

Structural decomposition analysis applied to the energy use in Poland

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Abstract: To understand historical changes in energy performance of economy or specific sector, it is useful to evaluate the driving forces underlying these changes. Structural decomposition analysis allows identifying the impact of the external factors, such as technological, demand, and demographic effects on the fluctuations of the total energy use, CO₂ emissions, and other socio-economic indicators. This study applies methods of structural decomposition analysis to determine relative prominence of diverse sources of changes in the energy use in the Polish economy and its main sectors between 2000-2015. The author presents the methodology of decomposition into different explanatory factors, among which energy savings based on top-down indicators, which allows showing additionally what the role of energy efficiency improvements is at the level of the different sub-sectors and end-uses. The analysis is extended into comparison to European statistics in the context of implementation and monitoring of the UE indicative energy targets.

Keywords: energy use, structural decomposition analysis, indicators, energy efficiency

JEL codes: O18, Q40, Q56

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1. Introduction

Environmental policy designed to limit environment deterioration, support protection of natural resources and safeguard people's health and quality of life is a hallmark of the 21st century and one of the biggest challenges. The European Union has launched a system of climate and energy targets for up to the year 2030, aimed at reducing GHG emissions by 40% compared with 1990; an improvement of energy efficiency by 27% and an increase in the share of renewables in the total EU gross final energy consumption to 27%. Implementation of new regulations at the

international and European levels and an increase in the number of energy targets entails the necessity of choosing appropriate indicators and measurement methodology. The purpose of the monitoring progress is to assess the obtained results, the extent to which the objectives have been met, while simultaneously enabling international benchmarking.

In every country, energy demand changes over time due to factors like: changes in the structure of the economy, demographic changes, efficiency improvements or changes in the consumption patterns. Factorial decomposition analysis has become a useful tool for understanding the trends in energy use and identifying drivers for relevant changes (Ang and Zhang, 2000; Weber, 2009). Early studies developed decomposition techniques considering discrete time, whereas Divisia (1925) considered continuous time span. Decomposition methods can be divided into two categories: index decomposition analysis and structural decomposition analysis (Hoekstra and van der Bergh, 2003; Ang and Zhang, 2000). Index decomposition analysis measures the impact of energy efficiency gains in energy consumption at very detailed, sector disaggregation level (by sub-sector or end-use). The latter methodology allows dividing changes in energy consumption over time into various driving forces of the changes and can be applied to the whole economy or particular sectors (Metcalf, 2008).

In this article, the structural decomposition analysis has been conducted for energy use in Poland between years 2000-2015. The aim is to determine the relative prominence of diverse drivers of changes in the final energy consumption and in the most important sectors, i.e. transport, industry and households. The analysis has been extended into comparison with European statistics in the context of the implementation of the UE indicative energy targets. The study was conducted on the basis of data provided for this purpose by Enerdata, the data controller of the EU ODYSSEE-MURE program comprising 28 EU Member States and Norway. It employs two complementary ODYSSEE databases: one for energy efficiency and second for CO₂ emissions, as well as MURE database for policy enforcement measures to reduce energy consumption. The programme has been developed to monitor changes in the energy consumption and to assess to what extent the energy policy targets introduced in the EU by Directive 2006/32/EC have been met.

2. Structural decomposition analysis methodology

Structural decomposition analysis allows examining the impact of external factors, such as technological, structural, lifestyle and demographic effects, on the fluctuations of total energy use. This tool is based on the environmental input–output analysis and has become a standard method in energy analysis (Hoekstra and van der Bergh, 2003). This methodology gives more insight into the factors determining energy consumption and can therefore complement the official monitoring process based on energy intensity.

The objective of the analysis is to decompose the change in the total energy consumption of Polish economy and in three main sectors in the years 2000-2015 into various components (e.g. economic growth, lifestyle changes, efficiency improvements, changes in the production patterns). Structural decomposition allows analysing the influence of each of these effects on the aggregate, as well as estimating the relative share of these factors, among which energy savings based on top-down indicators, which permits to additionally show what the role of energy efficiency improvements has been like.

Energy efficiency is now seen as one of the key instruments to reduce consumption of fossil fuels and CO₂ emissions in a relatively short time. Energy efficiency and energy use are intrinsically linked. Improved energy efficiency should lead to actual reduction in energy consumption, unless rebound effects appear. ODYSSEE structural decomposition methodology allows explaining how the change of the final energy consumption by sector is linked to the energy savings calculated with top-down methods (Enerdata, 2015). Energy savings are derived from:

- energy efficiency index ODEX, or
- the method proposed by the European Commission for Energy Service Directive (ESD)¹.

The Odyssee energy efficiency index (ODEX) is the leading indicator used in the ODYSSEE programme to verify progress on energy efficiency in the 28 EU Member-States and Norway. ODEX measures energy efficiency progress of the whole economy as well as by the three main sectors (industry, transport and households). It is an aggregated bottom-up index, constructed from specific energy consumptions or unit consumptions, at the very detailed sector

¹ The Energy Service Directive 2006/32/EC

disaggregation level and re-aggregated at the level of final energy consumption, as a weighted average of sub-sectoral indices (Enerdata, 2012).

The method proposed by ESD and the one used by ODEX are in fact very similar. In principle, in ESD methodology only the part of the consumption, and thus of savings, not covered by the Emission Trading Scheme is considered. In ODEX calculations, all savings are considered.

3. Decomposition of energy consumption in Poland between years 2000-2015

3.1. Decomposition of energy consumption in industry

The change in the energy consumption of industry sector can be decomposed into the following elements (Enerdata, 2015):

- Activity effect;
- Structural changes;
- Energy savings, as measured from ODEX;
- Other effects.

The activity effect measures the impact of the change in industrial activity, on the energy use. It is calculated by multiplying the change of the value added between years t and t_0 by the energy intensity of the base year t_0 (Enerdata, 2011):

$$EQ_t = \Delta VA_{t/t_0} * \left(\frac{C_{t_0}}{VA_{t_0}} \right) \quad (1)$$

where:

EQ - activity effect,

VA - value added of manufacturing or industry,

C - energy consumption,

t - year t ,

t_0 - reference year t_0 .

The structural effect appears when individual branches with different energy intensities are growing at different rates. It is equal to the difference between a fictive consumption calculated with an energy intensity at constant structure of value added between the various branches or sub-branches and the actual energy consumption (Enerdata, 2011):

$$SE_t = \Delta Cf_{t/t_0} - \Delta C_{t/t_0}, \text{ with } Cf_t = IE_{C_t} * VA_t \quad (2)$$

where:

SE - structural effect,

Cf - fictive consumption based on the energy intensity at constant structure,

C - energy consumption,

IEc - energy intensity at constant structure,

VA - value added in constant prices,

t - year t,

t₀ - reference year t₀.

Energy savings are based on the Odyssee energy efficiency index ODEX methodology and are calculated as follows (Enerdata, 2015):

$$ESI_t = C_t * \left(\left(\frac{ODEX_t}{ODEX_{t_0}} \right) - 1 \right) \quad (3)$$

where:

ESI - energy savings,

C_t - energy consumption,

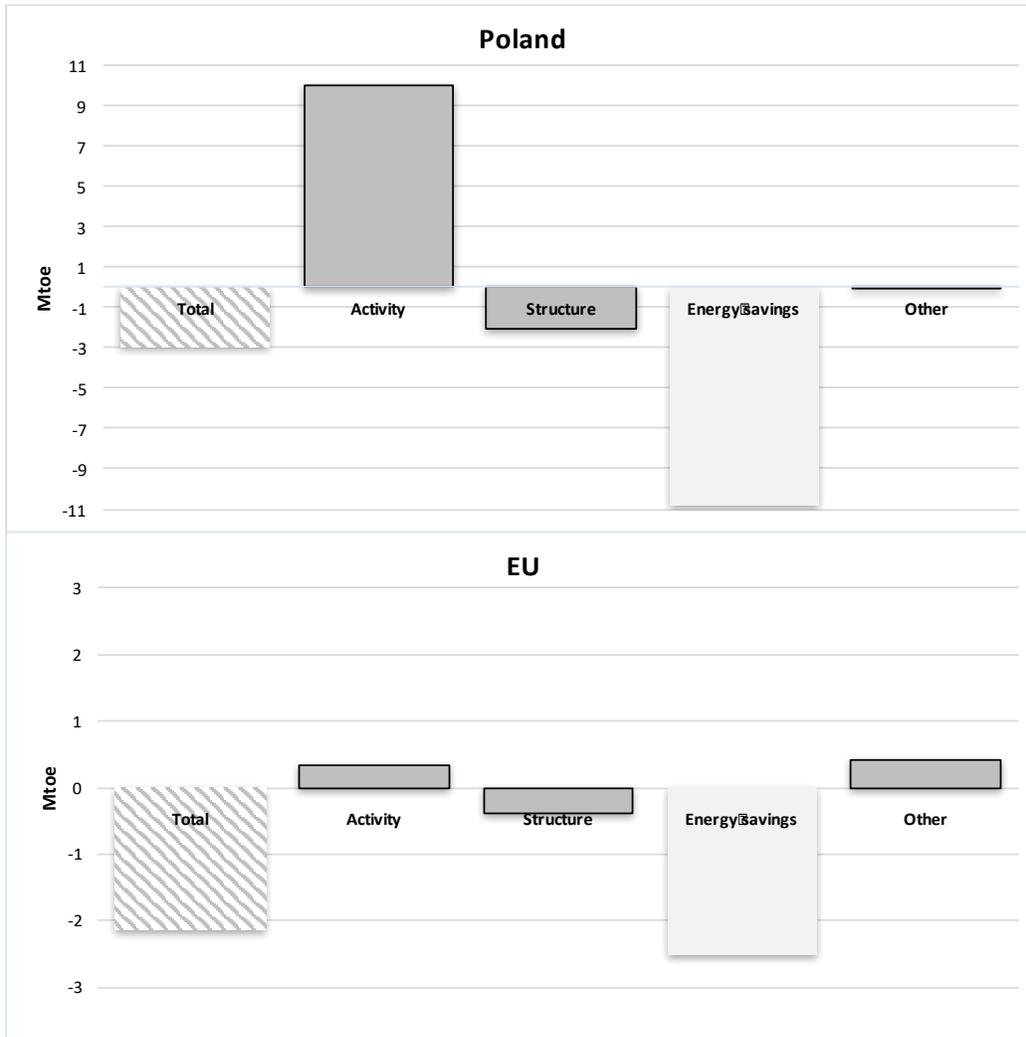
t - year t,

t₀ - reference year t₀.

For the industry sector, ODEX is carried out at the level of 12 branches – 10 manufacturing branches, mining and construction. The unit consumption is expressed in terms of energy used per ton produced for energy intensive products (steel, cement and paper) and in terms of energy used related to the production index for the other branches.

Decomposition of the decrease in the energy consumption in industry in Poland observed between the year 2000 and 2015 is presented on Figure 1. The total change and the influence of four factors of change in energy use are compared with the average level in the EU member states.

Figure 1. Decomposition of the energy use in industry for Poland and the EU (2000-2015)

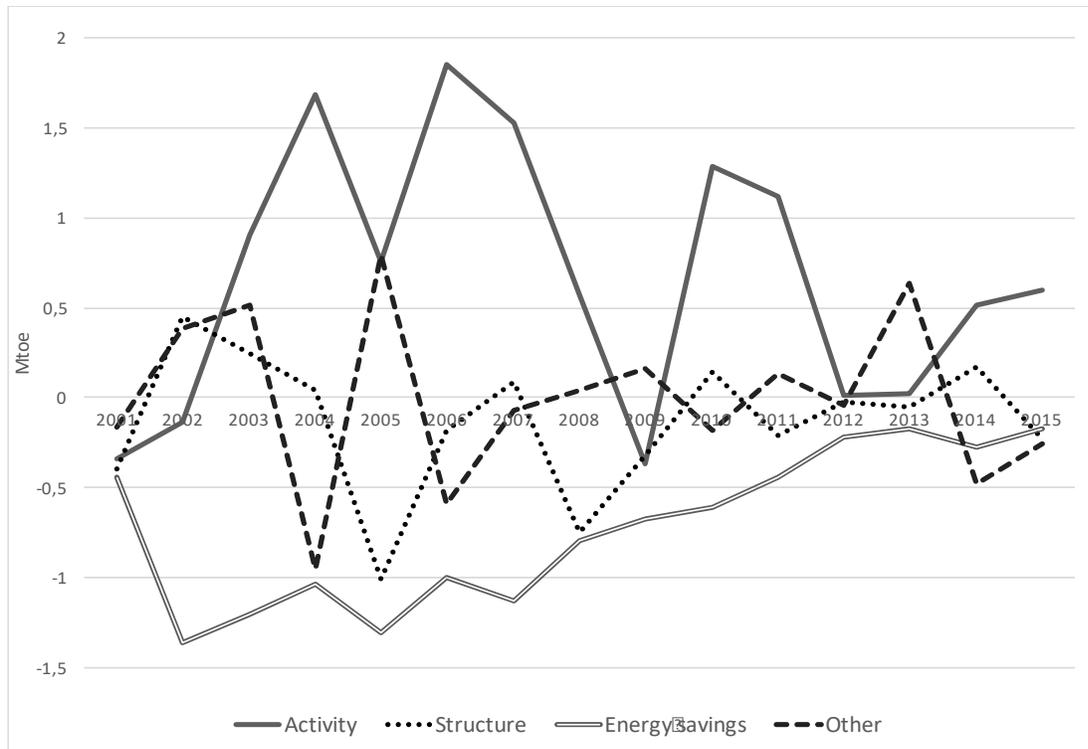


Source: author's own elaboration based on ENERA database

As shown in Figure 1, in the years 2000-2015, a small decrease by 2.93 Mtoe in the total energy consumption could be observed in the industry sector in Poland. There are two main factors which had the biggest influence on the final result, that is activity effect and energy savings. These two factors had big values, but in different directions, so they ultimately levelled. The positive activity effect of 10.01 Mtoe means that energy consumption of industry increased in the analyzed period, because of the higher industrial activity in Poland. Energy savings decreased the energy consumption by 10.84 Mtoe over the 2000-2015 period. The structural effect was negative (-2.04 Mtoe), which indicates that the structure of Polish economy changed into less energy consuming – branches with lower consumption grew faster.

The direction of changes and the relative impact of individual factors are quite similar to these observed in the European Union, but the values of the particular elements are much higher in the case of Poland. Figure 2 presents the main factors influencing energy use (Mtoe) in industry in Poland year by year in the analyzed period.

Figure 2. Main factors of change in the energy use in industry for Poland (2000-2015)



Source: author's own elaboration based on ENERA database

In Figure 2 we can see that, in general, activity effect had the biggest share in the energy consumption growth and almost every year saw an increase in the energy use. Whereas, the energy savings constantly decreased the energy use in the industry in the analyzed period, this impact in the last years of the period was not as strong as that observed in 2002-2008. The structural and other effects were variable in time and relatively smaller than the two other factors.

3.2. Decomposition of energy consumption in transport

Energy use in transport changes under the influence of the following factors (Enerdata, 2015):

- Activity effect;

- Energy savings;
- Modal shift effect.

Activity effect in the transport sector is caused by more traffic of passengers and goods. This effect is calculated for the different modes of transport separately and then summarized. The weighting method has been defined in such a way that the calculation of energy savings is strictly equal to the sum of energy savings by end-use, with energy savings obtained by multiplying the change in unit energy consumption by an indicator of activity. For passengers, it is calculated by multiplying the change in the traffic measured in passenger-kilometre for each mode (car, rail, bus), by the energy consumption per passenger-kilometre at base year. For goods, it is calculated by multiplying the change in the traffic in tonne-kilometre of each mode (road, rail and inland waterways) by the specific energy consumption per tonne-kilometre at base year, as follows (Enerdata, 2015):

$$EQT_t = \sum_{i=1}^n (\Delta pkm_{n,t/t_0} * CU_{n,t_0}) \text{ for passengers} \quad (4)$$

$$EQT_t = \sum_{i=1}^m (\Delta tkm_{m,t/t_0} * CU_{m,t_0}) \text{ for goods} \quad (5)$$

where:

EQT - activity effect,

CU - energy consumption per passenger or good kilometre by mode,

n - modes of passenger transport (car, bus, rail for passengers),

m - modes of goods transport (trucks and light vehicles, rail for goods, inland waterways),

pkm - number of passenger kilometre by mode,

tkm - number of ton kilometre for goods by mode,

t - year t,

t₀ - reference year t₀.

Energy savings effect is measured by multiplying the change of the energy consumption per passenger-km or tonne-kilometre of each mode of transport by the number of passenger/goods kilometre² (Enerdata, 2015):

$$EST_t = \sum_{i=0}^n (\Delta CU_{n,t/t_0} * pkm_{n,t}) \text{ for passengers} \quad (6)$$

² The methodology was proposed by the Commission to calculate energy savings for the monitoring of the ESD. It differs from the calculation used for the ODEX as the indicator used for cars is litre/100km instead of goe/pkm.

$$EST_t = \sum_{i=0}^m (\Delta CU_{m,t/t_0} * tkm_{m,t}) \text{ for goods} \quad (7)$$

where:

EST - energy savings,

CU - energy consumption per passenger or good kilometre for all transport mode,

n = cars, bus, rail for passengers,

m = trucks and light vehicles, rail for goods, inland waterways,

pkm - number of passenger kilometre by mode,

tkm - number of ton kilometre for goods by mode,

t - year t,

t₀ - reference year t₀.

Modal shift illustrates a change in the distribution of each mode in terms of traffic (for example, a decreasing share of public transport contributed to an increase in the consumption). It is calculated as a difference between the sum of savings of each mode for passenger and goods, respectively and the aggregate savings calculated for passenger or goods as a whole (Enerdata, 2015):

$$MST_t = EST_{t/t_0} - (\Delta CU_{t/t_0} \times pkm_t) \text{ for passengers} \quad (8)$$

$$MST_t = EST_{t/t_0} - (\Delta CU_{t/t_0} \times tkm_t) \text{ for goods} \quad (9)$$

where:

MST - modal shift effect,

EST - savings effect,

CU - energy consumption per passenger or good kilometre by mode,

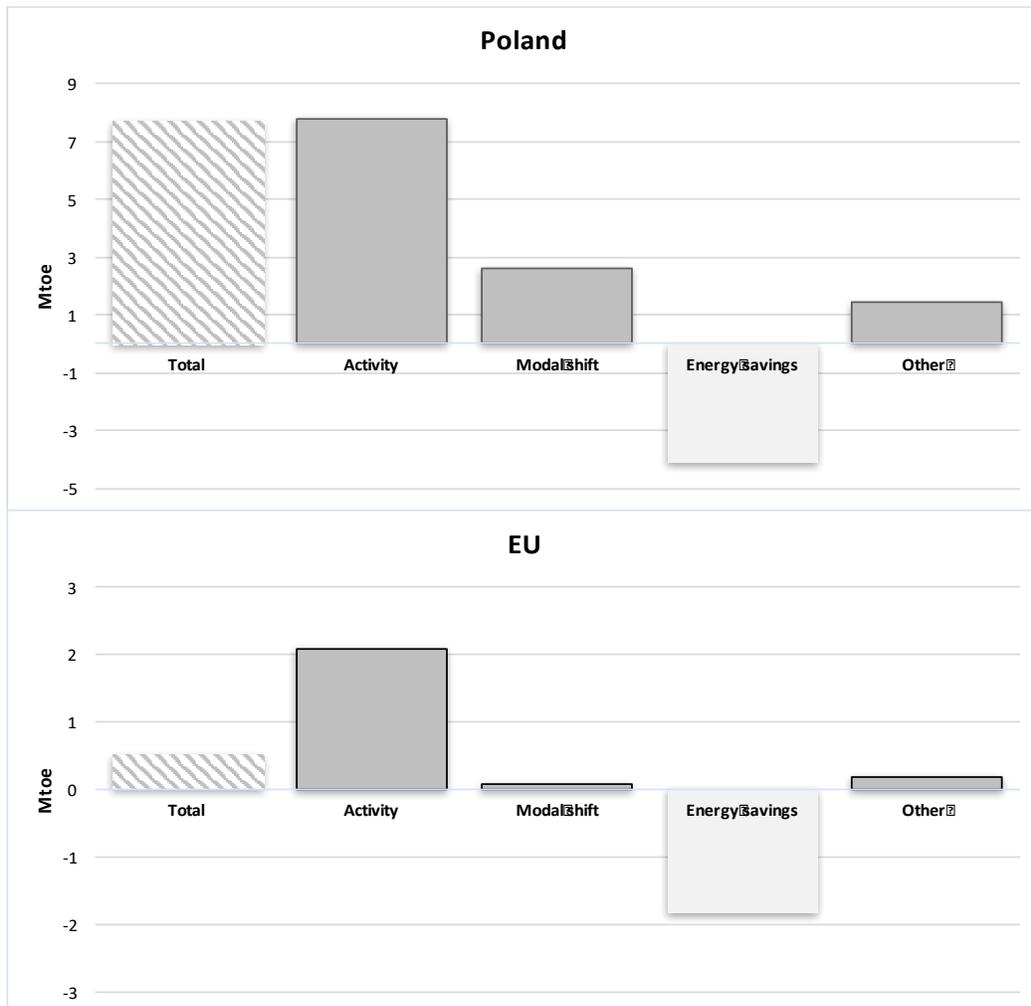
pkm - number of passenger-kilometres by mode,

tkm - number of ton-kilometres for goods by mode,

t - year t,

t₀ - reference year t₀.

Figure 3. Decomposition of the energy use in transport for Poland and EU (2000-2015)

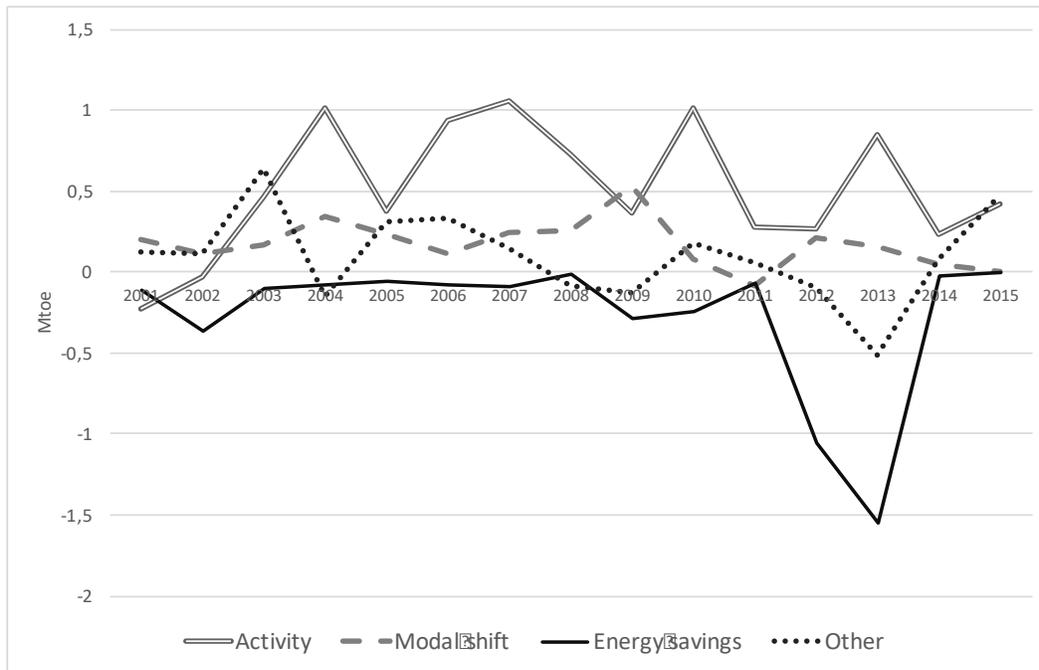


Source: author's own elaboration based on ENERA database

In the period under analysis, the increase by 7.69 Mtoe in the total energy consumption could be observed in the transport sector in Poland, as shown in Figure 3. It was mainly due to the increase in passenger and goods traffic (activity effect), which contributed to the increase in the energy consumption by 7.75 Mtoe. The two other factors, modal shift and energy savings, had a smaller influence on the final result. Another positive effect can be noted in a modal shift, with an increase of 2.63 Mtoe. On the other hand, it is only the energy savings that decreased the energy consumption by 4.14 Mtoe over the 2000-2015 period. It would be interesting to see, if this structure was more or less constant throughout the analyzed period of time, and if there were

any trends that can be observed and examined. Structural decomposition of annual changes in energy use in transport in Poland between the years 2000-2015 is illustrated by Figure 4.

Figure 4. Main factors of the change in the energy use in transport for Poland (2000-2015)



Source: Author's own elaboration based on ENERA database.

Figure 4 shows that the annual growth in the energy use in transport was caused mainly by activity effect, which added to the increase in the energy consumption between 0.5 and 1 Mtoe every year beginning with 2003. Also, modal shift effect was constantly contributing to the growth in the energy use in the years 2000-2015, with the exception of the year 2011. The biggest fluctuation can be observed in the energy savings. This effect was almost negligible in the earlier years and changed substantially in 2012 and 2013. As a result, energy savings caused the greatest decrease in the total energy consumption only at the end of the analyzed period.

3.3. Decomposition of energy consumption in households

Households consumption typically changes under the influence of various factors, such as (Enerdata, 2015):

- Climatic effect;

- More dwellings (demographic effect);
- Larger homes;
- More appliances per dwelling (electrical appliances, central heating);
- Energy savings, as measured from ODEX;
- Other effects (mainly changes in heating behaviours).

The demographic effect is a result of increasing number of dwellings. It is calculated as the change in the number of dwellings multiplied by the energy consumption per dwelling in a reference year, with climatic corrections (Enerdata, 2015):

$$DEH_t = \Delta n_{pr} \cdot pr_{t/t_0} * CU_{t_0} \quad (10)$$

where:

DEH - demographic effect,

n_{pr} - number of permanently occupied dwellings,

CU - energy consumption per dwelling with climatic corrections,

t - year t,

t_0 - reference year t_0 .

The energy consumption by households may also be influenced by the increase in the amount of household equipment (electrical appliances and central heating) and in the increasing size of dwellings. The increasing amount of equipment per households is due to the increasing number of electrical appliances in common use, like ICT, small electrical appliances and air conditioning. Moreover, larger homes require more energy while central heating requires around 25% more energy compared with heating a single room. The ‘central heating’ effect is calculated as a ratio between the unit consumption per m^2 and the unit consumption per equivalent dwelling (both with climatic corrections). Increasing penetration of central heating entails higher energy consumption, as all the rooms are well heated.

Energy savings are based on ODEX (Enerdata, 2015):

$$ESI_t = C_t * \left(\frac{ODEX_t}{ODEX_{t_0}} - 1 \right) \quad (11)$$

where:

ESI - energy savings,

C_t - energy consumption,

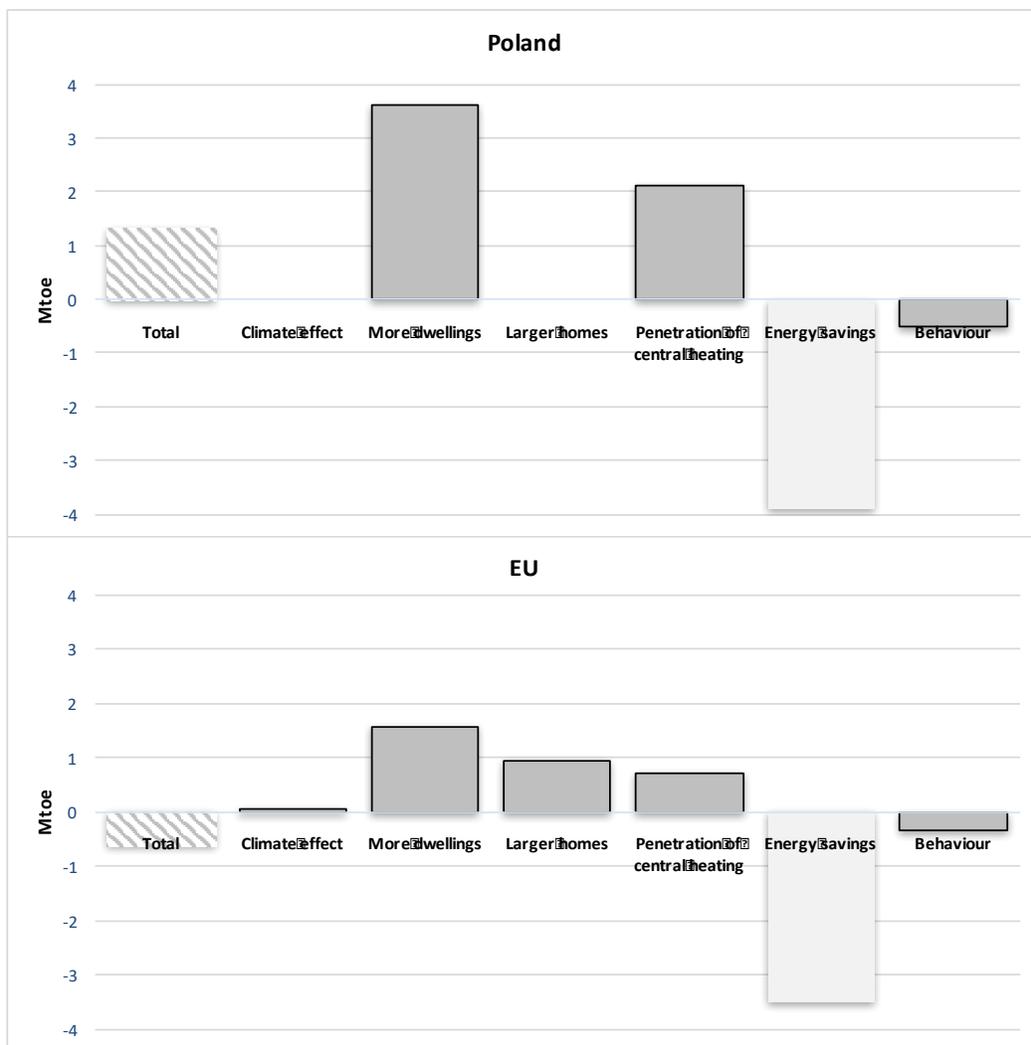
t - year t,

t₀ - reference year t₀.

For ODEX, the following indicators are considered to measure efficiency progress:

- Heating: unit consumption per m² at normal climate (koe/m²);
- Water heating: unit consumption per dwelling with water heating;
- Cooking: unit consumption per dwelling;
- Large electrical appliances: specific electricity consumption in kWh/year/appliance.

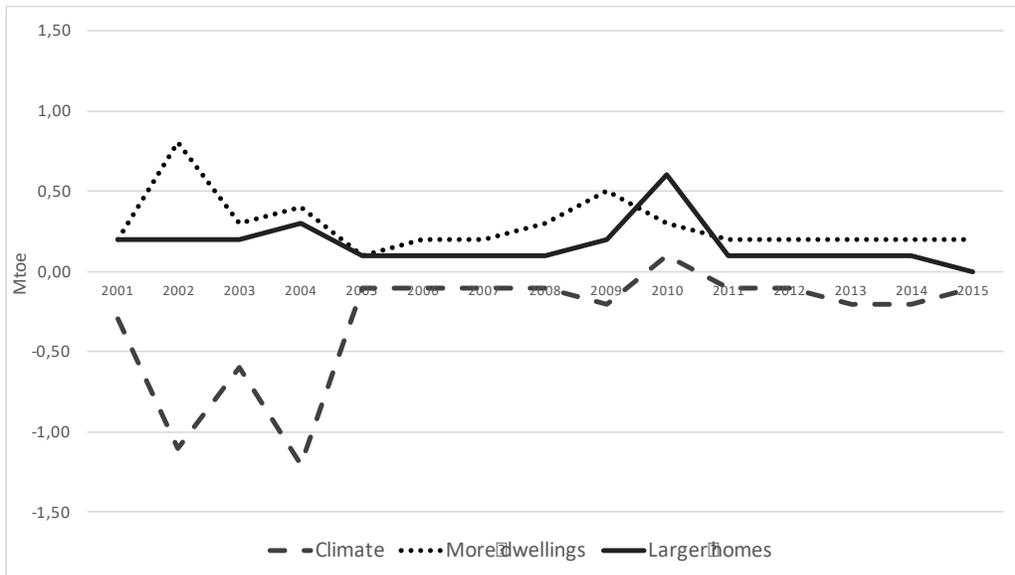
Figure 5. Decomposition of the energy use in households for Poland and EU (2000-2015)



Source: author's own elaboration based on ENERA database

In the analyzed period, the increase by 1.30 Mtoe in the total energy consumption was noticed in the households' sector in Poland, as shown in Figure 5. It was mainly due to the increase in the number of dwellings, which contributed to the change in the energy consumption by 3.60 Mtoe over the 2000-2015 period. Another important factor that increased the energy use in households was bigger penetration of central heating, which increased by 2.10 Mtoe. The factors of heating behaviour and energy savings decreased the energy consumption by 0.50 Mtoe and 3.90 Mtoe, respectively. The structure and relative share of the factors were similar in the UE in the analyzed period, the difference being that in the EU one of the important factors influencing energy use was increasing the average area of dwellings. Figure 6 shows the structural decomposition of the annual changes in the energy use in households in Poland between the years 2000-2015, which allows analysing relevant trends.

Figure 6. Main factors of the change in the energy use in households in Poland (2000-2015)



Source: author's own elaboration based on ENERA database

We can observe in Figure 6 that the growth in the energy use in households in the years 2000-2015 was caused by the increasing number and area of dwellings in Poland. These two factors constantly had a positive impact on the energy consumption throughout the analyzed period. At the same time, the most visible fluctuation concerned energy savings. This effect was rather high through the years 2000-2004, but from 2005 on it kept very low.

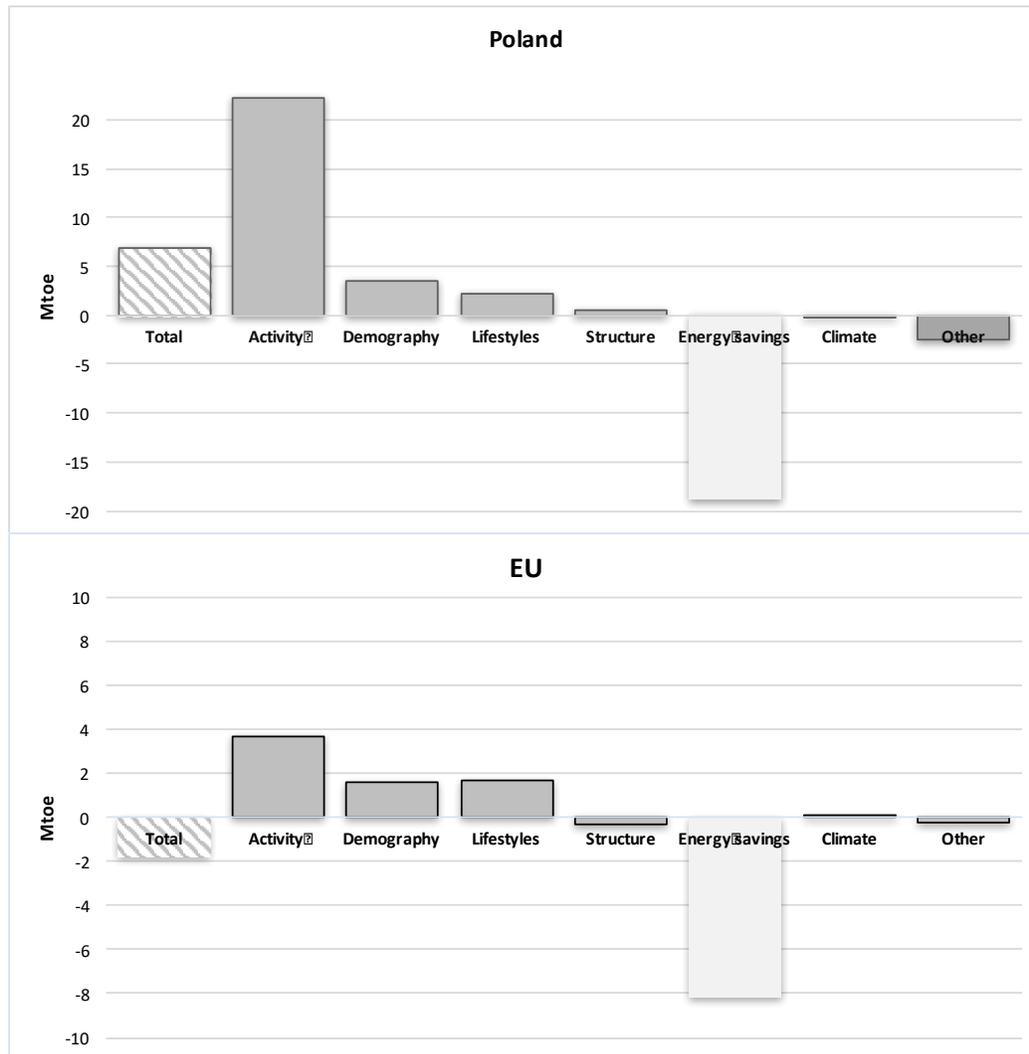
3.4. Decomposition of final energy consumption

The structural decomposition of the change in the final energy use is calculated by adding the contribution of the different factors by end-use sector (industry, transport, households, services and agriculture) in different categories (Enerdata, 2015):

- Activity: more traffic in goods and passenger transport, change in the economic activity, increasing number of dwellings;
- Demography effect: due to a larger number of dwellings;
- Lifestyles: more appliances in households and larger dwellings;
- Structural effect: due to a change in the structure of the value added in industry among the various branches or due to changes in transport mode distribution;
- Energy savings: as measured from ODEX;
- Climatic effect: impact of climate difference between the analyzed years;
- Other effects: behaviours for households, value of product in industry, “negative” savings due to inefficient operations in industry and transport.

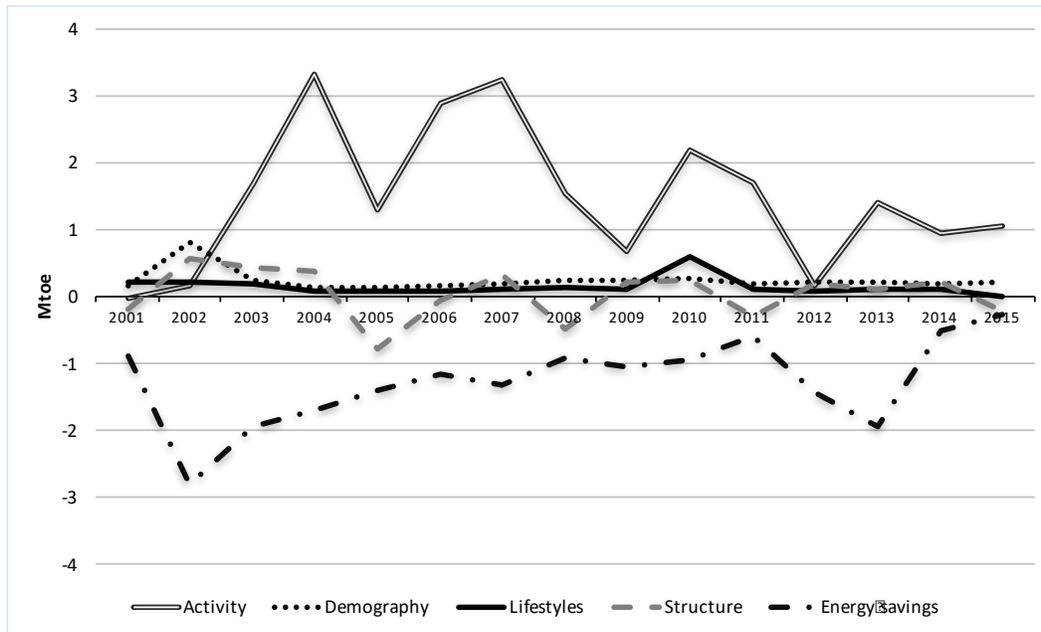
The change of the final energy consumption in Poland between the year 2000 and that of 2015 has been decomposed into main factors, as shown in Figure 7. The total change in the analyzed period and the relative share of diverse sources of changes in the energy use can be compared with the average level in the European Union countries.

Figure 7. Decomposition of the final energy consumption for Poland and the EU (2000-2015)



Source: author's own elaboration based on ENERA database

Over the period 2000-2015 the total energy consumption increased by 6.93 Mtoe (Figure 7). This increase in the energy use was due to the conjunction of three factors: an increase in the value added by 22.17 Mtoe (activity effect), a larger number of dwellings – an increase by 3.58 Mtoe (demography effect) and more appliances in households and larger sizes of dwellings – by 2.13 Mtoe (lifestyle effect). A decrease in the share of energy intensive branches (structural effect) contributed to the change in the total energy use by 0.59 Mtoe. Energy savings represent almost all of the decrease in the energy consumption by 18.88 Mtoe over the period 2000-2015, following by other effects (-2.49 Mtoe) and climatic effect (-0.18 Mtoe).

Figure 8. Main factors of the change in the final energy use in Poland (2000-2015)

Source: author's own elaboration based on ENERA database

The annual growth in the total energy use in Poland was caused mainly by activity effect, which substantially added to the increase in the energy consumption almost every year. The only important factor decreasing the energy consumption in the years 2000-2015 was energy savings. This effect was very visible throughout the analyzed period.

4. Conclusion

The structural decomposition analysis conducted for energy consumption in Poland allows identifying the driving forces for the changes in the energy demand over the period under analysis. The results of the energy usage decomposition at the national and sectoral level, show the activity effect to be the main reason for the growth over the period 2000-2015. The activity effect contributed to the increase in the energy consumption by 22.17 Mtoe. The only important factor in driving down the energy use was the energy savings resulting from energy efficiency improvements, which decreased the energy consumption by 18.88 Mtoe over the analyzed period.

The influence of energy efficiency improvement recorded in the industrial sector was stronger than the activity effect, which indicates technological progress and the development of

low-energy industries. In the case of the transport sector, activity and modal shift effect increased energy consumption in the analyzed period. This means that, unfortunately, in Poland relatively few people use public transport and the number of car users is increasing. As a result, despite the improvement in the energy efficiency of means of transport, the total energy consumption is growing. The most important factors affecting the increase in the volume of energy consumption in households are: number of dwellings, house area and penetration of central heating, which indicates better living conditions. Ultimately, energy consumption in this sector is falling due to changes in behaviour and above all energy savings, which should be considered a very positive trend.

Furthermore, making use of the structural decomposition analysis methodology allows getting a broader view on energy use trends, while enabling international benchmarking at the same time. The results for Poland presented in this paper were compared with the average values for the other EU countries. This juxtaposition can be helpful to evaluate the directions of changes in energy consumption in Polish economy and main sectors against other European countries. Moreover, the main factors influencing energy use in Poland were analyzed year by year. This detailed structural decomposition shows that in all of the analyzed sectors, the relative share and the direction of influence on change in the energy use of most of the factors did not change substantially over time.

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Zastosowanie dekompozycji strukturalnej do analizy zużycia energii w Polsce

Streszczenie

Celem lepszego zrozumienia historycznych zmian charakterystyki energetycznej gospodarki i poszczególnych sektorów, konieczne jest określenie sił napędowych tych tendencji. Metoda ta pozwala zidentyfikować wpływ czynników zewnętrznych, takich jak zmiany technologiczne, popytowe i demograficzne, na wahania całkowitego zużycia energii, emisji CO₂ oraz innych wskaźników społeczno-gospodarczych. W badaniu wykorzystano metodę dekompozycji strukturalnej do określenia relatywnego znaczenia różnorodnych źródeł zmian w zużyciu energii w polskiej gospodarce i jej głównych sektorach w latach 2000-2015. W artykule przedstawiono metodologię dekompozycji na różne czynniki objaśniające, która uwzględnia oszczędności energii oparte na wskaźnikach typu „top-down”, co pozwoliło wskazać, jaka była rola poprawy efektywności energetycznej w zmianach zużycia energii na poziomie różnych podsektorów i użytkowników końcowych. Analiza została poszerzona o zestawienie porównawcze ze statystykami europejskimi w kontekście wdrażania i monitorowania celów energetycznych UE.

Słowa kluczowe: zużycie energii, dekompozycja strukturalna, wskaźniki, efektywność energetyczna