GOSPODARKA SUROWCAMI MINERALNYMI – MINERAL RESOURCES MANAGEMENT

2023 Volume 39 Issue 4 Pages 67–84

DOI: 10.24425/gsm.2023.148167

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A decomposition analysis of primary energy consumption and economic transition: the case of Poland

Introduction

The primary energy consumption of a given country depends mainly on the size and structure of the national economy. The intensity of energy use can be measured by, among other indicators, the energy intensity of the gross domestic product (GDP), expressed in a unit of energy (e.g. GJ) per unit of the domestic product output (e.g. national currency or EUR) in a given period. The inverse of this indicator is the productivity of energy use, meaning the increase in GDP value from each unit of primary energy consumed in the economy. Figure 1 shows the development of the Polish economy in the period 1995–2021, measured by the value of GDP, expressed in real prices of 2021. Since 1995, the economy has been developing at a relatively constant pace, and the value of GDP increased by almost 290% in real terms throughout the analyzed period. At the same time, the structure of the economy

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was changing, the share of more energy-intensive industries was decreasing, and the share of service in generating national income – characterized by lower absolute primary energy consumption – was increasing.

Therefore, despite significant economic growth, the total primary energy consumption in Poland in 1995–2021 remained at a relatively constant level of 3800–4600 PJ/year (Table 1, Figure 2). Figure 2 also shows that in the analyzed period, along with the relative increase in GDP, the productivity of primary energy consumption increased from 1995. At the same time, the energy intensity of the economy decreased. The combination of these two factors contributed to maintaining the primary energy consumption at a constant level, despite continuous economic development.

It is also worth noting that due to the impact of the COVID-19 pandemic, there was a decline in total primary energy consumption in 2020 and a reduction in GDP expressed in real terms. Although there was an increase in GDP value expressed in current prices year on year, the economy's revenues expressed in real terms decreased in 2020 by approximately 2.1% compared to 2019, as shown in Figure 1 and Table 1. In 2021, a clear rebound can be seen in both primary energy consumption and GDP value (real prices 2021).

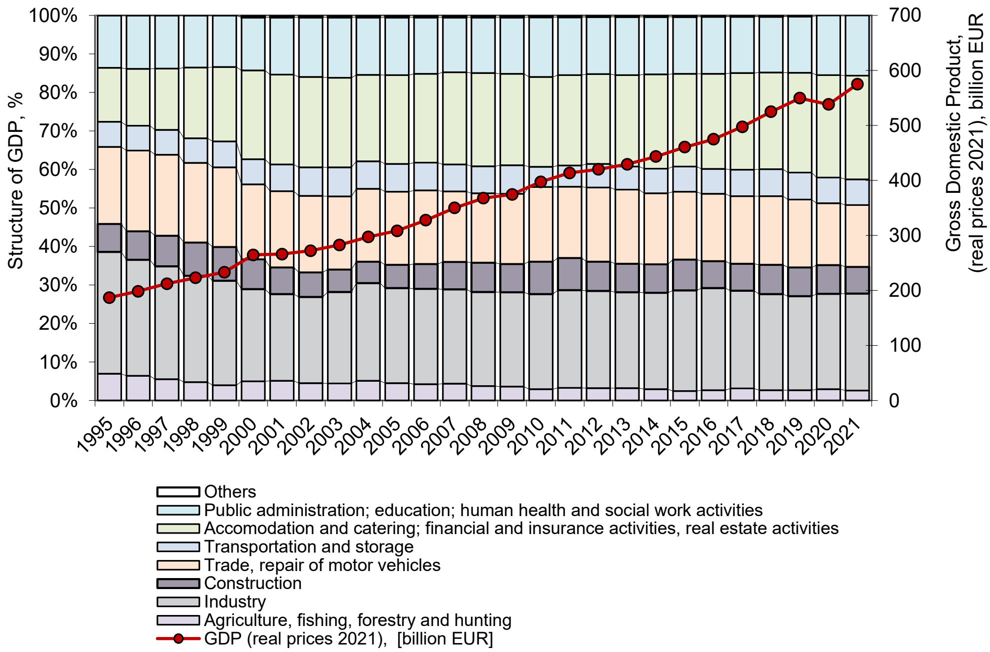

Fig. 1. Gross domestic product (billion EUR, real prices 2021) and the structure of the Polish economy (%) in the years 1995–2021

Source: own work based on Statistical Yearbook of the Republic of Poland 1996–2022

Rys. 1. Produkt krajowy brutto (mld EUR, ceny stałe 2021) oraz struktura gospodarki Polski (%) w latach 1995–2021

Table 1. Energy intensity, energy productivity, total primary energy consumption and Poland's gross domestic product in selected years from the period 1995–2021

Tabela 1. Energochłonność i produktywność gospodarki, całkowite zużycie energii pierwotnej oraz produkt krajowy brutto w Polsce w latach 1995–2021

Parameter	Unit	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Energy intensity	MJ/EUR	22.2	14.6	12.7	10.9	9.6	9.4	9.0	8.7	8.1	7.9	7.9
Energy Productivity	EUR/GJ	45.1	68.4	78.5	91.8	103.9	106.5	111.0	115.0	123.8	126.5	127.0
Primary energy consumption	PJ	4,148.0	3,870.3	3,931.7	4,329.2	4,430.3	4,459.0	4,480.4	4,564.5	4,438.6	4,253.9	4,526.2
GDP (real prices 2021)	billion EUR	186.93	264.69	308.50	397.38	460.52	474.68	497.43	524.72	549.59	538.18	574.77

Source: own work based on Energy Statistics in years 1995–2022 and Statistical Yearbook of the Republic of Poland, 1996–2022.

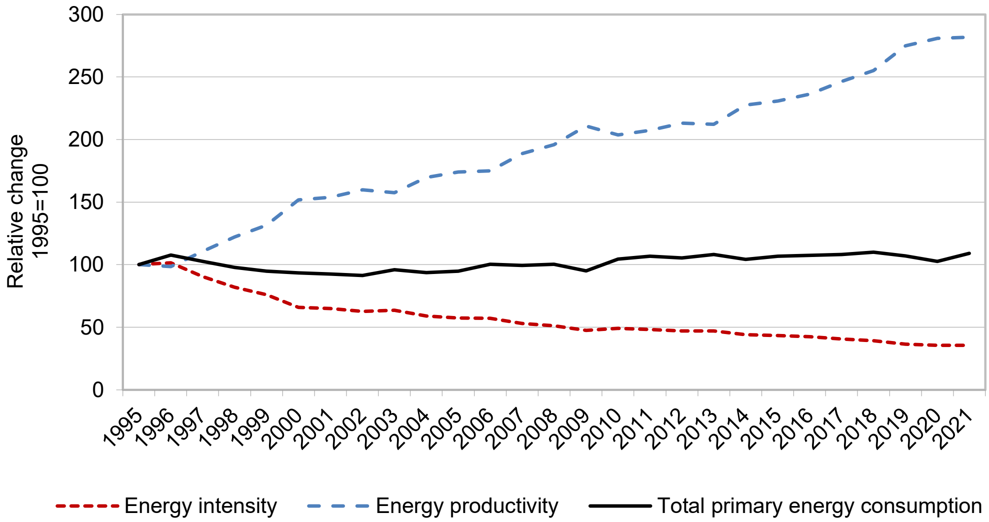

Fig. 2. Relative change of the energy intensity, energy productivity, and total primary energy consumption in Poland in years 1995–2021

Source: own work based on Energy Statistics in years 1995–2022 and Statistical Yearbook of the Republic of Poland, 1996–2022

Rys. 2. Względna zmiana energochłonności gospodarki, produktywności energetycznej oraz całkowitego zużycia energii pierwotnej w Polsce w latach 1995–2021

Aim of the study and contribution

A descriptive analysis of changes in primary energy consumption in Poland in 1995––2021, including changes in selected energy and economic indicators (i.e. energy intensity, energy productivity, gross domestic product), does not allow one for the identification of all key factors influencing the change of the examined value over time. It is also not possible to quantify this impact over the analyzed period. In this context, the main aim of the research presented in this paper is to propose a decomposition model of primary energy consumption in Poland and apply it in order to perform the analysis covering the period of economic transformation and then the period of energy transition to quantitatively estimate the impact of the identified factors on the change in primary energy consumption in the studied time span.

To the best of the author's knowledge, based on the literature review presented in Section 2, there is a research gap in terms of quantitatively estimating the impact of identified factors on long-term changes in primary energy consumption in Poland.

A better understanding of the quantitative impact of individual factors on primary energy consumption in countries in transition, such as Poland, may translate into adapting climate and energy policies implemented at the EU level to the specific conditions of individual member states (an example of the use of decomposition analysis for European policy and strategies evaluation can be found in Reuter et al. (2019)). As a consequence, the implemented instruments to enforce these policies can be more effective, which may have an impact on achieving the planned environmental goals (Malec 2023)). The results of the presented research may also be helpful in designing national energy strategies and policies and developing domestic forecasts of primary energy consumption, which is particularly important in the era of the ongoing energy transition aimed at decarbonizing the Polish economy.

The paper is structured as follows. Section 2 presents the methodological approach applied in the study, including the mathematical formulation of selected methods, and describes the main assumptions and data series used. Section 3 discusses the result with regard to the developed decomposition model of primary energy consumption in Poland. Finally, conclusions are provided in Section 4.

1. Materials and methods

The analysis of the energy intensity of the Polish economy presented in the previous section does not allow for the formulation of detailed conclusions regarding the impact of various factors on the total change in primary energy consumption. Therefore, the decomposition analysis was proposed, which enables the identification and quantitative assessment of factors contributing to the total or relative change of the decomposed value in a selected period. The decomposition analysis may refer to, inter alia, energy consumption, energy intensity or carbon dioxide emissions (Ang 1994; Sun 1998; Grunewald et al. 2014). It can be also applied to decompose other energy and emission measures, economic sectors or industry branches (Wang and Yang 2020; Weiss de Abreu at al. 2021; Wang and Liu 2021; Ščasný et al. 2021; Raza and Lin 2023).

Decomposition methods began to be used after the first oil crisis (1973), especially to study energy consumption and energy intensity in the economy, with a particular emphasis on the industrial sector. The results obtained and knowledge about the mechanisms behind the observed changes contributed to the design of new energy policies in individual countries (Ang 2004). Decomposition analysis methods are widely used and described in global literature. Ang (1995) and Ang and Zhang (2000) provided an extensive review of research on the methodological and empirical aspects of decomposition analysis.

Decomposition methods have also been used to identify the main indicators influencing the final energy consumption in a given country. The paper by Azami and Hajilooei (2020) used structural decomposition analysis (SDA) to analyze energy consumption in Iran in 2001–2011. An analysis of the impact of energy efficiency, also using SDA, on final energy consumption in Spain can be found in Román-Collado and Colinet (2018). Studies related to the use of decomposition methods were also conducted in Poland. Iskrzycki et al. (2011) performed an analysis of sulfur dioxide emissions in Polish power stations in 1995–2008. Gołaś (2022) applied the logarithmic mean Divisia index (LMDI) method to investigate the changes in carbon dioxide emissions related to energy consumption in the Polish agricultural sector in 2019 and 2020. Stachura (2017) and Stachura (2018) presented the results of a structural decomposition analysis of the ODEX energy efficiency index and final energy consumption in selected sectors of the Polish economy in 2000–2015. In addition to the described research, Poland has been used as a case study in a number of papers regarding, inter alia, the transformation towards a low-carbon energy system (Zych et al. 2023), the impact of environmental regulations on the demand for hard coal in the energy sector (Kaszyński and Kamiński 2020) and studies related to the competitiveness of using hard coal in the power industry and its regional distribution in the context of the impact of domestic and international prices of this energy carrier and prices of CO_2 emission allowances (Kamiński 2019; Kaszyński et al. 2019, 2020). Research has also been conducted on the impact of the implementation of the capacity market as a support mechanism for power industry companies and its impact on the long-term demand for hard coal (Komorowska 2023) and on the costs associated with the functioning of this mechanism in the context of the effects achieved on the ongoing energy transition of Poland (Komorowska et al. 2020, 2023). It should be emphasized, however, that none of these works included an analysis of primary energy consumption over a long-term horizon, covering the economic and energy transition period.

The period of economic transition enables detailed research and quantitative assessment of the effects of individual factors influencing primary energy consumption. These factors include:

- economic growth (measured by, for example, GDP);
- changes in the structure of the economy (share of individual sectors in GDP – the activity of each sector can be measured by the gross value added – GVA);
- changes in the energy intensity of the economy (divided into individual sectors);
- changes in the efficiency of energy transformation processes.

The decomposition analysis includes examining changes in primary energy consumption in Poland from 1995 to 2021. The first step was the selection of variables affecting primary energy consumption. A decomposition identity (where the left side of the equation is equal to the right side) was then formulated to identify the key factors contributing to the change of the decomposed quantity over time. These factors were selected based on the literature review regarding decomposition analysis of the energy consumption and energy intensity in the industrial sectors or at the national level (Ang 1995, 2005; Ang and Zhang 2000). In the next step, homogeneous time-series data were prepared regarding the identified factors influencing primary energy consumption in the examined period. Based on the formulated decomposition identity and the developed input data, decomposition calculations were performed using selected methods, considering both multiplicative and additive approaches.

The developed primary energy consumption decomposition model is described by the following identity (1):

$$TPEC_t = \frac{TPEC_t}{TFEC_t} \cdot \frac{\sum_i FEC_{i,t}}{\sum_i GVA_{i,t}} \cdot \frac{\sum_i GVA_{i,t}}{GDP_t} \cdot GDP_t$$

$TPEC_t$	–	total primary energy consumption in year *t* (TJ),
$TFEC_t = \sum_i FEC_{i,t}$	–	total final energy consumption in year *t* (TJ),
$FEC_{i,t}$	–	final energy consumption in sector *i* in year *t* (TJ),
$GVA_{i,t}$	–	gross value added of sector *i* in year *t* (million EUR 2021),
GDP_t	–	gross domestic product in year *t* (million EUR 2021).

For the purposes of the conducted research and due to the availability of homogeneous and consistent statistical data, the Polish economy was divided into five main sectors, namely:

- industry,
- construction,
- agriculture (including forestry and fishing),
- services (including transportation).

Gross value added was used as a measure of the activity of these sectors. All measures of this activity are expressed in real prices, i.e. EUR'2021.

The decomposition identity presented in equation (1) can be expressed as the product of the following coefficients (2):

$$TPEC_t = C_{eff_t} \cdot \sum_i C_{int_{i,t}} \cdot \sum_i C_{str_{i,t}} \cdot C_{dem_t} \tag{2}$$

$C_{eff_t} = \frac{TPEC_t}{TFEC_t}$	–	the reverse efficiency of the primary to final energy conversion/transformation process in year *t* (–),
$\sum_i C_{int_{i,t}} = \frac{\sum_i FEC_{i,t}}{\sum_i GVA_{i,t}}$	–	the energy intensity of a given economic sector *i* in year *t* (TJ/million EUR 2021),
$\sum_i C_{str_{i,t}} = \frac{\sum_i GVA_{i,t}}{GDP_t}$	–	the share of a given economic sector *i* in the gross domestic product in year *t*, which represents the structure of an economy (–),
$C_{dem_t} = GDP_t$	–	the demand coefficient measured by the value of the gross domestic product of an economy in year *t* (–).

To conduct a quantitative analysis to estimate the effects resulting from the proposed coefficients influencing the change in total primary energy consumption in Poland in the analyzed period, mathematical formulas appropriate for a given decomposition method should be used. There are many methods that can be applied, which in general can be divided into methods related to the Laspeyres index and the Divisia index. An extensive comparison and discussion of these methods can be found in Liu and Ang (2003), Ang et al. (2003), Ang (2004), Ang and Liu (2007). In this research, the generalized Fisher index (as in the works of Metcalf (2008) and Huntington (2010)) for the multiplicative approach and the logarithmic mean Divisia index (LMDI) method for the additive approach were used. Both selected methods provide a perfect decomposition, i.e. without a residual term.

- the multiplicative approach:

$$E_{total} = \frac{TPEC_t}{TPEC_0} = E_{eff} \cdot E_{int} \cdot E_{str} \cdot E_{dem} \tag{3}$$

- the additive approach:

$$\Delta TPEC_{total} = TPEC_t - TPEC_0 = \Delta TPEC_{eff} + \Delta TPEC_{int} + \Delta TPEC_{str} + \Delta TPEC_{dem} \tag{4}$$

In the multiplicative approach, in accordance with equation (3), the total change of the analyzed quantity is expressed in relative terms as the ratio of primary energy consumption in year t and in year 0 (it should be noted that index 0 denotes the first year (1995) of the analyzed period while index t denotes the subsequent years up to the last year of that period (2021)). This change is then calculated as the product of the effects coming from the identified factors, specifically energy conversion efficiency, energy intensity, structural and demand ($E_{eff} \cdot \mathrm{E}_{int} \cdot E_{str} \cdot E_{dem}$). However, in the case of the additive approach (4), the total change in the examined quantity is expressed in absolute terms as the difference between primary energy consumption in year t and in year 0. This change is then calculated as the sum of the effects coming from the factors identified and described earlier ($\Delta TPEC_{eff}$ + + $\Delta TPEC_{int} + \Delta TPEC_{str} + \Delta TPEC_{dem}$).

The generalized Fisher index is the geometric mean of the Paasche and Laspeyres indexes, and the mathematical formulas of this index for a two-factor model can be found in Boyd and Roop (2004). Since the developed decomposition model consists of four coefficients, it was not possible to directly apply the mathematical formulas presented in the cited paper. However, in the work of Ang et al. (2004), mathematical formulas for the n-factor model were presented. Denoting – for the sake of mathematical clarity – the factors identified in equation (2) as I1, I2, I3 and I4, respectively, the effects derived from these factors ($E_{eff} \cdot E_{int}$ $\cdot\, E_{str} \cdot E_{dem}$) can be calculated using the following mathematical formulas:

$$\begin{aligned} E_{eff} = {} & \left(\frac{I_1^t I_2^0 I_3^0 I_4^0}{I_1^0 I_2^0 I_3^0 I_4^0}\right)^{\frac{1}{4}} \cdot \left(\frac{I_1^t I_2^t I_3^0 I_4^0}{I_1^0 I_2^t I_3^0 I_4^0} \cdot \frac{I_1^t I_2^0 I_3^t I_4^0}{I_1^0 I_2^0 I_3^t I_4^0} \cdot \frac{I_1^t I_2^0 I_3^0 I_4^t}{I_1^0 I_2^0 I_3^0 I_4^t}\right)^{\frac{1}{12}} \cdot \\ & \cdot \left(\frac{I_1^t I_2^t I_3^t I_4^0}{I_1^0 I_2^t I_3^t I_4^0} \cdot \frac{I_1^t I_2^t I_3^0 I_4^t}{I_1^0 I_2^t I_3^0 I_4^t} \cdot \frac{I_1^t I_2^0 I_3^t I_4^t}{I_1^0 I_2^0 I_3^t I_4^t}\right)^{\frac{1}{12}} \cdot \left(\frac{I_1^t I_2^t I_3^t I_4^t}{I_1^0 I_2^t I_3^t I_4^t}\right)^{\frac{1}{4}} \end{aligned} \tag{5}$$

$$E_{\mathrm{int}} = \left(\frac{I_1^0 I_2^t I_3^0 I_4^0}{I_1^0 I_2^0 I_3^0 I_4^0} \right)^{\frac{1}{4}} \cdot \left(\frac{I_1^0 I_2^t I_3^t I_4^0}{I_1^0 I_2^0 I_3^t I_4^0} \cdot \frac{I_1^0 I_2^t I_3^0 I_4^t}{I_1^0 I_2^0 I_3^0 I_4^t} \cdot \frac{I_1^t I_2^t I_3^0 I_4^0}{I_1^t I_2^0 I_3^0 I_4^0} \right)^{\frac{1}{12}} \cdot$$
$$\cdot \left(\frac{I_1^0 I_2^t I_3^t I_4^t}{I_1^0 I_2^0 I_3^t I_4^t} \cdot \frac{I_1^t I_2^t I_3^0 I_4^t}{I_1^t I_2^0 I_3^0 I_4^t} \cdot \frac{I_1^t I_2^t I_3^t I_4^0}{I_1^t I_2^0 I_3^t I_4^0} \right)^{\frac{1}{12}} \cdot \left(\frac{I_1^t I_2^t I_3^t I_4^t}{I_1^t I_2^0 I_3^t I_4^t} \right)^{\frac{1}{4}} \tag{6}$$

$$E_{str} = \left(\frac{I_1^0 I_2^0 I_3^t I_4^0}{I_1^0 I_2^0 I_3^0 I_4^0} \right)^{\frac{1}{4}} \cdot \left(\frac{I_1^0 I_2^0 I_3^t I_4^t}{I_1^0 I_2^0 I_3^0 I_4^t} \cdot \frac{I_1^t I_2^0 I_3^t I_4^0}{I_1^t I_2^0 I_3^0 I_4^0} \cdot \frac{I_1^0 I_2^t I_3^t I_4^0}{I_1^0 I_2^t I_3^0 I_4^0} \right)^{\frac{1}{12}} \cdot$$
$$\cdot \left(\frac{I_1^t I_2^0 I_3^t I_4^0}{I_1^t I_2^0 I_3^0 I_4^t} \cdot \frac{I_1^t I_2^t I_3^t I_4^t}{I_1^t I_2^t I_3^0 I_4^0} \cdot \frac{I_1^0 I_2^t I_3^t I_4^t}{I_1^0 I_2^t I_3^0 I_4^t} \right)^{\frac{1}{12}} \cdot \left(\frac{I_1^t I_2^t I_3^t I_4^t}{I_1^t I_2^t I_3^0 I_4^t} \right)^{\frac{1}{4}} \tag{7}$$

$$E_{dem} = \left(\frac{I_1^0 I_2^0 I_3^0 I_4^t}{I_1^0 I_2^0 I_3^0 I_4^0} \right)^{\frac{1}{4}} \cdot \left(\frac{I_1^t I_2^0 I_3^0 I_4^t}{I_1^t I_2^0 I_3^0 I_4^0} \cdot \frac{I_1^0 I_2^t I_3^0 I_4^t}{I_1^0 I_2^t I_3^0 I_4^0} \cdot \frac{I_1^0 I_2^0 I_3^t I_4^t}{I_1^0 I_2^0 I_3^t I_4^0} \right)^{\frac{1}{12}} \cdot$$
$$\cdot \left(\frac{I_1^t I_2^t I_3^0 I_4^t}{I_1^t I_2^t I_3^0 I_4^0} \cdot \frac{I_1^0 I_2^t I_3^t I_4^t}{I_1^0 I_2^t I_3^t I_4^0} \cdot \frac{I_1^t I_2^0 I_3^t I_4^t}{I_1^t I_2^0 I_3^t I_4^0} \right)^{\frac{1}{12}} \cdot \left(\frac{I_1^t I_2^t I_3^t I_4^t}{I_1^t I_2^t I_3^t I_4^0} \right)^{\frac{1}{4}} \tag{8}$$

The mathematical formulas presented in equations (5)–(8) apply to the multiplicative approach and the generalized Fisher index method. In the case of the additive approach and the LMDI method, the appropriate formulas take the following form (Ang 2004, 2015):

$$\Delta TPEC_{eff} = \frac{TPEC_t - TPEC_0}{\ln TPEC_t - \ln TPEC_0} \cdot \ln \left(\frac{I_1^t}{I_1^0} \right) \tag{9}$$

$$\Delta TPEC_{int} = \frac{TPEC_t - TPEC_0}{\ln TPEC_t - \ln TPEC_0} \cdot \ln \left(\frac{I_2^t}{I_2^0} \right) \tag{10}$$

$$\Delta TPEC_{str} = \frac{TPEC_t - TPEC_0}{\ln TPEC_t - \ln TPEC_0} \cdot \ln \left(\frac{I_3^t}{I_3^0} \right) \tag{11}$$

$$\Delta TPEC_{dem} = \frac{TPEC_t - TPEC_0}{\ln TPEC_t - \ln TPEC_0} \cdot \ln \left(\frac{I_4^t}{I_4^0} \right) \tag{12}$$

A homogeneous and consistent statistical data series necessary to perform the decomposition analysis of primary energy consumption in Poland (1995–2021) is presented in Table 2 (the table shows data only for selected years). This data includes the following parameters:

- gross domestic product of Poland (EUR billion – real prices of 2021);
- total primary energy consumption in Poland (TJ);
- total final energy consumption in Poland, including the breakdown of selected economic sectors (TJ);
- gross added value of Poland, including the selected economic sectors breakdown (EUR billion – real prices of 2021).

Table 2. Statistical data for selected years from the period 1995–2021 used in the decomposition analysis of primary energy consumption in Poland

Tabela 2. Dane statystyczne dla wybranych lat z okresu 1995–2021 wykorzystane w analizie dekompozycyjnej zużycia energii pierwotnej w Polsce

Parameter	Unit	1995	2000	2005	2010	2015	2020	2021
Gross domestic product	billion EUR (2021)	**209.3**	**266.1**	**310.8**	**397.8**	**460.8**	**538.5**	**570.2**
Total primary energy consumption	TJ	**4,022.5**	**3,552.3**	**3,682.5**	**4,042.9**	**3,770.4**	**4,055.3**	**4,352.2**
Total final energy consumption, of which:	TJ	**2,550.7**	**2,242.5**	**2,406.7**	**2,732.2**	**2,548.1**	**2,941.3**	**3,105.7**
Agriculture, forestry and fishing		200.5	194.5	186.0	156.2	139.4	162.0	156.5
Industry		878.5	708.0	603.5	555.1	583.6	660.5	673.3
Construction		15.5	8.1	8.5	10.1	6.5	6.1	7.6
Services and transportation		1,456.2	1,331.9	1,608.7	2,010.8	1,818.6	2,112.7	2,268.1
Gross value added, of which:	billion EUR (2021)	**184.7**	**236.1**	**273.1**	**350.0**	**408.8**	**474.3**	**497.7**
Agriculture, forestry and fishing		11.7	8.3	9.1	11.4	10.9	13.4	13.5
Industry		54.7	57.2	68.3	85.4	106.1	115.7	133.3
Construction		15.4	19.4	20.7	29.4	32.7	33.7	33.7
Services and transportation		102.9	151.2	175.0	223.8	259.0	311.6	317.1

Source: own work based on Eurostat database.

2. Results and discussion

Calculations were performed on the basis of the developed decomposition model and the prepared data set. The results for the multiplicative approach (generalized Fisher index method) are presented in Section 3.1 and for the additive approach (LMDI method), in Section 3.2.

2.1. Decomposition analysis results for the multiplicative approach

The results of the decomposition analysis of primary energy consumption in Poland in 1995–2021 for the multiplicative approach are presented in Figure 3. It should be emphasized that in Poland, between 1995 and 2021, primary energy consumption increased by 8.2%, but during the analyzed years, this consumption was subject to certain changes; periods of both reduction and growth can be identified. The decomposition analysis indicates that the key impact on primary energy consumption had two factors – an increase in demand, expressed in terms of changes in GDP, and a reduction of the energy intensity, expressed as an aggregate ratio of changes in final energy consumption in a given sector and measures of the economic activity of this sector. The relative change of the effect coming from the demand factor in 2021, compared to the value from 1995, was over 276%. As for the energy intensity effect, which impacts on primary energy consumption in the opposite direction (reduction), this reached 45% in 2021 compared to the value in 1995.

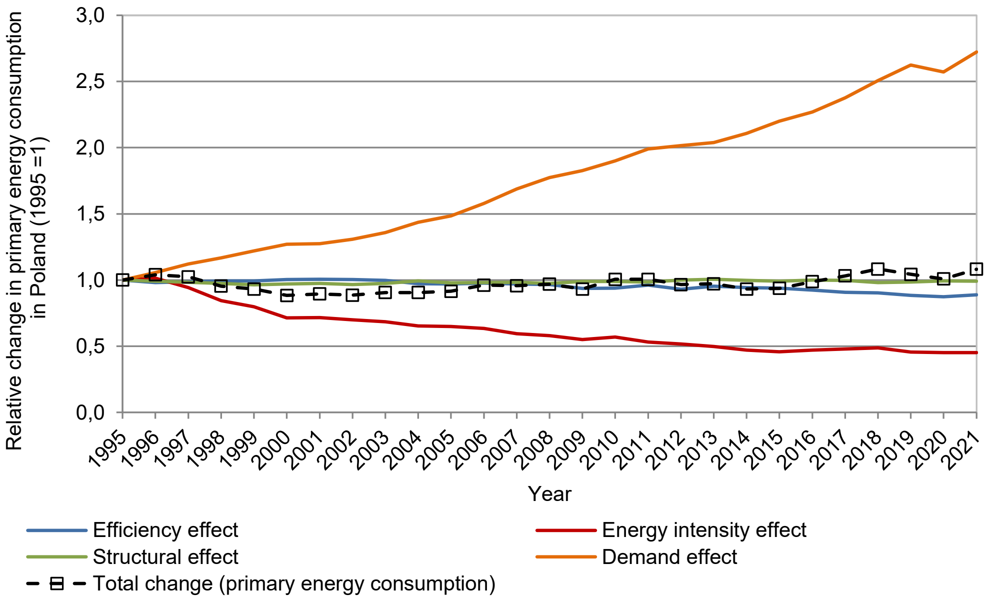

Fig. 3. Results of decomposition analysis of primary energy consumption in Poland in 1995–2021 (multiplicative approach)
Source: own work

Rys. 3. Wyniki analizy dekompozycyjnej zużycia energii pierwotnej w Polsce w latach 1995–2021 (podejście multiplikatywne)

The decomposition analysis results show that the impact of the structural factor was much smaller than the impact of the other identified factors (especially the effects coming from the demand factor and energy intensity) – ranging from 96% to 100.5% of the value from 1995 (Figure 4). This may contradict intuitive expectations that changes in primary energy consumption may have resulted from structural changes in the economy. However, the aggregate impact of the structural factor is practically at the same level throughout the analyzed period (on average, about 98% compared to the 1995 value). A similar tendency was observed in the case of the inverse efficiency of primary to final energy conversion. Until 2013, its impact was relatively insignificant (changes in the range of 93.8–100.7%), but after that period, it became noticeable – in 2021, its value amounted to approximately 88% of the level from 1995 (as shown in Figure 4).

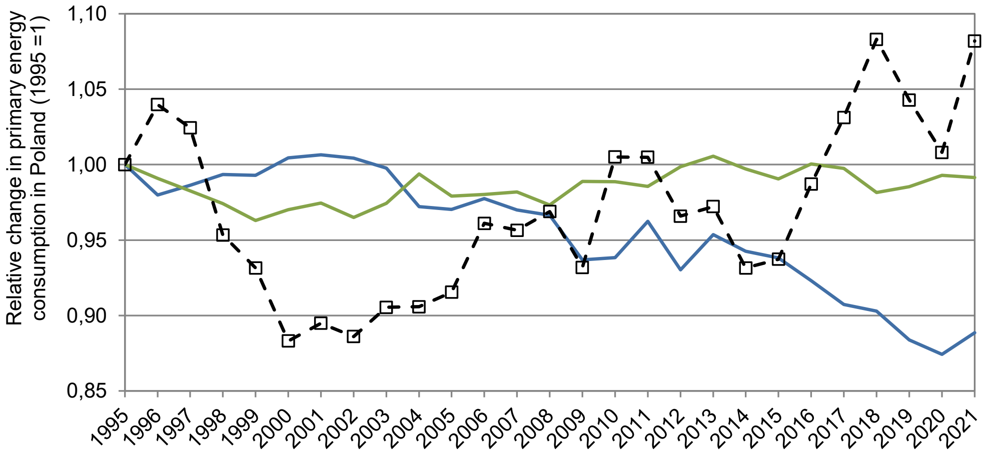

Fig. 4. Results of decomposition analysis of primary energy consumption in Poland in 1995–2021 (multiplicative approach) – efficiency and structural effects
Source: own work

Rys. 4. Wyniki analizy dekompozycyjnej zużycia energii pierwotnej w Polsce w latach 1995–2021 (podejście multiplikatywne) – efekty: strukturalny oraz efektywności wykorzystania energii

2.2. Decomposition analysis results for the additive approach

The results of the decomposition analysis of primary energy consumption in Poland in 1995–2021 for the additive approach are presented in Figure 5. The total change in primary energy consumption in Poland during this period amounted to 329.7 PJ. The greatest impact on this change had two effects (acting in the opposite direction) coming from the demand factor (+4193.5 PJ) and the energy intensity factor (–3325.5 PJ). The reverse conversion efficiency and structural factors also contribute to reducing primary energy consumption in Poland – the effects of these factors are relatively small and amount to –494.2 PJ and –44.1 PJ, respectively.

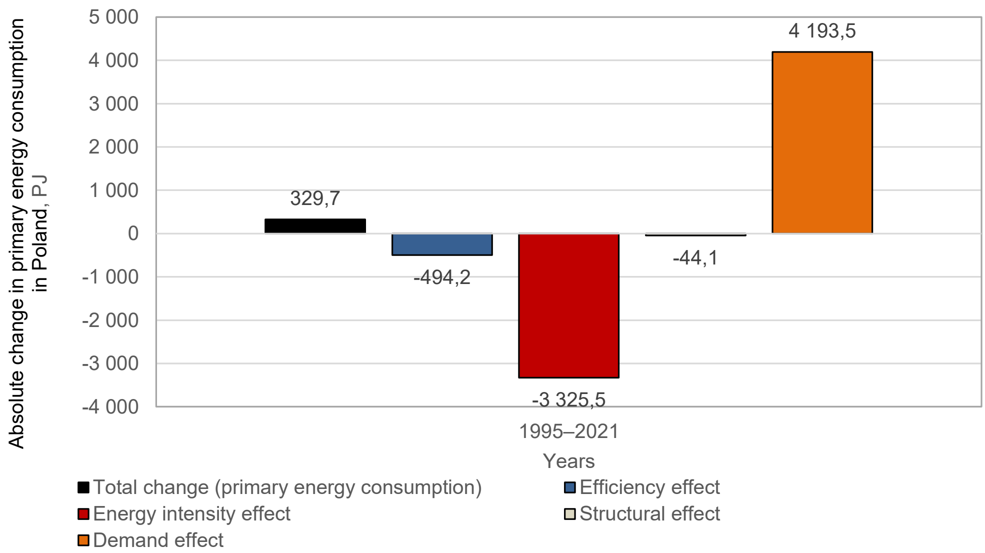

Fig. 5. Results of decomposition analysis of primary energy consumption in Poland in 1995–2021 (additive approach)
Source: Own work

Rys. 5. Wyniki analizy dekompozycyjnej zużycia energii pierwotnej w Polsce w latach 1995–2021 (podejście addytywne)

Conclusions

The study presented in this paper discusses the quantitative impact of the identified factors (efficiency, energy intensity, structural and demand) on changes in the total primary energy consumption in Poland in the long-term horizon, covering the period 1995–2021. To perform the described research, decomposition analysis was employed, including a multiplicative and additive approach. A decomposition model was developed based on the proposed identity. Mathematical formulas of two methods were used to perform the calculations: a generalized Fisher index for the multiplicative approach and the logarithmic mean Divisia index (LMDI) for the additive approach. It should be highlighted that both selected methods give a perfect decomposition, which means that there is no residual term in calculation outcomes.

The obtained results, regardless of the approach adopted and the calculation method applied, clearly indicate that in Poland (in 1995–2021), the effects of demand and energy intensity factors had the most significant impact on the primary energy consumption change. As pointed out in the introduction, the overall change in the consumption over the considered period was insignificant (approximately 330 PJ in absolute terms and 8.2% in relative terms). This was mainly due to the influence of the abovementioned factors, which worked in opposite directions and wiped out the effects of each other. Interestingly, of all the identified factors, the structural factor had the smallest impact on primary energy consumption in Poland. This result is consistent with the observations presented in the introduction, where changes in the structure of the national economy were relatively small despite the decrease in the share of the industrial sector and the increase of the service sectors. It should also be kept in mind that at the same time, technological changes were taking place in the industry which improved energy efficiency. As in the case of the structural factor, the efficiency factor also had a negligible impact on primary energy consumption, but after 2013, its share became significantly greater. This may be related to the changes observed in the energy sector, which is one of the largest primary energy consumers in Poland. The least effective and most exploited power generation units were shut down, and new ones with higher conversion efficiency were commissioned.

The presented study and the obtained results indicate the need to continue research in this area in order to better understand the shifts in the national economy related to changes in the consumption of primary and final energy. Another research area where decomposition analysis can be used should be a detailed analysis of changes in energy consumption caused by the COVID-19 pandemic. However, this would require considering a more extended series of data from the period after the pandemic has completely ended.

This work was carried out as part of the statutory research activity of the Mineral and Energy Economy Research Institute of the Polish Academy of Sciences.

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A DECOMPOSITION ANALYSIS OF PRIMARY ENERGY CONSUMPTION AND ECONOMIC TRANSITION: THE CASE OF POLAND

Keywords

decomposition analysis, primary energy, energy consumption, economic transition

Abstract

Primary energy consumption depends on the size of the economy and its structure, including both industrial and service sectors, characterized by different energy demands. Some of the basic energy and economic indicators that can be used to analyze primary energy consumption include energy intensity, energy productivity and indicators measuring the activity of the economy (gross domestic product or gross value added). In the years 1995–2021, the Polish economy developed at a relatively constant pace, and the value of gross domestic product increased in real terms by almost 290% over the entire analyzed period. However, despite this increase, total primary energy consumption remained at the relatively constant level of around 3,800–4,600 PJ/year. This was caused by, among other factors, an increase in energy productivity on the one hand and a reduction in energy intensity on the other.

It should be emphasized that a descriptive analysis of changes in primary energy consumption in Poland in the analyzed period, including changes in selected energy and economic indicators, does not allow the identification and quantification of the impact of all key factors on the total change of the examined value over time.

In this context, the main aim of the research presented in this paper is to propose a decomposition model of primary energy consumption in Poland and adapt it to conduct analyses covering the period of economic and energy transition to quantitatively determine the impact of the identified factors on the total change in primary energy consumption in the 1995–2021 period.

To perform the described research, decomposition analysis was applied, including a multiplicative and additive approach. A decomposition model was developed based on the formulated decomposition identity. Mathematical formulas of two methods were used to perform the calculations: a generalized Fisher index and the logarithmic mean Divisia index (LMDI). The obtained results indicate that the effects of demand and energy intensity factors had the most significant impact on the primary energy consumption change.

ANALIZA DEKOMPOZYCYJNA ZUŻYCIA ENERGII PIERWOTNEJ W POLSCE W OKRESIE TRANSFORMACJI GOSPODARCZEJ

Słowa kluczowe

zużycie energii, energia pierwotna, transformacja energetyczna, analiza dekompozycyjna

Streszczenie

Zużycie energii pierwotnej w danym kraju jest związane z wielkością gospodarki oraz jej strukturą, obejmującą zarówno sektory przemysłowe, jak i usługowe, które charakteryzują się inną intensywnością użytkowania energii. Jednymi z podstawowych wskaźników, które mogą być wykorzystane do analizy zużycia energii pierwotnej, są m.in. wskaźnik energochłonności, produktywności oraz produkt krajowy brutto. W latach 1995–2021 gospodarka Polski rozwijała się w stosunkowo stałym tempie, a wartość produktu krajowego brutto wzrosła realnie o prawie 290% w całym okresie. Jednak pomimo tego wzrostu całkowite zużycie energii pierwotnej pozostawało na względnie stałym poziomie około 3800–4600 PJ/rok.

Należy jednak podkreślić, że opisowa analiza zmian zużycia energii pierwotnej w Polsce, uwzględniająca zmiany wybranych wskaźników nie pozwala na identyfikację i ilościowe oszacowanie wpływu wszystkich kluczowych czynników na zmianę badanej wielkości w czasie.

W związku z tym głównym celem badań jest zaproponowanie modelu dekompozycji zużycia energii pierwotnej w Polsce i zastosowanie go do przeprowadzenia analiz obejmujących okres transformacji gospodarczej i energetycznej, w celu ilościowego określenia wpływu zidentyfikowanych czynników na zmianę zużycia energii pierwotnej w latach 1995–2021.

W celu realizacji opisanych badań wykorzystano analizę dekompozycyjną. Opracowano model dekompozycyjny, bazujący na sformułowanej tożsamości dekompozycyjnej. W celu wykonania obliczeń zastosowano formuły matematyczne dwóch metod: uogólnionej metody indeksu Fishera oraz logarytmicznej średniej indeksu Divisia. Uzyskane wyniki wskazują, że największy wpływ na zmianę zużycia energii pierwotnej w badanym okresie miały dwa efekty, tj. popytowy oraz energochłonności.