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Energy-Related Greenhouse Gas Emissions in Poland from 2000 to 2018: An LMDI Decomposition Analysis Perspective

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Abstract:

Purpose: *The primary purpose of this paper is to carry out a multidimensional analysis of determinants of changes to GHG emissions in Poland between 2000 and 2018. This study found that GHG emissions generally followed an upward trend over the study period, although deviations in different directions were recorded in some years. This means that shifting to a low-carbon economy-as a way to counteract climate warming-poses a considerable challenge to Poland. It becomes imperative as the EU has intensified its measures taken to become climate-neutral.*

Design/Methodology/Approach: *This paper contributes to research on climate change drivers related to energy use. The analysis was based on descriptive statistics and decomposition methods. The Logarithmic Mean Divisia Index (LMDI), one of the most widely adopted forms of index decomposition analysis, was employed to identify the determinants of GHG emissions. This was based on the additive specification.*

Findings: *This study identified rapid economic growth—and the corresponding increase in energy consumption primarily derived from fossil fuels, mainly including coal and lignite—as the main reason behind the increase in GHG emissions in Poland between 2000 and 2018. Moreover, it follows from the decomposition analysis that the reduction in GHG emissions was due to a decrease in GHG emissions per unit of energy, improvements in fuel conversion efficiency, a reduction in final energy consumption per unit of GDP, and a small extent-by population change. However, the positive impact of these factors on GHG reduction was smaller than the negative impact of economic growth. As a consequence of these differences, GHG emissions in Poland followed an upward trend.*

Practical implications: *These considerations could help develop an active energy policy focused on climate neutrality.*

Originality/value: *This document broadens and updates knowledge on the determinants of GHG emissions. Also, these findings can provide grounds for accelerating energy transformation processes in Poland.*

Keywords: *Greenhouse gas emissions, Poland, decomposition analysis, LMDI.*

JEL Classification: *O44, P18, Q50, C43*

Paper Type: *Research study.*

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1. Introduction

At the international level, the European Union (EU) is among the most active organizations that have taken several measures for several years to shift to a low-carbon economy to counteract climate warming (Wojtkowska-Łodej, 2014; O'Mahony, 2013). That transformation path is entirely justified given increasingly fast climate changes and their adverse consequences. According to what is known today, the average global temperature grew by ca. 0.8-1.3°C between the pre-industrial era (1850-1900) and the 2011-2020 period, and human industrial activity is believed to be the main reason behind climate warming. The Intergovernmental Panel on Climate Change (IPCC) stated that humans had a dominant impact on the warming process witnessed since the mid-1900s, whereas the combination of natural factors had a minor effect on the change in temperature levels compared to what was recorded in the pre-industrial era (IPCC, 2013).

The urgent need to counteract climate change was emphasized in a special report by IPCC in 2018 (IPCC, 2018). The key conclusion from their report is that while limiting global warming to 1.5°C is possible, it will require deep reductions in greenhouse gas emissions through fast, far-reaching changes at an unprecedented scale to energy, coastal, urban, infrastructural, and industrial systems (IPCC, 2018). Failure to address these challenges will result in a considerable increase in the intensity of adverse climate changes. An increase in the average global temperature above 1.5°C will significantly accelerate sea levels and increase the risk of flooding. It will also result in extreme temperatures and increases in frequency and intensity of precipitation and droughts. Furthermore, it will accelerate the negative changes in marine biodiversity and in coastal ecosystems, which, in turn, will translate into several threats to the functioning of human and ecological systems. These developments will pose more significant risks to health, livelihoods, food security, water supply, human security, and economic growth (IPCC, 2018).

Shifting to a low-carbon economy—to counteract climate warming—poses a considerable challenge both to the European Community and to each member state. As a signatory of the United Nations Framework Convention on Climate Change (UNFCCC) of 1994 and the Kyoto Protocol of 2002, Poland actively contributes to measures taken by the international community to reduce climate change. In the first commitment period of the Kyoto Protocol, Poland agreed to reduce GHG emissions in 2008-2012 by 6% against the baseline year. In turn, in the next period (2013-2020), as provided for in the 2012 Doha amendment, EU countries signed an agreement to meet the reduction goal set against the base year jointly. That goal was expressed in a commitment to attain a yearly average emission level equal to 80% of the total emissions of all countries in the base year (KOBiZE, 2020). Another major step in the fight against climate change was the Brussels summit held by EU countries in October 2014 to agree on the objectives for the EU climate policy by 2030. Reducing GHG emissions by no less than 40% from 1990 to 2030 remains the primary policy goal.

Also agreed was the objective for improvements in energy efficiency, which was afterward (in 2018) modified and set at a higher level. The objective is a 32% reduction in energy demand about forecasts and attaining a share of no less than 32.5% of renewable energies in total energy consumption (Communication, 2014). By seeking these goals, the EU economy and energy system will become more competitive while ensuring increased energy security and improved efficiency measures taken to fight against climate change. These climate policy goals apply to all EU countries. At the current stage, no detailed definition has been provided on how to attain them and how the member countries and sectors of the economy contribute to it (Communication, 2014).

Another crucial step in stopping climate change is the EU's new strategy, adopted at an EU summit held in Brussels in December 2019, focused on becoming climate-neutral by 2050. However, the Polish government found that at this stage, it would be challenging and costly for Poland to shift away from coal and lignite, their primary source of energy. Hence, they did not commit themselves to pursue that goal. Indeed, switching the economy to emission-free fuels will have a series of adverse economic and social impacts. Poland believes that climate neutrality requires more time, adequate investments, and a fair distribution of transformation costs. Note, however, that Poland has made enormous progress in the context of the Kyoto Protocol, reflected by a considerable reduction in GHG emissions from 578.6 Mt (the 1988 baseline) to 412.9 Mt in 2018, i.e., by 28.6% (KOBiZE, 2020). However, the reduction in emission levels is not a permanent trend in Poland. Indeed, an essential reduction in GHG emissions was witnessed only in 1988-2000. Afterward, the emissions level fluctuated quite modestly around a week, through growing trend.

This paper aims to carry out a multidimensional analysis of determinants of changes to GHG emissions in Poland between 2000 and 2018 using the decomposition technique. Formulated as such, that goal was attained using an extended Kaya identity (Kaya, 1990) and the decomposition technique.

2. Research Methodology

Statistical data published by Eurostat, the Union's Statistical Office, was the primary source of materials, including statistics for GHG emissions, energy consumption, and changes to Polish GDP and population (EUROSTAT, 2019 a,b,c). Also, much information was sourced from the National Center for Emissions Management (KOBiZE, 2020), an institution established to administer the Union's Emissions Trading System (ETS) in Poland and keep the national records of greenhouse gas and other emissions. In turn, the determinants of changes to GHG emissions in Poland were analyzed using the index decomposition method in its additive form. The decomposition of greenhouse gas emissions was addressed in many studies carried out at global, economic, sector, industry, and other analytical levels (Ang and Su, 2016; Baležentis *et al.*, 2011; Diakoulaki and Mandaraka, 2007; O'Mahony, 2013; Hatzigeorgiou *et al*., 200; Cansino *et al.,* 2015; González *et al.,* 2014; Ma *et al.,* 2020;

Bacon and Kojima, 2009; Kisielewicz *et al.,* 2016; Hoekstra and van den Bergh, 2003; Wood, 2009; Su and Ang, 2016; Casino *et al.,* 2016). These studies usually relied on two primary methods, i.e., the index and the structural decomposition analysis, to quantitatively determine the strength and direction of the impact of different factors on changes in emissions. The index-based method has an essential advantage over the structural one because it does not require a large amount of data and allows various indicators (absolute values and intensity and flexibility metrics). Also, it enables the relationships under investigation to be mathematically specified in an additive or multiplicative form (Sun *et al.,* 2012; Hoekstra and van den Bergh, 2003). This is not the case for the structural method, which is limited to analyzing absolute values of variables considered (Sun *et al.,* 2012).

The determinants of changes to GHG emissions in Poland were analyzed using the decomposition model proposed by Vailles *et al*. (2018), which builds upon the Kaya identity (1990). The model is as follows:

$$\begin{gathered}GHG \\ emissions\end{gathered} = \frac{Greenhouse\ gases\ emissions}{Gross\ inland\ consumption} \times \frac{Gross\ inland\ consumption}{Final\ energy\ consumption} \times \times \frac{Final\ energy\ consumption}{Gross\ Domestic\ Product} \times \frac{Gross\ Domestic\ Product}{Population} \times Population \quad (1)$$

Using appropriate designations, the model specified above (1) can be structured as:

$$GHG = \frac{GHG}{GIC} \times \frac{GIC}{FEC} \times \frac{FEC}{GDP} \times \frac{GDP}{P} \times P = EMI \times EFI \times ENC \times ECD \times PG \quad (2)$$

where: GHG- greenhouse gas emissions, GIC - gross inland consumption, FEC- final energy consumption, GDP - Gross Domestic Product, P - population.

The indexes used in model (2) allow to analyze the changes in GHG emission levels in a context of impacts driven by five factors (Vailles *et al.,* 2018), i.e., the emission intensity of primary energy (EMI), fuel conversion efficiency (EFI), the amount of final energy consumed per unit of GDP (ENC), economic growth measured as GDP per capita (ECD), and changes to population (PG). When using the additive specification, aggregated changes in GHG emission can be represented as:

$$\Delta GHG = GHG_t - GHG_0 = \Delta EMI + \Delta EFI + \Delta ENC + \Delta ECD + \Delta PG \quad (3)$$

As mentioned earlier, the analysis of model (2) relies on the index decomposition method in one of its most widely adopted forms, i.e., the Logarithmic Mean Division Index (LMDI) proposed by Ang (2005). In its additive specification, the use of LMDI translates into the following formulas that specify the impact of each model factor (2) on changes in GHG emissions:

$$\Delta EMI = L(GHG_0, GHG_t) \times ln\frac{EMI_t}{EMI_0} = \frac{GHG_t - GHG_0}{ln\frac{GHG_t}{GHG_0}} \times ln\frac{EMI_t}{EMI_0} \quad (4)$$

$$\Delta EFI = L(GHG_0, GHG_t) \times ln\frac{EFI_t}{EFI_0} = \frac{GHG_t - GHG_0}{ln\frac{GHG_t}{GHG_0}} \times ln\frac{EFI_t}{EFI_0} \quad (5)$$

$$\Delta ENC = L(GHG_0, GHG_t) \times ln\frac{ENC_t}{ENC_0} = \frac{GHG_t - GHG_0}{ln\frac{GHG_t}{GHG_0}} \times ln\frac{ENC_t}{ENC_0} \quad (6)$$

$$\Delta ECD = L(GHG_0, GHG_t) \times ln\frac{ECD_t}{ECD_0} = \frac{GHG_t - GHG_0}{ln\frac{GHG_t}{GHG_0}} \times ln\frac{ECD_t}{ECD_0} \quad (7)$$

$$\Delta PG = L(GHG_0, GHG_t) \times ln\frac{PG_t}{PG_0} = \frac{GHG_t - GHG_0}{ln\frac{GHG_t}{GHG_0}} \times ln\frac{PG_t}{PG_0} \quad (8)$$

where: $L(GHG_0, GHG_t)$ is the logarithmic average of two positive numbers is defined

as: $L(GHG_0, GHG_t) = \begin{cases} \frac{GHG_t - GHG_0}{lnGHG_t - lnGHG_0}, & GHG_t \neq GHG_0 > 0 \\ GHG_0, & GHG_0 = GHG_t > 0 \end{cases} \quad (9)$

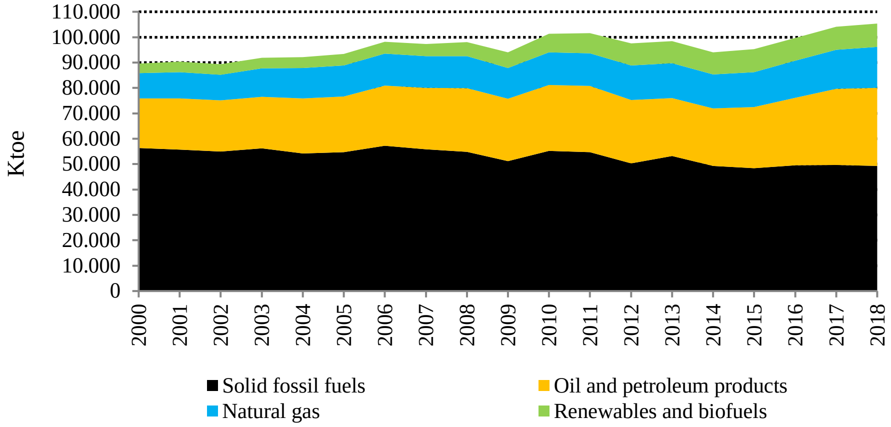
Table 1. *Gross inland energy consumption in Poland in 2000-2018.*

Years	Gross inland consumption	Total fossil fuels^1	Solid fossil fuels	Natural gas	Oil and petroleum products^2	Renewables and biofuels	Non-renewable waste	Electricity	Heat
Thousand tons of oil equivalent (Ktoe)									
2000	89,218	85,862	56,282	9,960	19,620	3,802	103	-548	0.0
2002	88,823	85,168	54,901	10,113	20,153	4,142	120	-608	0.0
2004	91,484	87,814	54,235	11,881	21,698	4,321	125	-799	22.7
2006	97,539	93,481	57,227	12,582	23,672	4,695	282	-945	25.4
2008	98,284	92,519	54,787	12,566	25,166	5,559	241	-58	23.2
2010	101,604	93,981	55,222	12,805	25,954	7,314	398	-116	27.3
2012	97,792	88,910	50,262	13,680	24,968	8,678	419	-244	28.9
2014	94,823	85,352	49,273	13,404	22,675	8,718	515	186	51.8
2016	100,582	90,737	49,537	14,633	26,567	8,910	742	172	21.6
2018	106,880	96,169	49,250	16,124	30,795	9,188	1.011	490	22.2
Structure (%)									
2000	100	96.2	63.1	11.2	22.0	4.3	0.12	-0.61	0.00
2002	100	95.9	61.8	11.4	22.7	4.7	0.14	-0.68	0.00
2004	100	96.0	59.3	13.0	23.7	4.7	0.14	-0.87	0.02
2006	100	95.8	58.7	12.9	24.3	4.8	0.29	-0.97	0.03
2008	100	94.1	55.7	12.8	25.6	5.7	0.24	-0.06	0.02
2010	100	92.5	54.4	12.6	25.5	7.2	0.39	-0.11	0.03
2012	100	90.9	51.4	14.0	25.5	8.9	0.43	-0.25	0.03
2014	100	90.0	52.0	14.1	23.9	9.2	0.54	0.20	0.05
2016	100	90.2	49.3	14.5	26.4	8.9	0.74	0.17	0.02
2018	100	90.0	46.1	15.1	28.8	8.6	0.95	0.46	0.02

^{1}Solid fossil fuels, natural gas, oil, and petroleum products. ^{2}Excluding biofuel portion.
Source: *Own creation.*

Changes in Inland Energy Consumption and GHG Emissions: Table 1 and Figures 1 and 2 present some basic statistics regarding inland energy consumption and its structure in 2000-2018. The analysis suggests that over the study period, energy consumption increased from 89.2-88.8 Mtoe in 2000-2002 to nearly 107 Mtoe in 2018, i.e., by as much as ca. 20%. Such a significant growth can be primarily explained by the increase in energy consumption derived from fossil fuels. Indeed, when considering the first and the last year of the study period, it can be noticed that total consumption of energy derived from fossil fuels went up from ca. 85-86 Mtoe to over 96 Mtoe, i.e., by nearly 12%. However, data are shown in Table 1 also reveals some moderate though noticeable changes in the energy mix. Despite the increase in total energy consumption derived from fossil fuels, its share in inland consumption went down from 96% to 90%. Also, considerable changes were witnessed in the structure of energy derived from fossil fuels. On the one hand, there is a pronounced reduction (from 63% to 43%) in the use of energy derived from solid fuels (coal and lignite). There is the growing importance of lower-emission fuels, i.e., natural gas (from 11.2% to 15.1%) and crude oil (from 22% to 28.8%).

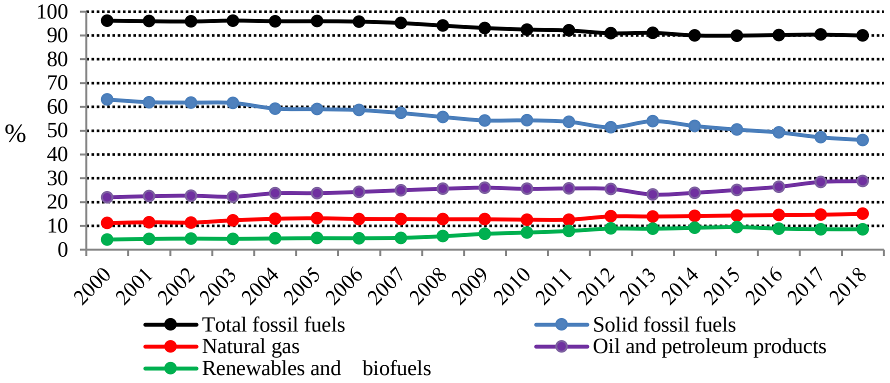
Figure 1. *Gross inland energy consumption in Poland in 2000-2018.*



Source: *Own creation.*

However, the changes depicted above were quite poorly related to renewable energies. Despite the sharp increase in the consumption of renewable energy in absolute terms, from 3.8-4.1 Mtoe (2000-2002) to 8.9-9.2 Mtoe (2016-2018), i.e., by ca. 125%, it had—and continues to have—relatively minor importance in the energy mix. Furthermore, over the last seven years of the study period, the consumption of renewable energies stabilized at a comparable level, with a share of no more than 8-9% in inland consumption (Table 1, Figure 2). Although Poland doubled the share of renewable energies in inland energy consumption, it lags far behind what most EU countries managed to achieve in that respect. In the EU-28, the average share of renewable energies in gross inland consumption in 2018 was ca. 15%, i.e., around 50% more than in Poland (EUROSTAT, 2019b).

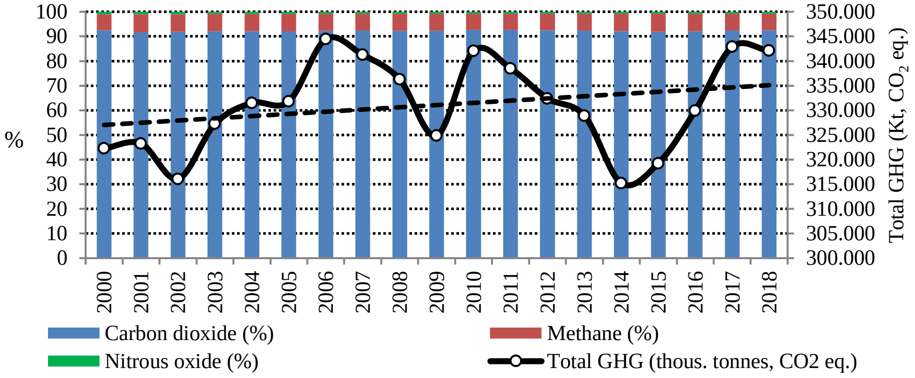
Figure 2. *Gross inland energy consumption structure in Poland in 2000-2018.*



Source: *Own creation.*

Figure 3 present the basic statistics for changes in GHG emission levels in Poland between 2000 and 2018. The analysis suggests that the increase in energy consumption, as mentioned earlier in this paper, translated into various changes in GHG emissions recorded in different sub-periods. In that period, the emissions varied quite modestly between 315,000 kt and 345,000 kt (CO2 eq.), making these changes not significant. However, from the perspective of the trend they follow, these are adverse developments that reflect increased emissions (Fig. 3). A detailed analysis of data (Fig. 3) suggests that the adverse trend is primarily driven by increased emissions in two sub-periods, i.e., 2002-2006 and 2014-2017. Indeed, GHG emissions rose from 316,000 kt to 344,000 kt and from 315,000 kt to 343,000 kt, respectively, i.e., by ca. 9% in both sub-periods. Conversely, a reduction in emissions was recorded in 2006-2009 (by 5%), especially in 2010-2014, with the emissions fell from 342,000 kt to 315,210 kt, i.e., by ca. 8%. However, the drops recorded in these sub-periods were not enough to offset the increased emissions experienced in other years. Therefore, the whole period covered by this analysis generally witnessed a moderate yet positive growth trend in GHG emissions.

Figure 3. *GHG emissions from energy use in Poland in 2000-2018.*



Source: *Own creation.*

Decomposition of Polish Greenhouse Emissions: This section presents the analysis of main conditions that affect the relationship between energy consumption and GHG emissions in Poland following the additive specification of the LMDI method presented earlier in this paper. Changes in GHG emissions between 2000 and 2018 were considered from the perspective of purposefully selected sub-periods and in the context of five determinants of emission levels, namely: the effect of changes in emission intensity (EMI), the effect of changes in fuel conversion efficiency (EFI), the impact of the evolution of final energy consumed per unit of GDP (ENC), the effect of economic growth (ECD), and the effect of demographic change (PG). The sub-periods were identified based on the direction of changes in emissions. Consequently, the analysis results are split into eight sub-periods, including four where an increase in gaseous emissions was recorded and the other four where GHG emissions followed a downward trend. The decomposition analysis was preceded by presenting changes in the values of factors used in the model throughout the 2000-2018 period.

Data shown in Table 2 suggest that the model's factors were changing at a different pace over the study period, and therefore strongly differed in their impact on changes in GHG emissions. Regarding the emission intensity factor (EMI), it can be noticed that despite the establishment of a favorable trend, the changes were minimal. Indeed, emission intensity declined from ca. 3.5-3.6 kt/toe in 2000-2008 to 3.2-3.3 kt/toe in 2014-2018. The marginal changes in that factor are confirmed by the descriptive statistics and by the growth ratio. This is because the coefficient of variation (V=3.94%) is extremely low for the emission factor, matching the meager yearly average growth rate (ΔRC=-0.67%).

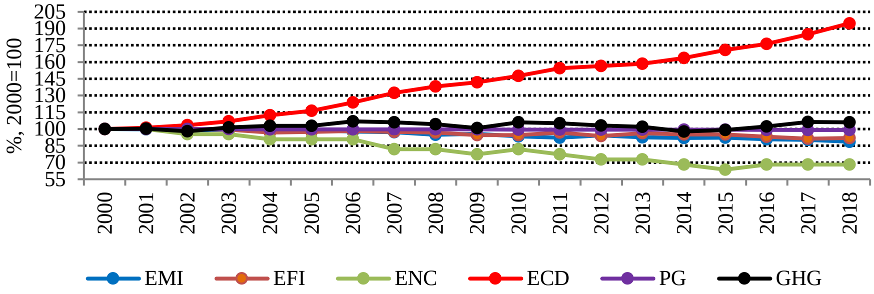
***Table 2.** Changes in GHG emission factors in Poland in 2000-2018.*

Years	GHG/ gross inland energy (kt/toe)	Gross inland energy/ final energy consumption (toe/toe)	Final energy consumption/ GDP[1] (toe/EUR million)	GDP[1]/ population (EUR thousand per capita)	Population (thousand)	GHG emission (kt)
	EMI	EFI	ENC	ECD	PG	GHG
2000	3.61	1.62	0.22	6.63	38,263	322,256
2002	3.56	1.62	0.21	6.85	38,242	316,066
2004	3.62	1.57	0.20	7.45	38,191	331,489
2006	3.53	1.59	0.20	8.20	38,157	344,428
2008	3.42	1.57	0.18	9.15	38,116	336,286
2010	3.37	1.53	0.18	9.79	38,023	342,037
2012	3.40	1.52	0.16	10.38	38,064	332,413
2014	3.32	1.54	0.15	10.86	38,018	315,210
2016	3.28	1.51	0.15	11.69	37,967	329,947
2018	3.20	1.49	0.14	12.91	37,977	342,088
Descriptive statistics[2]						
$\bar{x}$	3.44	1.56	0.18	9.37	38,107	331,064
V (%)	3.94	2.76	14.18	21.03	0.26	2.82
Δ_{RC} (%)	-0.67	-0.47	-2.16	3.78	-0.04	0.33

[1]at 2015 constant prices, [2]statistics calculated for all years from 2000 to 2018, $\bar{x}$ - mean level, V- coefficient of variation, Δ_{RC} - average annual growth rate.

***Source:** Own creation.*

Figure 4. *Dynamics of changes in GHG emission factors in Poland in 2000-2018.*



Source: *Own creation.*

Generally, quite similar conclusions can be drawn from analyzing changes in the fuel conversion efficiency factor (EFI). In this case, too, a favorable trend was discovered, but the changes in efficiency were even slower. In most years, the gross inland consumption to final energy consumption ratio fell within a highly narrow interval of 1.5-1.6. Some symptoms of reducing this ratio (reflecting an improvement in fuel conversion efficiency) become noticeable only in 2017-2018. The above also is corroborated by descriptive statistics. Indeed, both the coefficient of variation (V=2.76%) and the average annual growth rate (ΔRC=-0.47%) are extremely low for that factor.

In turn, much more substantial and favorable changes were recorded for final energy used per unit of GDP (ENC). Indeed, between 2000 and 2018, the use intensity of that energy followed a downward trend at an average annual rate of 2.16%. Because of this direction and a relatively high pace of changes, there was a significant reduction in the energy intensity of GDP. Data presented in Table 2 suggest that while in 2000-2006 the amount of final energy used per unit of GDP was 0.20-0.22 toe, it went down to 0.14-0.15 toe (i.e., by ca. 28%) the last three years of the study period.

It follows from Table 2 data that the economic growth factor (ECD) was the one that changed the most. Indeed, the GDP per capita ratio followed a solid upward trend over the study period. In 2000-2002, it was EUR 6.6-6.8 thousand whereas, in 2018, it reached almost EUR 13 thousand. This means an actual increase by ca. 95%. The extent of these changes is confirmed by descriptive statistics, reaching the highest levels for that very factor (V=21.03%, ΔRC=3.78%).

Population, the last factor of the GHG emissions decomposition model, was the least variable (V=0.26%). While the Polish population was on a decline, the depopulation process was not dynamic. This is because the population decreased at an annual average rate of 0.04%, suggesting this factor was a near-negligible determinant of changes in emission levels. The direction and pace of changes in each of the factors of the GHG decomposition model clearly show that they strongly differed in their impact on GHG emission levels in Poland in the study period. The importance of these differences is confirmed by data in Table 3 and Figure 5, which present the results of emission decomposition.

It can be noted that changes in the emissions factor (ΔEMI) positively impacted reducing GHG emissions throughout the period 2000-2018. Although the changes in that factor were relatively slow, a consistent decrease in its levels reduced total emissions. Indeed, because of the reduction in emissions per unit of energy, overall emissions dropped by a total of 40,529.7 kt. That factor can be observed to have a positive impact in all sub-periods identified in this study. This is especially true for 2006-2009 (ΔEMI=-8,308.8 kt) and 2009-2010 (ΔEMI=-7,837.7 kt) when the reduction in emission intensity per unit of energy entailed the relatively most significant drop in total GHG emissions. Generally, quite similar conclusions can be drawn from the fuel conversion efficiency factor (ΔEFI), which also changed how favorably affected total GHG emissions.

However, its impact was not as strong as that of the emission factor (ΔEMI) in 2000-2018, the improvement in fuel conversion efficiency reduced GHG emissions by a total of 27,920.6 kt. Also, data in Table 3 suggest that the impact this factor had on emission changes varied enormously between the sub-periods. From that perspective, this factor had the strongest (and favorable) impact on emission levels in 2006-2009 and 2014-2017, reducing them by 13,085.9 kt and 12,416.7 kt, respectively. The developments witnessed in these sub-periods are why the changes in that factor can be deemed to have an overall favorable impact on GHG emissions (which is driven by a relatively more substantial improvement in fuel conversion efficiency in these sub-periods).

Table 3. *Decomposition results for GHG emissions in Poland in 2000-2018 (additive decomposition for eight sub-periods).*

Years	ΔEMI	ΔEFI	ΔENC	ΔECD	ΔPG	ΔGHG
kt GHG						
2000-2001	-1,331.7	-9.1	-1,702.8	4,115.2	-78.9	992.7
2001-2002	-3,460.2	-467.6	-9,697.3	6,540.6	-98.3	-7,182.7
2002-2006	-2,751.1	-4,968.3	-22,543.1	59,359.2	-734.1	28,362.5
2006-2009	-8,308.8	-13,085.9	-44,746.7	46,759.1	-195.8	-19,578.1
2009-2010	-7,837.7	157.0	12,625.9	13,231.6	-989.3	17,187.5
2010-2014	-4,137.1	1,837.9	-59,160.1	34,655.3	-23.2	-26,827.4
2014-2017	-6,582.0	-12,416.7	7,585.1	39,449.3	-379.3	27,656.4
2017-2018	-6,121.0	1,032.2	-13,551.2	17,827.6	33.6	-778.8
2000-2018	**-40,529.7**	**-27,920.6**	**-131,190.0**	**221,937.8**	**-2,465.4**	**19,831.9**
percentage weights of factors (%)						
2000-2001	-134.1	-0.9	-171.5	414.5	-7.9	100.0
2001-2002	48.2	6.5	135.0	-91.1	1.4	100.0
2002-2006	-9.7	-17.5	-79.5	209.3	-2.6	100.0
2006-2009	42.4	66.8	228.6	-238.8	1.0	100.0
2009-2010	-45.6	0.9	73.5	77.0	-5.8	100.0
2010-2014	15.4	-6.9	220.5	-129.2	0.1	100.0
2014-2017	-23.8	-44.9	27.4	142.6	-1.4	100.0

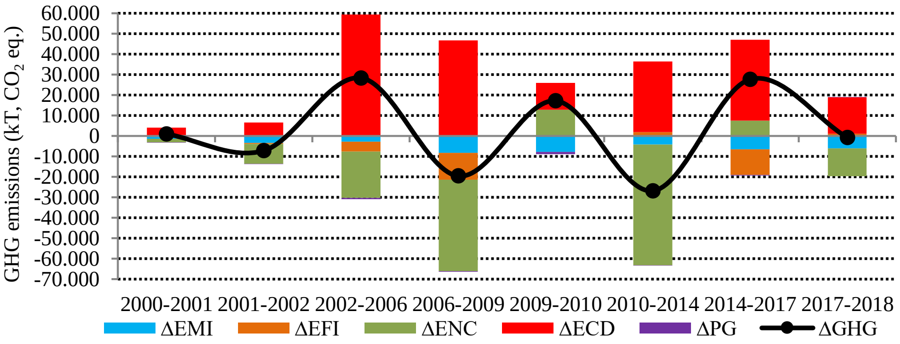
2017-2018	786.0	-132.5	1,740.0	-2,289.1	-4.3	100.0
2000-2018	**-204.4**	**-140.8**	**-661.5**	**1,119.1**	**-12.4**	**100.0**

Source: *Own creation.*

Generally, quite similar conclusions can be drawn from the fuel conversion efficiency factor (ΔEFI), which also changed favorably affected total GHG emissions. However, its impact was not as strong as that of the emission factor (ΔEMI), in 2000-2018, the improvement in fuel conversion efficiency reduced GHG emissions by a total of 27,920.6 kt. Also, data in Table 3 suggest that the impact this factor had on emission changes varied enormously between the sub-periods. From that perspective, this factor had the strongest (and favorable) impact on emission levels in 2006-2009 and 2014-2017, reducing them by 13,085.9 kt and 12,416.7 kt, respectively. The developments witnessed in these sub-periods are why the changes in that factor can be deemed to have an overall favorable impact on GHG emissions (which is driven by a relatively more substantial improvement in fuel conversion efficiency in these sub-periods).

In turn, the intensity of final energy consumption (ΔENC) had a much more significant impact on GHG emissions. In most years covered by this study and in the sub-periods considered, a consistent decrease in final energy consumption per unit of GDP had a strong favorable impact on GHG emission levels. Indeed, throughout the 2000-2018 period, that factor can be found to account for a reduction in emissions by 131,190 kt, which is over three and nearly five times more than what is attributed to the emission factor (ΔEMI) and the fuel conversion efficiency factor (ΔEFI), respectively. The relatively most significant and favorable impacts of that factor on emission levels were mainly recorded in 2006-2009 (by 44,747 kt) and in 2010-2014 (by 59,160 kt), i.e., in years which witnessed the most substantial drop in GDP energy intensity.

Figure 5. *Graphical presentation of findings from the additive analysis of the distribution of GHG emissions in Poland for eight sub-periods between 2000 and 2018.*



Source: *Own creation.*

Conversely, LDMI suggests that economic growth (ΔECD) is the factor that had the most significant adverse impact on gaseous emissions in Poland. Between 2000 and 2018, the aggregated increase in GHG emissions accounted for was as much as

221,938 kt. Moreover, that factor's adverse impacts on emission levels were recorded in all years, reaching a peak in 2002-2006, i.e., in the pre-and post-accession period. At that time, rapid economic growth accounted for an increase in emission levels by as much as 59,359 kt and was decisive for the overall rise in emissions. Also, that factor can be observed to have had relatively adverse solid impacts in the following three years (2006-2009), with an increase in emissions by 46,759 kt.

However, unlike in 2002-2006, the favorable effects of other factors were much more potent in that period, and consequently, there was a decline in aggregated emission levels. Similar conclusions can be drawn from the analysis of subsequent periods. Generally, it reveals a strong negative relationship between economic growth and emission levels. Considering the distribution structure of factors covered by this study, it can be noticed that the adverse impact of economic growth on GHG emissions (1119%) was, in absolute terms, several or more than ten times stronger than the favorable impacts of other factors.

Compared to the factors discussed above, GHG emissions in Poland were poorly related to changes in population. Data in Table 3 suggests that changes in the demographic factor (ΔPG) related to a decline in population size had a favorable yet weak impact on emission levels. The aggregated effect these changes had on emission levels during the entire period from 2000 to 2018 was reduced by 2,465 kt. Hence, compared to other factors used in the model, demographics generally had a marginal impact on GHG emission levels.

4. Conclusion

Shifting to a low-carbon economy-to counteract climate warming-poses a considerable challenge both to the EU and each member state. In Poland, this is particularly problematic because its economy is built upon energy derived from fossil fuels (mainly coal and lignite), while renewable energies are of marginal importance.

In 2000-2018, Poland recorded a moderate yet favorable trend followed by its energy mix, which continues to be dominated by non-renewable high-emission fuels. The combination of rapid economic growth increased energy consumption, and small changes in emission intensity and fuel conversion efficiency resulted in an adverse trend, which means a rise in emission levels. The effects these drivers have on changes in GHG emissions are corroborated by findings from the decomposition method employed in this study. It suggests that the adverse trends followed by emission levels in Poland were determined mainly by rapid economic growth. While other factors of the decomposition model evolved in a favorable direction, their changes were not significant enough to offset the increase in emissions caused by a rapidly developing economy. Therefore, it seems reasonable to conclude that Poland struggles hard to separate emissions from economic growth given this analysis.

Considering the EU's new strategy focused on attaining climate neutrality, Poland must radically accelerate its decarbonization processes. However, this will require spending large amounts of money on infrastructural, economic, and social projects. Indeed, investment expenditure required to be incurred in 2021-2050 in the Polish energy sector alone to enable a 96-97% reduction in emissions by 2050 is estimated at as much as EUR 200 billion (Tatarewicz *et al.*, 2019). However, it seems unfeasible for Poland to finance such extensive investments on its own. Moreover, this problem cannot be solved with EUR 7.5 billion allocated from the EU's Just Transition Fund. Hence, Poland stands the slight realistic possibility of attaining the emission reduction target, as specified in the climate neutrality strategy, by 2050. This is likely to take much more time.

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