.4	3,413.8	9.7	–1,202.9
2007–2008	533.2	–949.0	1,805.5	28.7	1,418.4
2008–2009	–882.9	–834.3	–1,850.1	43.2	–3,524.1
2009–2010	–941.7	1,017.1	1,519.3	29.3	1,624.0
2010–2011	1,244.8	–2,892.2	846.3	41.2	–759.9
2011–2012	–1,656.7	–1,913.8	441.7	51.0	–3,077.8
2012–2013	–1,836.2	388.8	383.5	30.0	–1,033.9
2013–2014	1,632.5	–2,344.1	718.1	26.6	33.1
2014–2015	49.5	–768.8	1,017.4	26.3	324.4
2015–2016	–490.7	–96.0	878.2	36.0	327.5
1993–2016	–5,081.5	–31,670.1	28,700.3	621.6	–7,429.8

Source: see Table A1.

Streszczenie

Emisja CO_2 w krajach Grupy Wyszehradzkiej a polityka klimatyczna Unii Europejskiej

Zmiana klimatu jest jednym z najbardziej palących wyzwań naszych czasów. W związku z tym podejmowany jest szereg działań mających na celu złagodzenie tego negatywnego zjawiska. Redukcja emisji gazów cieplarnianych, poprawa efektywności energetycznej oraz wzrost udziału energii ze źródeł odnawialnych stanowią także priorytet polityki Unii Europejskiej. W tym kontekście celem artykułu jest zbadanie czynników wpływających na zmiany emisji CO_2 w czterech państwach członkowskich UE tworzących Grupę Wyszehradzką, w latach 1993–2016. Analiza przeprowadzona z wykorzystaniem metody dekompozycji LMDI (Logarithmic Mean Divisia Index) oraz tożsamości Kaya pozwala zidentyfikować czynniki, które w największym stopniu przyczyniają się do zmian emisji CO_2. Umożliwia ona także omówienie uzyskanych wyników w powiązaniu z polityką klimatyczną Unii Europejskiej.
Zgodnie z wynikami analizy dekompozycyjnej energochłonność oraz wzrost gospodarczy wyrażony PKB per capita były głównymi czynnikami przyczyniającymi się do zmian emisji CO_2 we wszystkich rozważanych krajach. Spadek emisji wynikał głównie z poprawy efektywności energetycznej i w mniejszym stopniu ze zmian koszyka energetycznego w stronę odnawialnych źródeł energii.

Słowa kluczowe: emisja dwutlenku węgla, analiza dekompozycyjna LMDI, polityka klimatyczna Unii Europejskiej, kraje Grupy Wyszehradzkiej