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The Driving Forces of Change in Energy-related CO_2 Emissions in the Polish Iron and Steel Industry in 1990-2017

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ABSTRACT

The main purpose of this paper was to identify the driving forces of change in energy-related CO_2 emissions in the Polish iron and steel industry in 1990-2017. The analysis relied on the logarithmic mean Divisia index method used for both the entire study period and the seven 3-year sub-periods. Changes in energy-related CO_2 emissions were considered in the context of four factors: the effect of the emission factor; the effect of the energy mix; the effect of energy consumption; and the effect of the production volume of steel. As shown by these analyses, CO_2 emissions in the Polish iron and steel industry dropped by as much as over 60% during the study period. That process was primarily driven by a reduction in steel production volumes and in energy intensity of production. In 1990-2017, these factors contributed 48.0% and 50.7%, respectively, to total change in CO_2 emissions. Other factors, i.e. emission intensity and energy mix, had a marginal impact. However, the opportunities for further reduction in CO_2 emissions seem very limited in the Polish iron and steel industry. That sector is unable to incur the costs of decarbonization investments and requires financial support. Moreover, its continued existence depends on changes to the ETS which will promote low-emission production and will stop the shrinking of the steel market. Thirdly, the steel market needs to be protected against unfair imports, and requires the establishment of the same competition conditions for producers who are not charged with CO_2 emission costs.

Keywords: CO_2 Emission, ENERGY USE, Logarithmic Mean Divisia Index Decomposition, Iron and Steel Industry, Poland
JEL Classifications: Q42, Q43, Q53

1. INTRODUCTION

As a signatory of the United Nations Framework Convention on Climate Change 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 greenhouse gas (GHG) emissions in 2008-2012 by 6% against the baseline year. In turn, in the second commitment period (2013-2020), as provided for in the Doha amendment, European Union countries and Iceland signed an agreement to jointly meet the reduction goal set against the base year. That goal was expressed in a commitment to attain a yearly average emission level equal to 80% of total emissions of all countries in the base year (KOBIZE, 2019). Another event that encouraged stronger action against climate change was the Brussels summit held by European Union countries in October 2014 to agree on the objectives for the EU climate policy by 2030. A reduction of GHG emissions by no less than 40% from 1990 to 2030 remains the basic policy goal. Also agreed was the objective for improvements in energy efficiency which was afterwards (in 2018) modified and set at a higher level. The objective is a 32% reduction in energy demand in relation to forecasts, and attaining a share of no less than 32.5% of renewable energies in total energy consumption (European Commission, 2014). By seeking these goals, the economy and the energy system of the European Union will become more competitive while ensuring increased energy security and improved efficiency of measures taken to fight against climate change. These climate policy goals are applicable to all European Union countries. At the current stage, no detailed definition has been provided on how to attain them and on how should the member countries and sectors of the economy contribute to it (European Commission, 2014). Another very important step in fighting climate change is the intensification of measures focused on attaining a condition referred to as climate neutrality, i.e. a balance between anthropogenic emissions and removals of GHGs in natural processes. That very ambitious goal was set in December 2019 at the Brussels summit held by the European Council to approve the objective of climate neutrality by 2050, in accordance with the Paris agreement. Although an EU member, Poland did not commit itself to pursuing that objective because the authorities found it extremely difficult and costly to shift away from coal. Indeed, switching the Polish economy to emission-free fuels will have a series of adverse economic and social impacts. A rapid transformation towards climate neutrality will result in mass closure of mines, shutdown of blast furnaces and, as a consequence, in the liquidation of tens of thousands of jobs. Poland believes that climate neutrality requires more time, adequate investments and a fair distribution of transformation costs. Note however that in the context of the Kyoto Protocol, Poland has made enormous progress in reducing GHG emissions. Indeed, Poland has taken considerable measures to stop climate change by reducing GHG emissions. This is reflected by a reduction in emission levels from 577.5 million toe in 1990 to 413.8 million toe in 2017, i.e. by 28.4% (KOBIZE, 2019).

In 1990-2017, sectors of the Polish economy differed in the pace of reduction in gas emissions. The differences were particularly pronounced between industrial processes. This paper focuses on analyzing the changes in CO_2 emissions in the iron and steel industry. This is because that sector considerably contributes to global anthropogenic CO_2 emissions as a consequence of great demand for energy and the related large carbon emissions (Steel's, 2019). The iron and steel industry is the second largest industrial consumer of energy, with ca. 20 EJ in 2017 (International Energy Agency, 2019a) while also being among the major sources of CO_2 emissions (2.0 Gt in 2017). According to the International Energy Agency (IEA), the production of iron and steel accounts for ca. 24% of energy consumption in the global production industry, and has a share of ca. 25-30% in carbon emissions (International Energy Agency, 2019a and 2019b; Hasanbeigi and Springer, 2019). Also, the share of the steel industry in global emissions of GHG is estimated at 4-7% (Energy…, 2019; Kim and Worrell, 2002). However, CO_2 emissions, both in absolute terms and per ton, differ significantly between the countries (Gielen and Moriguchi, 2002; Kim and Worrell, 2002; Sun et al., 2011; Sun et al., 2012). This can be explained by the following factors: Size and importance of that sector; production technologies; product mix; energy efficiency of production; fuel mix; share of coal in the fuel mix; and the intensity of emissions from the electricity sector.

The main purpose of this paper is to identify the drivers of change in CO_2 emissions in the Polish iron and steel industry with the use of the decomposition technique. The decomposition of CO_2 emissions was addressed in many studies carried out at economy, sector, enterprise and other analytical levels. These studies usually relied on two basic analytic methods, i.e. the index decomposition analysis (IDA) and the structural decomposition analysis (SDA), in order to quantitatively determine the strength and direction of impact of different factors on changes in CO_2 emissions. As emphasized by Sun et al. (2012), IDA has an important advantage over SDA because it does not require a large number of variables and allows to use diverse indicators, i.e. absolute values, as well and intensity and flexibility metrics. This is not the case for SDA which is limited to analyzing absolute values of variables considered (Sun et al., 2012).

The literature proposes many methodologies of index decomposition, as used in research into energy and environmental issues (Ang and Zhang, 2000; Liu and Ang, 2007; Ang, 2015; Nnaemeka and Kyung-Jin, 2015). This paper used the logarithmic mean Divisia index (LMDI), one of the most commonly used and recommended methods of index decomposition, in order to identify the factors that affect the volume of CO_2 emissions related to energy consumption in the Polish iron and steel industry, (Ang and Liu, 2001; Ang, 2004; Ang, 2005).

2. METHODOLOGY AND DATA

2.1. Methodology

The decomposition of CO_2 emissions in the Polish iron and steel industry in 1990-2017 relied on a method which refers to the Kaya identity (Kaya, 1990; Yamaji et al., 1991). The decomposition results can be presented as the following four-factor equation (Sun et al., 2011, 2012):

$$C = \sum_i C_i = \frac{C_i}{E_i} \times \frac{E_i}{E} \times \frac{E}{SP} \times SP \quad (1)$$

where: the subscript i denotes the various fuels (solid fossil fuel, manufactured gases, natural gas, crude oil and petroleum products, electricity, heat); C means total energy-related CO_2 emissions; E_i means consumption of energy derived from fuel i which entails CO_2 emissions; and P is the production volume of crude steel.

In the above equation, $EMI=C_i/E_i$ is a factor that informs of average CO_2 emissions from energy source i; $ENS=E_i/E$ represents the share of energy from source i in total energy consumption; and $ENC=E/SP$ reflects the total energy consumption per unit of steel production. Having in mind the defined symbols, equation (1) can be written as:

$$C = \sum_i C_i = EMI \times ENS \times ENC \times SP \quad (2)$$

If the LMDI technique is used and ΔC denotes the changes in CO_2 emissions between the baseline year (0) and the final year (t), the changes can be considered to be driven by four effects, i.e.: the effect of changes in the CO_2 emissions factor (ΔEMI); the effect of changes in the energy mix (ΔENS); the effect of changes in energy consumption (ΔENC); and the effect of changes in the steel production volume (ΔSP). Hence, the aggregated changes in CO_2 emissions can be calculated as:

$$\Delta C = C_t - C_0 = \Delta EM + \Delta ENS + \Delta ENC + \Delta SP \quad (3)$$

In turn, the impact of different effects on changes in CO_2 emissions can be presented with the following equations:

$$\Delta EMI = L(C_0, C_t) \times ln\frac{EMI_t}{EMI_0} = \frac{C_t - C_0}{ln\frac{C_t}{C_0}} \times ln\frac{EMI_t}{EMI_0} \quad (4)$$

$$\Delta ENS = L(C_0, C_t) \times ln\frac{ENS_t}{ENS_0} = \frac{C_t - C_0}{ln\frac{C_t}{C_0}} \times ln\frac{ENS_t}{ENS_0} \quad (5)$$

$$\Delta ENC = L(C_0, C_t) \times ln\frac{ENC_t}{ENC_0} = \frac{C_t - C_0}{ln\frac{C_t}{C_0}} \times ln\frac{ENC_t}{ENC_0} \quad (6)$$

$$\Delta SP = L(C_0, C_t) \times ln\frac{SP_t}{SP_0} = \frac{C_t - C_0}{ln\frac{C_t}{C_0}} \times ln\frac{SP_t}{SP_0} \quad (7)$$

2.2. Data

This paper relies on three sources of information. CO_2 emission and energy consumption figures for the Polish iron and steel sector used in this study are based on data presented by Eurostat, the Union's statistical office (Eurostat, 2019a and 2019b), data retrieved from the European Environment Agency (EAA) and reports of the National Center for Emissions Management (KOBIZE, 2019). In turn, information on iron and steel production is derived from papers of the World Steel Association which consistently publishes comprehensive statistics for steel production, consumption and trade by country in 2009-2018 (The World Steel Association, 2000-2019).

3. RESULTS AND DISCUSSION

3.1. Changes in Energy Consumption and CO_2 Emissions

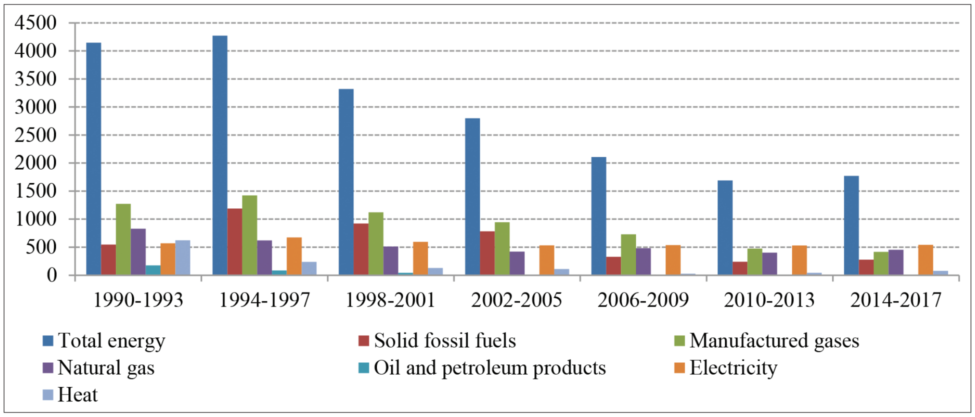
Table 1 and Figure 1 show the statistics of energy consumption and mix in the Polish iron and steel industry in 1990-2017. The analysis suggests that over the study period, total energy consumption in that sector decreased from 4146.6 to 1777.3 thousand toe, i.e. by as much as 57.3%. Such a considerable drop in energy consumption levels in the iron and steel industry results from a reduction in the consumption level of energy from virtually all sources, except for electricity. In the years covered by the study, the consumption of energy derived from the combustion of solid fossil fuels was highly volatile. However, while these fuels accounted for 545-1188 thousand toe in 1990-2001, they delivered only 239-278 thousand toe at the end of the study period. Another remark is that a significant drop in the consumption of energy derived from solid fossil fuels way mainly driven by a strong reduction in the use of anthracite and coal. Conversely, the reduction in the volume of coke burnt in coke ovens (which generated 75-88% of total energy

Table 1: Energy consumption and energy mix in the polish iron and steel industry in 1990-2017

Specification	1990-1993	1994-1997	1998-2001	2002-2005	2006-2009	2010-2013	2014-2017
Energy consumption (thousand tons of oil equivalent, toe)							
Total	4146.6	4271.2	3321.2	2800.0	2107.8	1691.0	1772.3
Solid fossil fuels; including	545.9	1,187.9	922.2	783.0	328.8	239.2	278.0
Anthracite and otherbituminous coal	77.8	515.4	435.8	313.9	170.6	57.3	34.1
Coke-oven coke	461.1	672.0	485.4	468.7	152.2	180.6	243.6
Manufactured gases, including	1273.3	1423.4	1120.6	946.0	730.3	474.6	417.0
Coke-oven gas	551.1	608.0	448.9	353.0	250.0	200.3	142.8
Gasworks gas	29.7	1.6	0.0	0.0	0.0	0.0	0.0
Blast furnace gas	692.5	813.8	669.9	565.9	457.6	271.5	262.1
Natural gas	829.7	620.4	512.2	422.2	481.9	401.7	453.6
Oil and petroleum products	175.9	85.8	41.9	6.2	2.9	4.1	4.9
Renewables and biofuels	0.10	0.17	0.11	0.08	0.02	0.01	0.02
Non-renewable waste	129.0	43.0	0.0	0.0	0.0	0.0	0.0
Electricity	569.0	673.2	594.3	531.4	537.4	529.2	541.9
Heat	623.8	237.3	129.8	111.1	26.5	42.2	76.8
Energy consumption mix (%)							
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Solid fossil fuels, including	13.2	27.8	27.8	28.0	15.6	14.1	15.7
Anthracite and other bituminous coal	1.9	12.1	13.1	11.2	8.1	3.4	1.9
Coke-oven coke	11.1	15.7	14.6	16.7	7.2	10.7	13.7
Manufactured gases, including	30.7	33.3	33.7	33.8	34.6	28.1	23.5
Coke-oven gas	13.3	14.2	13.5	12.6	11.9	11.8	8.1
Gasworks gas	0.7	0.0	0.0	0.0	0.0	0.0	0.0
Blast furnace gas	16.7	19.1	20.2	20.2	21.7	16.1	14.8
Natural gas	20.0	14.5	15.4	15.1	22.9	23.8	25.6
Oil and petroleum products	4.2	2.0	1.3	0.2	0.1	0.2	0.3
Renewables and biofuels	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non-renewable waste	3.1	1.0	0.0	0.0	0.0	0.0	0.0
Electricity	13.7	15.8	17.9	19.0	25.5	31.3	30.6
Heat	15.0	5.6	3.9	4.0	1.3	2.5	4.3

Source: Eurostat (2019b) and KOBIZE (2019)

Figure 1: Changes in energy consumption in the Polish iron and steel industry in 1990-2017 (thousand tons of oil equivalent, toe)



derived from fossil fuels in the last two periods) contributed to a clearly smaller extent.

The significant reduction in energy consumption in the iron and steel sector is also explained by a strong decrease in the use of energy derived from both manufactured and natural gases. Data presented in Table 1 suggests that the consumption of energy derived from manufactured gases dropped from 1120-1423 thousand toe (1990-2001) to 417-474 thousand toe (2010-2017), i.e. by as much as ca. 65%. Similar conclusions can be drawn from the analysis of natural gas consumption. Indeed, the consumption of natural gas energy declined from ca. 830 thousand toe in 1990-1993 to 454 thousand toe in 2014-2017. This means the consumption of energy derived from that fuel was reduced by ca. 45%.

In turn, the polish iron and steel sector particularly strongly reduced (if not eliminated) the use of crude oil, petroleum products and non-renewable waste. In 1990-1993, nearly 176 thousand toe were derived from crude oil and petroleum products, compared to only 2.9-6.2 thousand toe in 2002-2017. This means that the consumption of energy derived from crude oil went down by over 97% in that period. As recently as in 1990-1997, non-renewable waste accounted for 43-129 thousand toe; in the subsequent periods, it was entirely eliminated and is no longer used as a source of energy.

The consumption of heat was also affected by rapid changes. Data shown in Table 1 suggests that 624 thousand toe of heat were consumed in the production of iron and steel between 1990 and 1993, but the consumption of energy derived from that source declined by more than 90% in 2006-2017, reaching 26.5-76.8 thousand toe.

In the context of rapid change in the consumption of energy from solid fossil fuels, manufactured gases, natural gas, crude oil, non-renewable waste and heat, the change in electricity consumption was by far the smallest. Although a downward trend is observed in this case, too, no sharp decline was experienced over the study period. Another conclusion from data shown in Table 1 is that the highest levels of energy consumption in the iron and steel sector were recorded in 1990-2001 (569-673 thousand toe). The following years saw a relatively small decline in energy consumption levels which remained within a quite stable interval of 529-542 thousand toe.

The changes in the consumption of energy derived from different sources, as discussed above, translated into a quite substantial shift in the energy consumption mix of the polish iron and steel sector. However, that shift does not form a clear trend followed by all sources of energy. From 1999 to 2005, the share of energy derived from solid fossil fuels increased from 13.2% to ca. 28%. Afterwards (2006-2017), it declined and stabilized at 14.1-15.7%. In turn, the strong reduction in the use of energy derived from manufactured gases translated into a relatively small decline in the share of that energy source. Indeed, the share of energy from manufactured gases in total energy consumption was quite stable (31-35%) in most years of the study period. Relatively greater differences were discovered only in 2014-2017 as the share declined to reach 23.5%. Changes in the share of natural gas in the energy mix follow another trend. In 1990-1993, it was 20% but then decreased to ca. 15% (1994-2005). Steady growth was recorded from 2006 onwards; in 2014-2015, it went above 26%. Conversely, crude oil and petroleum products were of a relatively minor importance in the energy mix in all of the periods considered. Energy derived from these sources played a certain role only in 1990-2001 (1.3-4.2%). Later on, its share was close to zero (0.1-0.3%). Changes in the share of heat followed a similar trend. Only in the first period (1990-1993), that source of energy represented a considerable part of total energy consumed (15%). From 1994 onwards, it remained stable at a clearly lower level (1.3-5.6%). Of the fuels listed above, only electricity clearly increased its importance in the energy mix. Indeed, the share of electricity in total energy consumption in the iron and steel sector grew from 13.7-19% in 1990-2005 to over 30% in 2010-2017.

Table 2 and Figure 2 present the basic statistics of changes in the level of GHG emissions in the iron and steel industry in 1990-2017. The analysis suggests that the significant drop in energy consumption, as mentioned earlier in this paper, translated into a strong reduction in gaseous emissions. It can be noticed that in 1990-1997, the processing industry emitted 18.2-20.1 million tons of GHG (CO_2-eq), whereas in 2010-2017, the level of GHG (CO_2-eq) emissions went down to 6.95-7.48 million tons. This means that the level of gaseous (GHG) emissions in the Polish iron and steel industry decreased by as much as ca. 62%. Similar conclusions can be drawn from the analysis of changes in carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions. Similarly like in the case of GHG, the comparison reveals that CO_2, CH_4 and N_2O emissions went down by 62%, 49% and ca. 61%, respectively.

3.2. Changes in Steel Production

In the polish iron and steel industry, the significant reduction in energy consumption and in GHG emissions witnessed in 1990-2017 is strongly related to a drop in production volume and to the changing importance of manufacturing processes. In Poland, according to data in Table 3, the production volume of steel was 10.96-11.26 million tons in 1990-1997, and went down to 8.27-9.27 million tons (i.e. by ca. 20%) in 2010-2017. The biggest drop in steel production was recorded in 2009 (Figure 2), with only 7.13 million tons, the lowest level of the period 1990-2017. Since 2010, steel production in Poland has been on a consistent increase, and reached a level of 10.17 million tons (Figure 2) in 2017, which is comparable to volumes recorded in 1990-1993. Data in Table 3 also suggests that steel production processes have undergone a major transformation. These changes are reflected in a growing volume of electric furnace (EF) steel production and oxygen-blown converter, and in the discontinuation of open-hearth furnace production processes. When it comes to the pace of changes, growth is particularly rapid in EF steelmaking. In 1990-1993, the EF technology was used to manufacture 2.09 million tons of steel, whereas in 2014-2017, it was nearly double that level, i.e. 3.97 million tons. That trend is strongly convergent with changes in the energy consumption mix. As mentioned earlier, the share of electricity in the energy mix of the Polish steel industry increased from 13.7% to 30.6%.

3.3. Decomposition Analysis

This section presents the results of the analysis of main conditions that affect the relationship between energy consumption and CO_2 emissions in the Polish iron and steel industry in accordance with the LMDI methodology presented earlier in this paper. Changes in CO_2 emissions were considered from the perspective of seven 3-year sub-periods, and in the context of drivers of CO_2 emissions, i.e. the effect of the emission factor; the effect of changes in the energy mix; the effect of changes in energy consumption; and the effect of changes in the production volume of steel.

The decomposition analysis was preceded by the presentation of changes in the values of factors used in the model. Data shown in Table 4 suggests that the model's factors changed at a different pace over the study period, and therefore strongly differed in their impact on changes in CO_2 emissions. It may be noted that in the Polish iron and steel industry, the emission factor (EMI) varied only slightly and fell within a narrow interval of 5.94 (1994-1997) to 6.47 (2014-2017). The marginal changes in that factor are confirmed by the descriptive statistics and by the growth ratio. Standard deviation (δ =0.30) and the coefficient of

Table 2: Greenhouse gas emissions in the polish iron and steel industry in 1990-2017 (CO2-eq, thousand tons)

Specification	1990-1993	1994-1997	1998-2001	2002-2005	2006-2009	2010-2013	2014-2017
Greenhouse gases (GHG)	18,245.9	20,055.0	15,867.9	13,374.3	9857.9	6952.7	7481.0
Carbon dioxide (CO_2)	18,146.0	19,951.4	15,791.1	13,308.2	9810.4	6913.0	7430.2
Methane (CH_4)	46.8	47.4	35.9	32.5	24.2	21.7	26.4
Nitrous oxide (N_2O)	53.2	56.2	40.8	33.6	23.3	18.0	24.3

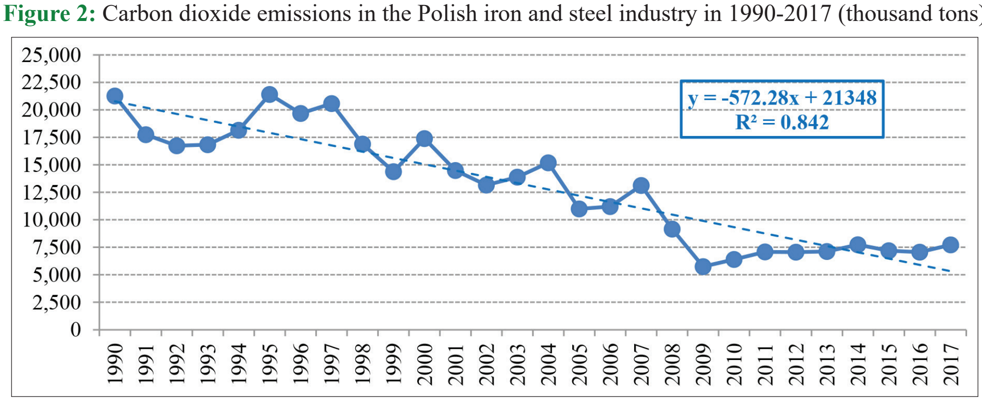
Source: Eurostat (2019a)

Table 3: Steel production in Poland in 1990-2017 (million tons)

Specification	1990-1993	1994-1997	1998-2001	2002-2005	2006-2009	2010-2013	2014-2017
Total steel production	10.96	11.26	9.52	9.10	9.37	8.27	9.27
Steel from oxygen-blown converter	6.34	7.30	6.07	5.92	5.11	4.26	5.30
Steel from electric furnace	2.09	2.67	3.08	3.18	4.26	4.01	3.97
Steel from open hearth furnace	2.53	1.29	0.36	-	-	-	-

Source: The World Steel Association (2000-2019)

Figure 2: Carbon dioxide emissions in the Polish iron and steel industry in 1990-2017 (thousand tons)



variation (V = 4.39%) are very low for the emission factor, and therefore match well the very low yearly average growth rate (Δ_{RC} = –0.13%).

Generally, quite similar conclusions can be drawn from the analysis of the energy mix factor (ENS). In this case, although a permanent trend was recorded which suggests a consistent decline in the share of solid fossil fuels, manufactured gases, natural gas and crude oil in the energy mix, the intensity of these changes was of minor importance. In 1990-2009, these fuels had a share of 71-79% in the energy mix, but dropped to 65-66% in 2010-2017. Hence, in the polish iron and steel sector, changes in the energy consumption mix are noticeable but quite slow. The above is corroborated by descriptive statistics. Indeed, the metrics of variability of the energy mix factor over time, i.e. standard deviation (δ =0.10) and the coefficient of variation (V = 7.81%), are very low throughout the period 1990-2017 and are consistent with the low average yearly growth rate (Δ_{RC} = –0.29%).

In turn, the changes were much more pronounced in the case of energy intensity of production (ENC). This is because in 1990-2017, total energy consumption per production unit of steel followed a downward trend at an average annual rate of 2.27%. As a consequence of this direction and a relatively high pace of changes, there was a significant reduction in energy intensity of steel production processes. Data presented in Table 4 suggests that while 0.38 toe of energy per ton of steel was used in 1990-1997, that rate went down to 0.19-0.22 (i.e. by ca. 47%) in the last three sub-periods.

The last factor of the CO_2 emissions decomposition model, related to the production volume of steel (SP), also underwent considerable changes in the years covered by this study. As shown in Table 4, steel production evolved in different directions in each sub-period. However, a quite clear downward trend can be seen in 1990-2017. Indeed, the steel production volume decreased at an average annual rate of 1.02%; in 2014-2017, it was ca. 15% smaller than in 1990-1993. However, data in Table 4 and Figure 3 suggests that the downward trend followed by steel production stopped at the end of the study period. Indeed, a moderate though quite pronounced upward trend started in 2010. As a consequence, the steel production volume increased from 8.27 to 9.27 million tons, i.e. by ca. 12%.

The direction and pace of changes in each of the factors of the CO_2 decomposition model clearly show that they strongly differed in their impact on gaseous emission levels in the study period. The extent of these variations is confirmed by data in Table 5 and Figure 4 which present the results of CO_2 emissions decomposition taking into account the changes in the emissions factor, changes in the energy mix, changes in energy consumption, and changes in steel production volume.

Table 4: Changes in factors of the CO_2 emission decomposition model in the Polish iron and steel industry

Year	CO_2	$EMI=CO_2/E_i$	$ENS=E_i/E$	ENC=E/P	SP
Average value in sub-periods (arithmetic mean)					
1990-1993	18,162	6.15	0.71	0.38	10961
1994-1997	19,966	5.94	0.79	0.38	11255
1998-2001	15,803	6.10	0.78	0.35	9518
2002-2005	13,321	6.16	0.77	0.31	9101
2006-2009	9821	6.33	0.72	0.22	9374
2010-2013	6924	6.19	0.66	0.20	8272
2014-2017	7443	6.47	0.65	0.19	9272
1999-2017[1]					
$\bar{X}$	13,063.1	6.20	0.70	0.30	9678.9
δ	5131.0	0.30	0.10	0.10	1394.8
V (%)	39.28	4.39	7.81	27.52	14.41
Δ_{RC} (%)	–3.68	–0.13	–0.29	–2.27	–1.02

[1]Descriptive statistics calculated based on the whole time series 1999-2017, $\bar{x}$: Arithmetic mean, δ: standard deviation, V: coefficient of variation ($\frac{\delta \times 100}{\bar{x}}$), Δ_{RC}: Average annual rate of change (geometric mean)

Figure 3: Steel production in Poland in 1990-2017 (million tons)

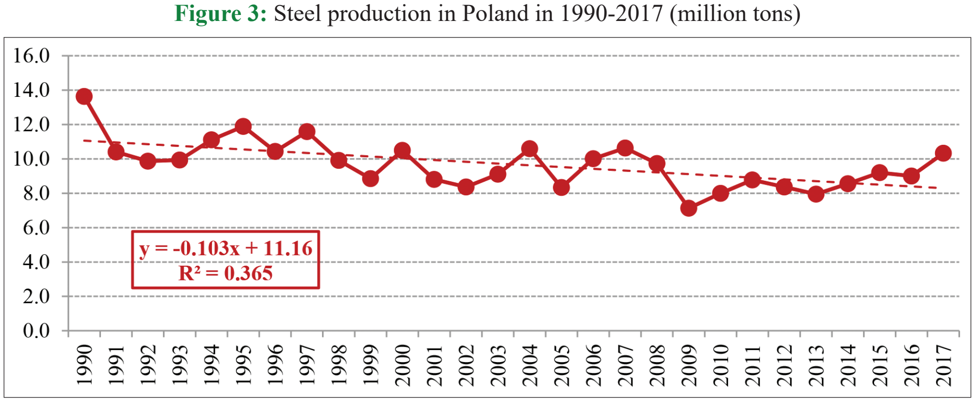
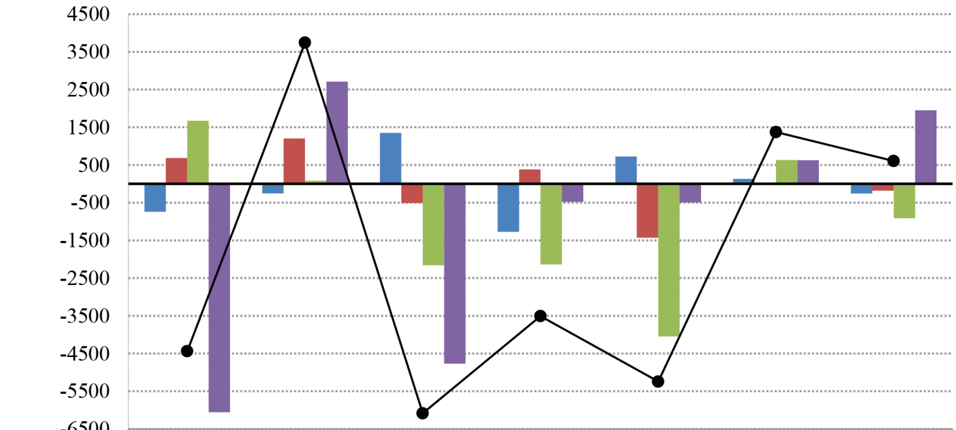


Figure 4: Components of change in CO_2 emissions from energy consumption in the polish iron and steel industry



	1990-1993	1994-1997	1998-2001	2002-2005	2006-2009	2010-2013	2014-2017
Δ EMI	-741.3	-253.6	1,349.7	-1,273.5	724.7	132.4	-256.5
Δ ENS	685.0	1,204.0	-507.9	382.7	-1,427.7	-16.1	-179.4
Δ ENC	1,674.3	82.9	-2,158.5	-2,137.1	-4,045.8	632.6	-910.7
Δ P	-6,054.7	2,711.3	-4,767.7	-478.6	-494.2	624.6	1,953.0
Δ C	-4,436.7	3,744.7	-6,084.5	-3,506.5	-5,242.9	1,373.5	606.5

Table 5: Decomposition result of CO_2 emission in the Polish iron and steel industry in 1990-2017

Years	ΔEMI	ΔENS	ΔENC	ΔP	ΔC
Partial deviations (Δ)					
1990-1993	–741.3	685.0	1674.3	–6054.7	–4436.7
1994-1997	–253.6	1204.0	82.9	2711.3	3744.7
1998-2001	1349.7	–507.9	–2158.5	–4767.7	–6084.5
2002-2005	–1273.5	382.7	–2137.1	–478.6	–3506.5
2006-2009	724.7	–1427.7	–4045.8	–494.2	–5242.9
2010-2013	132.4	–16.1	632.6	624.6	1373.5
2014-2017	–256.5	–179.4	–910.7	1953.0	606.5
1990-2017	–318.1	140.5	–6862.2	–6506.2	–13,546.0
Structure of partial deviations (%)					
1990-1993	16.7	–15.4	–37.7	136.5	100.0
1994-1997	–6.8	32.2	2.2	72.4	100.0
1998-2001	–22.2	8.3	35.5	78.4	100.0
2002-2005	36.3	–10.9	60.9	13.6	100.0
2006-2009	–13.8	27.2	77.2	9.4	100.0
2010-2013	9.6	–1.2	46.1	45.5	100.0
2014-2017	–42.3	–29.6	–150.2	322.0	100.0
1990-2017	2.3	–1.0	50.7	48.0	100.0

It can be noted that changes in the emissions factor (ΔEMI) had a positive impact on reducing CO_2 emissions throughout the period 1990-2017. However, that factor was of minor importance to the reduction in gaseous emissions. In the light of LMDI, the drop in gaseous emissions from fuel combustion reduced the CO_2 emission levels in the Polish iron and steel sector only by 318.1 thousand tons from 1990 to 2017. As a consequence, the share of that factor in total variation of CO_2 was only 2.3%. Also, it had a noticeably small impact in most of the sub-periods covered by this study, except for 1998-2001 (ΔEMI =1349 thousand tons) and 2002-2005 (ΔEMI = –1273 thousand tons). In the two latter sub-periods, the diverse changes in that factor were a relatively stronger (positive or negative) determinant of changes in CO_2 emissions; but in absolute terms, its share in total variation (ΔC) was considerably lower compared to other factors.

Generally, highly similar conclusions can be drawn from the analysis of impacts of changes in the energy mix (ΔENS). Changes in that factor also had a marginal role (ΔENS = –1.0%) as a determinant of variation in CO_2 emissions, and their aggregated effect on CO_2 emissions was negative (ΔENS =140.5 thousand tons, calculated for the entire period 1990-2017). However, note that this was largely driven by changes witnessed in 1994-1997, a period marked by a major increase in that factor which considerably contributed (ΔENS =32.2%) to a relatively large increase in CO_2 emissions (ΔENS =1204 thousand tons). In other sub-periods, the share of fossil fuels in the energy mix was generally on a decline, and therefore had a favorable impact on reducing CO_2 emissions. This is especially noticeable in 2006-2009, a period where the strong reduction in the energy mix factor translated into a significant reduction in CO_2 emissions (ΔENS = –1427 thousand tons) and into a relatively large contribution of that factor to total variation (ΔENS =27.2%).

In turn, the reduction in energy intensity of production (ΔENC) and in the production volume (ΔP) were factors that considerably contributed to reducing CO_2 emissions in the Polish metallurgy sector. Data shown in Table 5 suggests that the aggregated effect of the reduction in energy intensity of production processes was a reduction in gaseous emissions by 6862 thousand tons over the entire study period. As a consequence, that factor contributed as much as 50.7% to total variation in CO_2 emission levels in 1990-2017. Hence, such a great importance of the energy intensity factor in reducing CO_2 emissions is consistent with previous analyses (Table 4) which revealed that energy consumption per production unit of steel went down by ca. 47%. In turn, it can be noted that (in aggregate terms) the quite strong decline in the production volume resulted in reducing gaseous emissions by 6506 thousand tons, and contributed as much as 48% to total variation in CO_2 emissions over the entire period 1990-2017. However, after 2009, the production of iron and steel in Poland embarked on a new growth path which resulted in increased carbon emissions. Indeed, the significant growth in steel production volumes in 2010-2013 and 2014-2017 resulted in an increase in CO_2 emissions (by 1373 and 606 thousand tons, respectively) and contributed 45.5% and 322% to total variation in CO_2 emissions in the relevant sub-periods.

4. CONCLUSIONS

The iron and steel sector considerably contributes to global anthropogenic CO_2 emissions as a consequence of great demand for energy and the related large carbon emissions. It is the second largest industrial consumer of energy and a major source of industrial CO_2 emissions. However, carbon emissions in the iron and steel industry, both in absolute terms and per production unit, significantly differ between the years. This can be explained by the following factors: size and importance of that sector; production technologies; product mix; energy efficiency of production; fuel mix; share of coal in the fuel mix; and the intensity of emissions from the electricity sector. The study carried out in the Polish iron and steel sector showed that two factors had a comparable decisive impact on the significant reduction in CO_2 emissions in 1990-2017: The reduction in energy intensity of production processes (which contributed 50.7%) and the drop in production volume (40.7%). The impact of other factors, i.e. emission intensity (2.3%) and energy mix (–1.0%) was generally of a very small importance (or was negligible in aggregated terms). However, the opportunities for further reduction in carbon emissions seem very limited in the Polish iron and steel industry. This is due to a number of environmental, economic and geopolitical conditions. Indeed, the metallurgy industry is unable to implement decarbonization investments at its own cost and requires financial support. Whether it will survive also depends on changes to the ETS which, on the one hand, will stimulate the development of low-carbon steel production technologies and, on the other, will not reduce in a shrinkage of the steel market. Furthermore, the steel market needs to be protected against unfair imports, and requires the establishment of the same competition conditions for producers who are not charged with CO_2 emission costs.

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