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Economic growth and carbon dioxide emissions

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Summary. The emissions of carbon dioxide (CO_2) are an objective result of the civilizational development of the world. Ensuring a steady decline in CO_2 emissions in the conditions of economic growth and social welfare requires a structural analysis of systemic dependencies. The purpose of the study is to investigate the contribution of different socio-economic factors to the changes in carbon dioxide emissions. A decomposition analysis is performed to examine the pace of CO_2 emission changes in relation to changes in: emissivity of gross domestic product (GDP), productivity of man-hours, number of employees and working time per employee. Statistical data refer to the Polish economy in the period of 1990—2015.

The results provided in this paper show that the economic growth in Poland had the most noticeable contribution to CO_2 emission changes. The solid growth of economy was accompanied by decreasing emissivity of GDP. The increase in the labour supply, observed in some periods, contributed to the relative growth of that factor in pollutant emission changes. Considering the growing labour productivity, efforts to increase employment should be correlated with decreasing number of working hours per employee.

Keywords: emissivity of GDP, CO_2 emissions, pollution, economic growth

Wzrost gospodarczy a emisja dwutlenku węgla

Streszczenie. Emisja dwutlenku węgla (CO_2) jest obiektywnym skutkiem rozwoju cywilizacyjnego świata. Zapewnienie stałego spadku emisji CO_2 w warunkach wzrostu gospodarczego i dobrobytu społecznego wymaga strukturalnej analizy zależności systemowych. Celem niniejszego opracowania jest zbadanie udziału różnych czynników społeczno-gospodarczych w kształtowaniu się zmian emisji CO_2. Analizę przeprowadzono na podstawie dekompozycji tempa zmian emisji CO_2 w odniesieniu do zmian: emisyjności produktu krajowego brutto (PKB), produktywności roboczogodziny, liczby zatrudnionych i czasu pracy jednego zatrudnionego. Wykorzystano dane statystyczne odnoszące się do gospodarki w Polsce. Przyjęto okres badawczy obejmujący lata 1990—2015.

Wyniki badań pokazują, że najbardziej znaczący wkład w zmiany emisji CO_2 w Polsce miał wzrost gospodarczy. Stałemu wzrostowi gospodarczemu towarzyszył spadek emisyjności PKB. Obserwowany w niektórych okresach wzrost podaży pracy przyczyniał się do wzrostu udziału tego czynnika w zmianach emisji zanieczyszczeń. Biorąc pod uwagę rosnącą produktywność siły roboczej, wysiłkom zmierzającym do zwiększenia wielkości zatrudnienia powinno towarzyszyć zmniejszanie się liczby godzin pracy jednego pracownika.

Słowa kluczowe: emisyjność PKB, emisje CO_2, zanieczyszczenie, wzrost gospodarczy

JEL: O04, Q05

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The civilizational development of the world is connected with an increase in energy consumption for the developing industry, construction, transport, communications, agriculture, trade and service networks, and the growing social needs of the population. The needs of the economy and the inhabitants for energy are met mainly by the energy sector. The energy sector encompasses a wide range of industries, beginning with the mining industry — coal and lignite mines as well as oil and gas extraction — through utility and industrial power plants, combined heat and power plants and the fuel industry to energy generation, including energy from the renewable sources. The processes for meeting energy demand are accompanied by greenhouse gas emissions, in both domestic and global dimension. The main contributor to greenhouse gases is carbon dioxide (CO_2), which is emitted not only in the energy sector but also in other areas of production and service provision.

A global consensus has been reached on the fact that CO_2 emissions are a fundamental cause of climate change (Wang, Li & Fang, 2018, pp. 2144—159). Since the Kyoto agreement in 1997, international policies have been implemented to reduce the anthropogenic effects on climate warming and decouple economic growth from energy consumption. The relationship between economic growth and CO_2 emissions has received considerable attention from scholars. Numerous studies have examined gross domestic product (GDP) and other different factors considered as possible driving forces of CO_2 emissions (Mardani, Streimikiene, Cavallaro, Loganathan & Khoshnoudi, 2018, pp. 31—49). Most research, however, has overlooked the possible impact of employment issues. Systemic dependency and possible changes in the structure of socio-economic system may result in unfavourable structural adjustments and social conflicts.

The research hypothesis assumes that pollutant emissions are an objective result of production and distribution, especially of energy. However, changes in these emissions should be correlated with GDP, employment, working time per employee and productivity resulting in the welfare of society.

The aim of the study is to investigate the contribution of different socio-economic factors to the changes in carbon dioxide emissions. A decomposition analysis is performed to examine the pace of CO_2 emission changes in relation to changes in: emissivity of GDP, productivity of man-hours, number of employees and working time per employee. Empirical data refer to the Polish economy in the period of 1990—2015. The justification for the decomposition assumes that the reduction of emissions should be accompanied by a decrease in GDP emission rate, an increase in the pace of productivity of working time, and a decrease in the rate of working time per employee with the increased number of employees.

Significant policy implications exist for research that focuses on the relationship between socio-economic development and CO_2 emissions. By exploring the structure of changes in carbon dioxide emissions from the viewpoint of GDP emissivity and variables describing human work it may be possible to assist in adjusting the changes in greenhouse gas emissions to favourable changes in social welfare.

The study is based on (national and foreign) literature, strategic documents on climate and energy policy, statistical reports of Statistics Poland and statistical bases of the International Energy Agency (IEA) and Eurostat, to the extent permitted by the framework and volume of the study, and the knowledge and research experience of the authors.

SYSTEMIC PREMISES FOR RESEARCHING THE RELATIONSHIP BETWEEN EMISSIVITY AND SOCIO-ECONOMIC DEVELOPMENT

The perception of the world as a set of systems and the general sense of systemic dependency have given rise to the theory of systems. The theory of systems has been applied in almost all branches of natural and social sciences, and nowadays also in the humanities (Wilkin, 2016, pp. 38 and 39). Researchers pose the following questions: what is the relation between a part and the whole? How to explain the operating mechanism of the whole while knowing the properties of a part? Structural analysis is particularly useful in response to such questions. Structural analysis on a global scale can involve a broad range of issues: ownership forms, size of entities, financial situation of entrepreneurs, countries, industries, sectors, resources, incomes, types of business activity (Szukalski, 2013, p. 203). Structural analysis allows for an adjustment of structures to the requirements of socio-economic development, especially growth of an economy, sectors and entities. Systemic structural analysis allows for identifying and explaining systems of all sizes. It clarifies the links between the elements of an economic system and assesses how these links influence both the behaviour of persons and entities in the economy and the management of scarce resources. Economic systems are always open systems, but the degree of openness varies. In the evolution of the structure of systems, the adaptation process is of key importance, both internally and externally. For centuries the ability of systems to adapt to the natural environment has been the most important factor for their existence. In recent decades, common computerization and progress in communication processes has become particularly important (Wilkin, 2016, p. 40).

The most important and always relevant reference to structural research is the economy and its interrelationships, resulting in socio-economic development. The problem of researching an economy as a very complex and open system, as well as the influence of various factors on its structure changes and the effectiveness of these changes in the form of socio-economic growth is interdisciplinary, diverse and goes beyond economic knowledge (Mises, 2007, p. 59).

Socio-economic development requires the application and selection of size, quality and the specific time dynamics supply of production factors. Such a factor responsible for all production processes is primary energy. Many economists (Ayres & Warr, 2005, pp. 181—209; Hall, Tharakan, Hallock, Cleveland & Jefferson, 2003, pp. 318—322; Sorrell, 2010, pp. 1784—1809) believe that energy related innovations play a crucial role in socio-economic development. Time-series analysis shows that energy converted into useful forms is needed in addition to capital and labour to explain the growth of GDP (Ayres & Voudouris, 2014, pp. 16—28; Stern & Kander, 2012, pp. 125—152; Warr & Ayres, 2010, pp. 1688—1693). Societies require energy resources to fuel socio-economic processes and it appears that economic growth depends on high inputs of fossil fuels (Warr, Schandl & Ayres, 2008, pp. 126—140). On the other hand, the accumulation of environmental changes caused by the burning of fossil fuels, especially the emissions of CO_2, is an important barrier to economic growth (Ayres, 2008, pp. 281—310). The mix and amount of energy used is dependent on the structures a society consists of (Eisenmenger, Warr & Magerl, 2016, pp. 1—12).

Structural adjustments are a positive factor for structural change, but they can also pose serious threats to their development. These risks, by failing to adjust the scale and force of changes in individual structural components of the systems and their interrelations, are expressed, among others, by social conflicts and unfavourable changes in the structure of systems, including conflicts between the development of the real sphere and the financial sphere of the economy. A particular manifestation of the distortion of the structure and factors of social and economic growth is the failure to adjust the changes in greenhouse gas emissions, including CO_2, to changes in social welfare, measured by the emissivity of GDP, working time per employee and employment levels, and the productivity of employees per time unit.

A TRADEMARK MODEL FOR THE STUDY OF CARBON DIOXIDE EMISSION CHANGE FACTORS

The basic method for describing the relationship between the growth of the variable and changes in various related factors is decomposition analysis.

The decomposition of CO_2 emissions into the factors considered as "underlying causes" dates back mainly to influential study undertaken by Kaya (1990). The starting point for the decomposition analysis is an "identity" equation where the analysed variable is written as the product of the factors considered as possible driving forces of CO_2 emissions. The choice of the factors depends both on the "conceptual model" and on data availability (Seibel, 2003, p. 11).

The decomposition approach and the factors included in this paper refer to the research on economic policy in German literature, including, in particular, the achievements of economists and politicians, published by the German Center for Political Education in Bonn as part of the debate *Is prosperity possible without economic growth?* (Treeck, 2012, pp. 32—51). In their view, the percentage changes in CO_2 emissions (E_{CO_2}) were reduced to the sum of percentage changes in four factors: emissivity of GDP $\left(\frac{E_{CO_2}}{GDP}\right)$, working time productivity (GDP per hour of work — $\left.\frac{GDP}{H}\right)$, number of employees (*L*) and working time per one employee (*H/L*). This decomposition can be achieved by developing and transforming the following identity:

$$E_{CO_2} = E_{CO_2} \tag{1}$$

$$E_{CO_2} = E_{CO_2} \cdot \frac{GDP}{GDP} \cdot \frac{H}{H} \cdot \frac{L}{L} \tag{2}$$

$$E_{CO_2} = \frac{E_{CO_2}}{GDP} \cdot \frac{GDP}{H} \cdot \frac{H}{L} \cdot L \tag{3}$$

By logarithmising and differentiating the equation (3) with respect to time, growth rate decomposition is obtained[1]:

$$\frac{\dot{E_{CO_2}}}{E_{CO_2}} = \frac{\dot{\frac{E_{CO_2}}{GDP}}}{\frac{E_{CO_2}}{GDP}} + \frac{\dot{\frac{GDP}{H}}}{\frac{GDP}{H}} + \frac{\dot{\frac{H}{L}}}{\frac{H}{L}} + \frac{\dot{L}}{L} \tag{4}$$

Thus, the annual rate of changes in CO_2 emissions can be presented, in discrete terms $\left(\frac{\Delta E_{CO_2}}{E_{CO_2}}\right)$, as the sum of rates of the changes in the adopted factors:

$$\frac{\Delta E_{CO_2}}{E_{CO_2}} = \frac{\Delta\left(\frac{E_{CO_2}}{GDP}\right)}{\frac{E_{CO_2}}{GDP}} + \frac{\Delta\left(\frac{GDP}{H}\right)}{\frac{GDP}{H}} + \frac{\Delta\left(\frac{H}{L}\right)}{\frac{H}{L}} + \frac{\Delta L}{L} \tag{5}$$

where:

$\frac{\Delta\left(\frac{E_{CO_2}}{GDP}\right)}{\frac{E_{CO_2}}{GDP}}$ — the rate of change of emissivity of GDP,

$\frac{\Delta\left(\frac{GDP}{H}\right)}{\frac{GDP}{H}}$ — the rate of change of productivity of one working hour,

$\frac{\Delta\left(\frac{H}{L}\right)}{\frac{H}{L}}$ — the rate of change of working time per employee,

$\frac{\Delta L}{L}$ — the rate of change of the number of employees.

[1] A dot placed over the symbol of a variable, e.g. $\dot{A}$, denotes a derivative $\frac{dA(t)}{dt}$ of variable *A* after time *t*, in compliance with the convention commonly used in the literature of the subject.

The emission reduction assessment performed in this paper aims at investigating the contribution of these four factors to the changes in the energy-related CO_2 emissions. The problem of development of an economy is not only the level of greenhouse gas emissions, but also — or above all — that this reduction should be accompanied by: GDP growth, a decrease in the burden of emission on GDP unit, an increase in the productivity of working time, an increase in employment in the economy and a decrease in working time per employee.

BASIC TRENDS AND RELATIONSHIPS BETWEEN ENERGY USE, CO_2 EMISSIONS, GDP AND LABOUR IN POLAND IN THE YEARS 1990—2015

One of the objectives of this study is to provide an overview of the basic trends existing in Poland in the years 1990—2015 and to identify patterns that can be useful to explain the results obtained in the decomposition analyses. Input data required to perform the analyses are summarized in Table 1.

TABLE 1. PRIMARY ENERGY CONSUMPTION, CO_2 EMISSION, GDP, LABOUR INPUT AND ANNUAL WORKING TIME OF ALL EMPLOYEES

Year (*t*)	*E* in Mtoe	E_{CO_2} in million tons	*GDP*[a] in billion PLN	*L* in millions	*H* in billion hours
1990	105.78	373.47	309.17	17.56	31.46
1991	101.70	371.73	287.53	16.49	29.41
1992	95.24	361.98	295.00	15.77	28.01
1993	97.07	362.35	306.21	15.36	27.15
1994	96.23	358.07	322.13	15.12	26.97
1995	96.55	359.34	344.68	14.44	25.64
1996	101.01	373.24	366.05	14.48	25.83
1997	96.73	364.19	392.04	14.78	26.13
1998	95.14	336.76	411.65	15.12	26.97
1999	93.05	327.38	430.17	14.94	26.54
2000	89.82	316.11	448.67	14.32	25.55
2001	90.48	312.71	454.05	14.15	25.13
2002	89.36	300.93	460.41	13.70	24.22
2003	91.64	312.97	478.36	13.35	23.60
2004	91.89	316.63	503.72	13.47	24.13
2005	93.08	317.89	521.85	13.77	24.45
2006	97.90	331.45	554.20	14.19	25.09
2007	97.44	332.31	591.89	14.84	26.35
2008	99.01	326.62	622.08	15.52	27.55
2009	95.32	312.25	632.03	15.71	28.03
2010	101.78	332.07	656.68	15.57	27.78
2011	102.18	331.74	686.23	15.36	27.28
2012	98.10	315.40	699.95	15.40	27.35
2013	97.70	311.30	711.15	15.57	27.52

a GDP expressed at constant (1995) prices.

TABLE 1. PRIMARY ENERGY CONSUMPTION, CO_2 EMISSION, GDP, LABOUR INPUT AND ANNUAL WORKING TIME OF ALL EMPLOYEES (cont.)

Year (*t*)	*E* in Mtoe	E_{CO_2} in million tons	*GDP*[a] in billion PLN	*L* in millions	*H* in billion hours
2014	93.80	310.30	738.14	15.86	27.92
2015	95.10	310.60	772.32	16.08	28.57

a GDP expressed at constant (1995) prices.

Note. *E* — primary energy consumption, E_{CO_2} — CO_2 emission, *L* — labour input, *H* — annual working time of all employees.

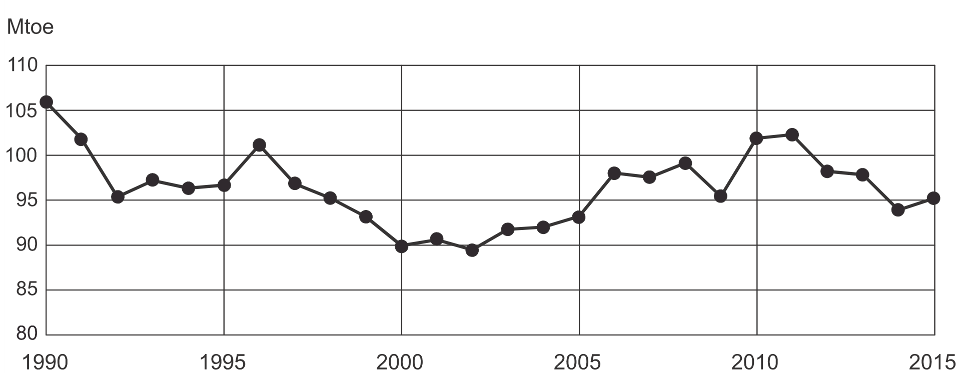
Source: own compilation and calculations based on the statistical bases of Statistics Poland, IEA and Eurostat.

Primary energy is any energy commodity that can be captured directly from natural resources. This includes energy contained in raw fuels, and other forms of energy that have not been subjected to human engineered conversion process.

Poland has relatively large reserves of solid fuels (hard coal and lignite), small reserves of natural gas and scarce oil reserves. Renewable energy sources are dominated by biomass and geothermal water energy. Poland has no uranium ores with a significant concentration of this element, whereas significant amounts of uranium are in diffused form (Soliński, 2012, p. 62). Electricity is mainly produced by professional thermal coal- and lignite-fired power plants. Some of the electricity comes from industrial power plants and gas-fired power plants. Hydroelectric power plants, wind turbines, biomass-fuelled power plants and biogas combustion plants play an inconsiderable part in the generation of electricity.

Primary energy consumption fell sharply after the fall of the Soviet Union from 105.78 Mtoe in 1990 to 95.24 Mtoe in 1992 (Figure 1). Since then, the dynamics of energy consumption has been relatively stable at between 90 Mtoe and 101 Mtoe per year, with a recent peak of 102.18 Mtoe in 2011 before falling to 95.1 Mtoe in 2015.

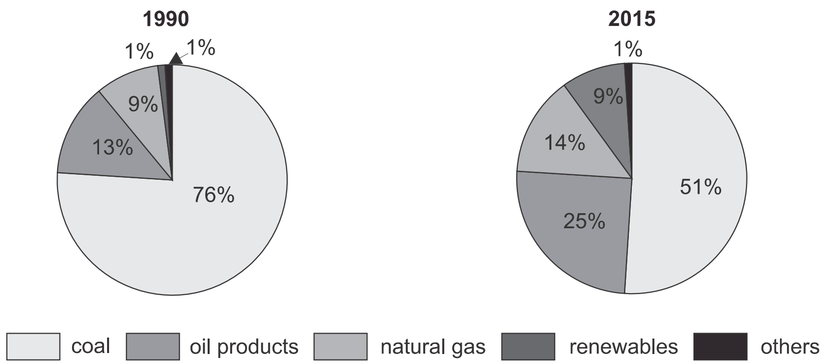
FIGURE 1. PRIMARY ENERGY CONSUMPTION



Source: own compilation and calculations based on the IEA statistical base.

The structure of primary energy consumption changed significantly during the examined period. The main source of energy in the period analysed was coal. Since the beginning of the 1990s, the share of coal had systematically decreased from 76% to 51% in 2015. Poland has started a slow transition from coal towards more oil, gas and renewables. Changes in the structure of sectors and economic activities can be the main factors responsible for this trend. Figure 2 shows the structure of primary energy consumption in 1990 and 2015.

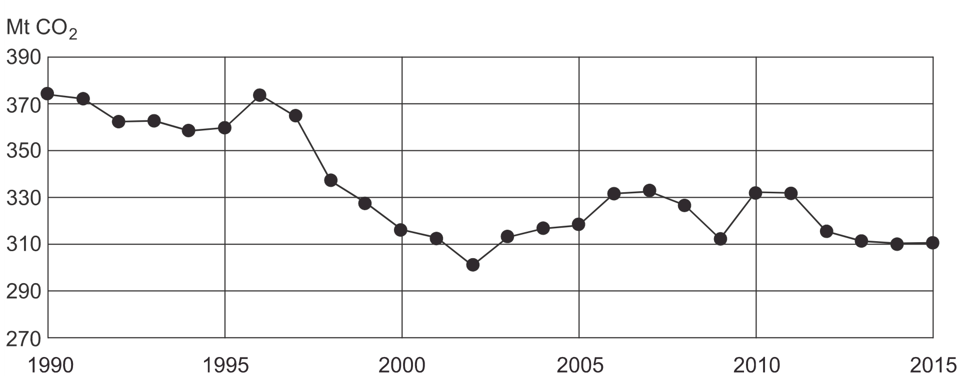
FIGURE 2. STRUCTURE OF PRIMARY ENERGY CARRIER CONSUMPTION



S o u r c e: own compilation based on the IEA statistical base.

Fossil fuel combustion in energy-related processes is a major source of CO_2 emissions. Power and heat generation accounts for more than half of these greenhouse gas emissions in Poland. The large share of coal in power production results in a relatively high carbon intensity from the sector.

FIGURE 3. CO_2 EMISSIONS

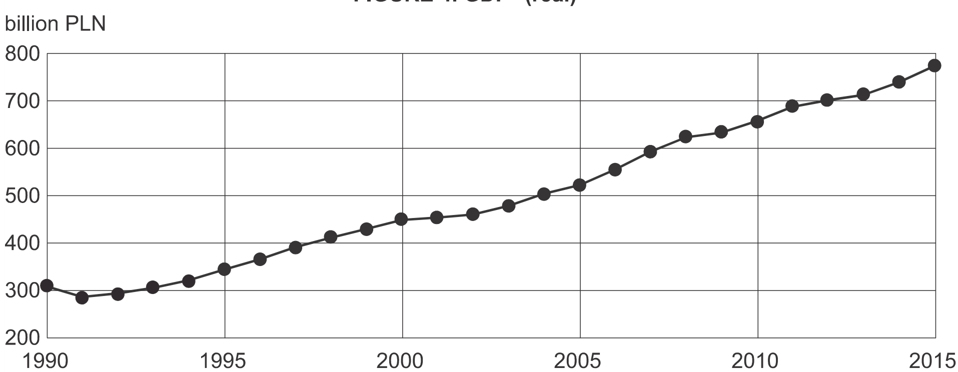


S o u r c e: as in Figure 2.

Between 1990 and 1995 emissions showed a slight downward trend (Figure 3). A slight increase in CO_2 emissions in Poland was observed in 1997. In the subsequent years, CO_2 emissions continued to decline until 2002, which was a record low for emissions, representing a decline of 19% compared to 1990. After five years of increasing, CO_2 emissions would continue to fall until 2008. In 2011, CO_2 emissions increased to the level of 331.74 million tons. A similar level of emissions persisted in the next year. At the end of the studied period CO_2 emissions slightly decreased. Although emissions from power and heat production declined in the last decade, as renewable energy sources and more efficient coal-fired power generation were introduced into the energy system, the decline in CO_2 emissions from this sector was partly offset by increased transport emissions (OECD/IEA, 2017).

Since 1992 Poland has continued to grow strongly in terms of gross domestic product, remarkably resilient to the 2009 world economic and financial crisis. After a modest slowdown in 2001 and 2002, Poland benefited from joining the European Union (EU) in 2004, and the economy enjoyed a solid growth in the subsequent years. Real GDP has increased almost 2.5 times since 1990 (Figure 4).

FIGURE 4. GDP[a] (real)



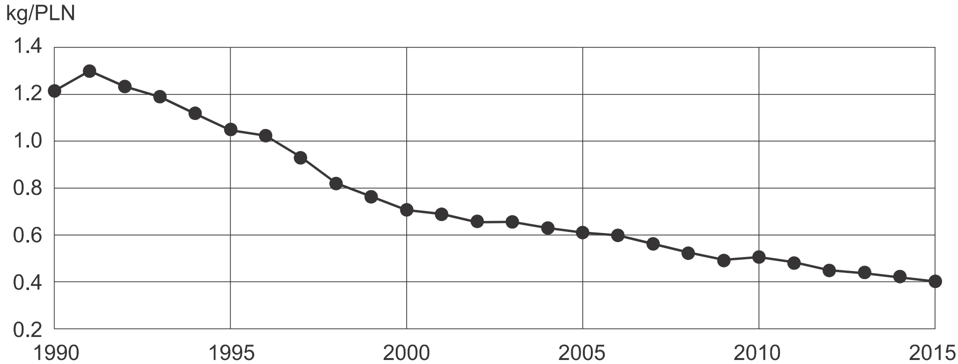
a GDP expressed at constant (1995) prices.

S o u r c e: own compilation based on the statistical bases of Statistics Poland and Eurostat.

A similar increasing trend was characteristic for productivity of man-hours. The value of GDP per hour worked was 9.83 PLN/hour in 1990, while in 2015 it increased to 27.04 PLN/hour. The annual working time of employees in the economy did not change much in the analysed period. In 1990 it amounted to 1.792 hours per employee, and by 2015 it had decreased slightly to 1.776 hours per employee.

Collected values of CO_2 emissions and estimated real GDP values allowed to determine the emissivity level (E_{CO_2}/GDP). Carbon emissions per GDP declined by two-thirds from 1.208 kg/PLN in 1990 to 0.402 kg/PLN in 2015 (Figure 5). In 1990, one zloty (1 PLN) of GDP was burdened with the emission of 1.2 kg of CO_2, and in 2015 it was only 0.4 kg per zloty of GDP.

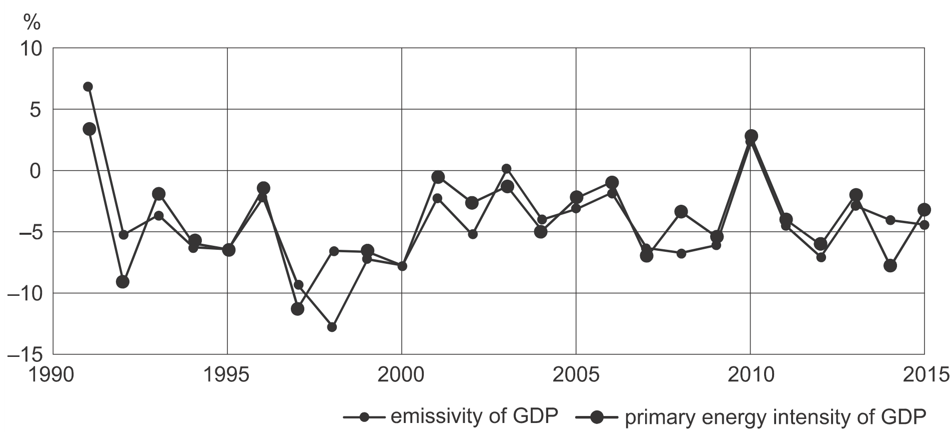
FIGURE 5. GDP EMISSIVITY



S o u r c e: own compilation based on the statistical bases of Statistics Poland, IEA and Eurostat.

It is worth mentioning that the rate of changes in GDP emissivity is significantly correlated with changes in GDP energy intensity (Figure 6). The determined correlation coefficient is at a level of 0.83.

FIGURE 6. ANNUAL RATE OF CHANGES IN EMISSIVITY OF GDP AND IN GDP PRIMARY ENERGY INTENSITY



S o u r c e: as in Figure 5.

The main factors contributing to the decreasing trend of GDP emissivity can be related to the solid growth of GDP, and declining level of CO_2 emission due to changes in energy mix, technological progress and to changes in structure of economic sectors in Poland and their share in the GDP generation. The observed decreasing trend in GDP emissivity can be also explained in terms of energy policy objectives.

EU REQUIREMENTS AND CO_2 EMISSION REDUCTION TARGETS ACHIEVED IN POLAND

Polish energy policy is driven to a very large extent by EU directives and requirements. The key ecological environmental policy objectives have been curtailed to a reduction of CO_2 emissions as compared to 1990. Table 2 presents the EU Member States' targets concerning greenhouse gas emission reduction to be achieved by 2030.

TABLE 2. THE EU MEMBER STATES' GREENHOUSE GAS EMISSION REDUCTION TARGETS BY 2030

Grounds for setting the target	Target year of reduction	EU Member States' greenhouse gas emission reduction targets	Achieved CO_2 emission reduction targets in the period under examination in % a — actual b — on the basis of an annual average target
Kyoto Protocol to the United Nations Framework Convention on Climate Change	up to 2012	by 6% compared[1] to the 1990 level	for 2012: a 15.55 b 6.00
European Union climate and energy package — 3x20%	up to 2020	by 20% compared[2] to the 1990 level	for 2015: a 16.83 b 16.60
Climate and energy policies up to 2030	up to 2030	by 40% compared to the 1990 level	for 2015: a 16.83 b 25.00

1 For 15 EU Member States. 2 For 28 EU Member States.
S o u r c e: own compilation on the basis of https://ec.europa.eu/clima/policies/strategies/2020_en.

Poland has met the guidelines contained in the Kyoto Protocol and the measures taken to reduce greenhouse gas emissions in the field of CO_2 have been implemented above the assumed limits. The action programme for all EU countries, called the climate and energy package, or 3x20% by 2020, endorsed by the European Council in March 2007 and implemented in April 2009, set out three key objectives, which were, at the same time, the objectives of the Europe 2020 strategy for smart, sustainable and inclusive growth:

- reducing by 20% greenhouse gas emissions in the EU by 2020 compared to the 1990 levels;
- increasing the share of renewable energy to 20% of final gross energy consumption in the EU in 2020;
- increasing energy efficiency in the Union by 20% as compared to forecasts for 2020, as well as increasing the share of biofuels in total transport fuel consumption to 10% by 2020.

As part of the climate and energy policy up to 2030, adopted by national leaders in October 2014, the EU is in pursuit of three main objectives, which include:

- reduction by at least 40% greenhouse gas emissions as compared to the 1990 levels;

- ensuring at least a 27% share of renewable energy sources in total energy consumption;
- at least a 27% increase in energy efficiency.

By achieving the first of these objectives, the EU will be able to undertake cost-effective measures to attain the long-term goal of reducing emissions by 80—95% by 2050 in the context of the necessary reductions that should be achieved collectively by the developed countries, and to provide a fair and ambitious contribution to reaching the Paris Agreement.

However, in order for it to be implemented, the sectors covered by the EU Emissions Trading Scheme (ETS)[2] would have to reduce emissions by 43% compared to the 2005 levels, which necessitates the reform and strengthening of the ETS; sectors not covered by this scheme[3] would have to reduce emissions by 30% as compared to the 2005 levels, which requires the setting of individual binding targets for individual Member States.

The European Commission is seeking cost-effective ways to make the European economy more climate-friendly and more energy-efficient. The improvement of energy efficiency is perceived as the most cost-effective way of reducing greenhouse gas emissions and the largest source of energy available to the world (Cullen & Allwood, 2010, pp. 2059—2069). The EU's road map for moving to a low-carbon economy indicates that by 2050 the EU should have reduced its greenhouse gas emissions by 80% as compared to the 1990 levels only through national emission reductions. The key steps in meeting this objective would be to achieve a 40% emission reduction by 2030 and a 60% emission reduction by 2040. It is assumed that all sectors must be involved, to the extent appropriate to their technological and economic capacity, but it should be borne in mind that there are differences in the size of the reductions to be achieved between sectors.

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[2] The system covers the following sectors and gases with the focus on emissions that can be measured, reported and verified with a high level of accuracy:

- carbon dioxide from: power and heat generation; energy-intensive industry sectors including oil refineries, steel works and production of iron, aluminium, metals, cement, lime, glass, ceramics, pulp, paper, cardboard, acids and bulk organic chemicals; commercial aviation;
- nitrous oxide from production of nitric, adipic and glyoxylic acids and glyoxal;
- perfluorocarbons from aluminium production.

Participation in the EU ETS is mandatory for companies in these sectors, but in some sectors only plants above a certain size are included. Certain small installations can be excluded if governments put in place fiscal or other measures that will cut their emissions by an equivalent amount. In the aviation sector, until 2023 the EU ETS will apply only to flights between airports located in the European Economic Area.

[3] Non-ETS emissions include the following sectors: transport, agriculture, waste, industrial emissions outside the EU ETS and the municipal and housing sector with buildings, small sources, households, services, etc.

DECOMPOSITION OF CO_2 EMISSION CHANGE RATE

As a result of the analyses conducted in the part *A trademark model…*, absolute and relative changes in CO_2 emissions (E_{CO_2}) in Poland in the years 1990—2015, the emissivity of GDP (E_{CO_2}/*GDP*), labour productivity (*GDP/H*), the number of working hours per employee (*H/L*) and labour input (*L*) were distinguished and presented in Table 3.

TABLE 3. DECOMPOSITION OF THE RATE OF CO_2 EMISSION CHANGES DUE TO THE EMISSIVITY OF GDP, LABOUR PRODUCTIVITY PER HOUR, NUMBER OF WORKING HOURS PER EMPLOYEE AND LABOUR INPUT

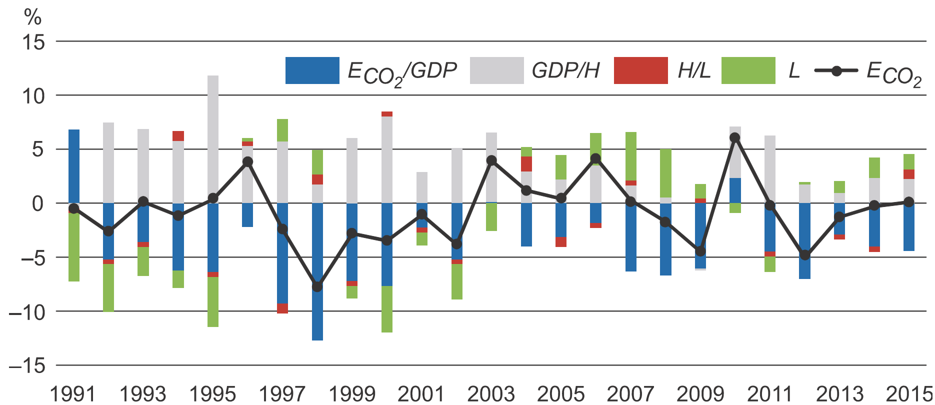
Y e a r (*t*)	E_{CO_2} [a] in %	E_{CO_2}/*GDP*	*GDP/H*	*H/L*	*L*
		in p.p.			
1990	—	—	—	—	—
1991	–0.47	6.79	–0.50	–0.45	–6.31
1992	–2.66	–5.22	7.44	–0.45	–4.42
1993	0.10	–3.63	6.85	–0.45	–2.67
1994	–1.19	–6.26	5.74	0.90	–1.57
1995	0.35	–6.41	11.82	–0.45	–4.60
1996	3.80	–2.22	5.27	0.45	0.30
1997	–2.45	–9.31	5.72	–0.90	2.04
1998	–7.83	–12.71	1.73	0.90	2.25
1999	–2.82	–7.23	6.01	–0.45	–1.16
2000	–3.50	–7.71	8.01	0.45	–4.25
2001	–1.08	–2.27	2.84	–0.45	–1.20
2002	–3.84	–5.23	5.08	–0.45	–3.24
2003	3.92	0.10	6.41	0.00	–2.58
2004	1.16	–4.00	2.94	1.35	0.87
2005	0.40	–3.14	2.22	–0.90	2.22
2006	4.18	–1.84	3.45	–0.45	3.02
2007	0.26	–6.32	1.65	0.45	4.48
2008	–1.73	–6.70	0.52	0.00	4.45
2009	–4.50	–6.09	–0.14	0.45	1.27
2010	6.15	2.33	4.72	0.00	–0.89
2011	–0.10	–4.50	6.24	–0.45	–1.39
2012	–5.05	–7.03	1.73	0.00	0.25
2013	–1.31	–2.90	0.94	–0.45	1.10
2014	–0.32	–4.05	2.31	–0.45	1.87
2015	0.10	–4.43	2.23	0.90	1.39

a The growth rate of individual quantities was determined as a difference of the logarithms of these quantities in periods *t*+1 and *t*.

S o u r c e: as in Table 1.

It can be noticed that the most significant contribution to the formation of the annual decline rate of CO_2 emission (among the GDP emissivity, labour input, labour productivity per hour and number of working hours per employee) has the emissivity of GDP and the productivity of man-hours (Figure 7).

FIGURE 7. DECOMPOSITION OF THE RATE OF CO_2 EMISSION CHANGES DUE TO THE EMISSIVITY OF GDP, LABOUR PRODUCTIVITY PER HOUR, NUMBER OF WORKING HOURS PER EMPLOYEE AND LABOUR INPUT

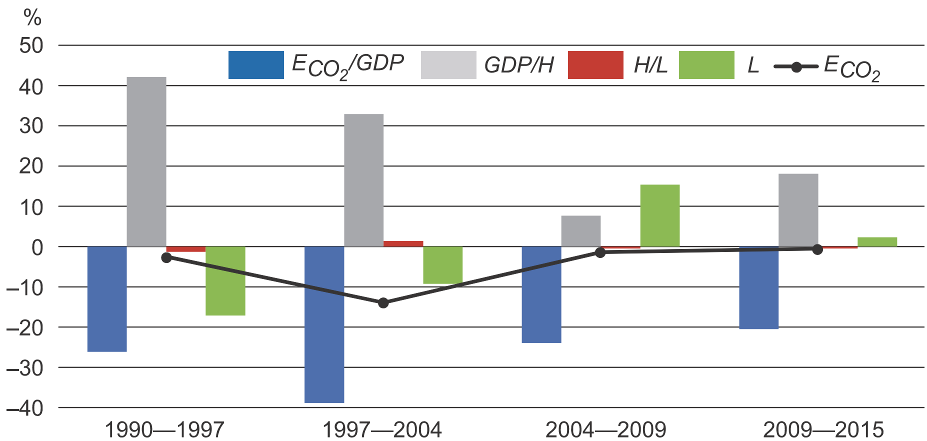


N o t e. As in Table 3.
S o u r c e: own compilation on the basis of Table 3 data.

It seemed useful to aggregate analysed data for better understanding the contribution of the explanatory factors in changes of CO_2 emissions. The period of the analysis was split into four sub-periods (1990—1997, 1997—2004, 2004——2009, 2009—2015) determined by important events for the Polish economy. The analysis provides interesting results (Figure 8).

In the years 1990—1997, till the Kyoto agreement, the level of CO_2 decreased by 2.52% compared to 1990. The important role in carbon-dioxide emission decrease played decreasing emissivity of GDP and decreasing number of employees with effects (contributions) respectively –26.27 p.p. and –17.23 p.p. The economic growth measured by labour productivity per hour had the most noticeable positive contribution to CO_2 emission change (42.33 p.p.). Decreasing number of working hours per employee had slightly positive effect on decreasing emissions (–1.35 p.p.). From 1997 till the EU joining in 2004, CO_2 emissions presented a strong decline of nearly 14%. Similarly to the previous period, decreasing emissivity of GDP and decreasing number of employees with effects respectively –39.06 p.p. and –9.31 p.p. were mainly responsible for this declining process. The growing labour productivity per hour with the effect 33.03 p.p. and increasing number of working hours per employee (1.35 p.p.) had positive contributions to CO_2 emission change. In the next five years, till the financial crisis in 2009, CO_2 emissions fell by 1.39% mainly due to decreasing emissivity of GDP (–24.09 p.p.) and slightly decreasing working time per employee (–0.45 p.p.). The growing number of employees (15.45 p.p.) and economic growth per working hour (7.69 p.p.) had the important positive effect on CO_2 emission change. In the period of 2009—2015 CO_2 emissions decreased by only 0.53% due to decreasing GDP emissivity (–20.58 p.p.), falling number of working hours per employee (–0.45), increasing productivity per working hour (18.17 p.p.) and growing number of employees (–1.35 p.p.).

FIGURE 8. DECOMPOSITION OF THE CUMULATED RATE OF CO_2 EMISSION CHANGES DUE TO THE EMISSIVITY OF GDP, LABOUR PRODUCTIVITY PER HOUR, NUMBER OF WORKING HOURS PER EMPLOYEE AND LABOUR INPUT



N o t e. As in Table 3.
S o u r c e: as in Figure 7.

CONCLUSION

The study provided a decomposition of the changes in CO_2 emissions rates in Poland between 1990 and 2015 to determine contribution of different socio-economic factors to the formation of the changes in the energy-related CO_2 emissions. The pollutant emission changes were examined in relation to changes in emissivity of GDP, productivity of working time, number of employees and working time per employee.

The main results provided in this paper show that:

- CO_2 emissions in 2015 decreased by 18.43% compared to 1990. Changes in the emissions were accompanied by steady economic growth of the Polish economy;
- among the analysed factors, the economic growth (measured by GDP per working hour) had the most noticeable contribution to CO_2 emission changes. The fundamental role in carbon-dioxide emission decrease played declining emissivity of GDP. The increase in the labour supply, observed in some periods, contributed to the relative growth of that factor in pollutant emission changes. Decreasing number of working hours per employee had a slight positive effect on decreasing emissions;

- considering the growing labour productivity, efforts to increase employment should be correlated with a decreasing number of working hours per employee.

As a result of the analyses of the information collected, a clear picture of interdependence and multidimensionality of economic processes is shaped. Changes made in one dimension result in consequences in other aspects. Rational and responsible management requires not only an examination of the extent to which individual objectives have been achieved. Systemic analysis of interdependencies is necessary to ensure social well-being.

Further research would be needed to examine the CO_2 emission changes for other members of EU in relation to changes in: emissivity of GDP, productivity of man-hours, number of employees and working time per employee in relation to other countries. It would be interesting to contrast the obtained results.

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