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Analysis of the Country's Energy Efficiency using ODEX indicators

***Abstract**. One of the priority tasks in the country's energy economy is the improvement of energy efficiency. Sectoral energy consumption indicators enable the monitoring of the country's energy economy. The analysis of sectoral ODEX indicators is essential for predicting energy savings. The courses of the ODEX indicators and energy efficiency indicators were modeled with stochastic differential equations. Solving the equations using the Euler method enables the simulation of curves in the medium-term horizon. The results of simulation were presented.*

***Streszczenie.** Jednym z priorytetowych zadań w gospodarce energetycznej kraju jest poprawa efektywności energetycznej. Sektorowe wskaźniki zużycia energii umożliwiają monitorowanie gospodarki energetycznej kraju. Analiza sektorowych wskaźników ODEX jest niezbędna do prognozowania oszczędności energii. Przebiegi wskaźników ODEX i wskaźników sektorowych efektywności modelowano stochastycznymi równaniami różniczkowymi. Rozwiązanie równań metodą Eulera umożliwia symulację krzywych w horyzoncie średniookresowym. Przedstawiono wyniki symulacji. (**Analiza efektywności energetycznej kraju z wykorzystaniem wskaźników ODEX**)*

Keywords: energy efficiency, energy savings, simulation models.
Słowa kluczowe: efektywność energetyczna, oszczędności energii, modele symulacyjne.

Introduction

The basic activity of pursuing a sustainable energy policy in the country and in the EU is to increase the energy efficiency of the processes of energy production, transmission and use. Changes in this area in EU and national legislation stimulate appropriate actions of national and EU institutions.

Observation of trends in energy consumption allows for the assessment of progress in improving energy efficiency on a national and EU scale. Valuable tools for analyzing energy efficiency have been developed, among others, by as part of the Odyssee-Mure project coordinated by ADEME in France and sponsored by the H2020 EC program [1]. ODEX coefficients [2] have been defined in order to assess energy savings and thus improve energy efficiency. The above coefficients were used in the database of the Central Statistical Office GUS [3]. The article attempts to assess the improvement of energy efficiency by 2030 on the basis of the forecast of ODEX coefficients and sectoral efficiency indicators, and to confront the results with the EU requirements in this area.

ODEX Indicators

The database [3] on energy efficiency contains a number of unit consumption indicators, measured in physical units. Detailed indicators can be used to assess energy efficiency effects at the end-use level. An indicator called "ODEX" was introduced to assess changes in the energy efficiency of the sector.

ODEX indicators measure changes in energy efficiency for major economy sectors (industry, transport, households, services) and for the economy as a whole (all end consumers). For each sector, the indicator is calculated as the weighted average of the sub-sector energy efficiency change indices. The subsectors can be industry branches, service sector industries, household end-users or types of transport.

The rules for calculating ODEX indicators can be reduced to two stages. In the first stage, energy consumption indicators are determined by end-use or sub-sector, and on this basis, change indices are determined. Then a sector weighted average rate of change is calculated based on the share of each end user or sub-sector in the energy consumption of the sector. It is therefore necessary for each user or subsector to determine a share of the energy consumption.

Requirements for energy efficiency

The legal status of energy efficiency in Poland is currently defined by three documents:

- Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency [4]
- New Act on Energy Efficiency(AEE) adopted by the Polish Parliament on May 20, 2016 [5]
- Directive 2018/2002/EU of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency [6].

Directive 2012/27/EU of 25 October 2012 on energy efficiency, adopted in order to intensify activities in this area, obliges EU Member States to introduce energy efficiency improvement instruments in order to achieve the target of 20% savings in primary energy consumption by 2020 year. In the case of Poland, the primary energy consumption target was set at 96.4 Mtoe. Directive 2018/2002 of 11 December 2018 amending Directive 2012/27/EU on energy efficiency introduced the target of improving energy efficiency of 32.5% by 2030.

The new AEE Act should be adopted in achieving a specified energy savings level by the end of 2020 by means of modernization of energy installations in private and public buildings. The new AEE Act will provide for more efficient energy usage and will increase the innovativeness of the Polish economy. The AEE Act sets forth an obligation of the Minister of Energy to prepare every three years a national plan for energy efficiency. The AEE encourages to participate in public tenders for "white certificates" (i.e. energy efficiency certificates issued by the President of the Energy Regulatory Office for companies supporting efficiency) and trade them on the Polish Power Exchange (currently companies selling energy, heat or gas to end users are obliged to obtain and present a certain number of white certificates for redemption in order to meet the requirements of the current AEE, otherwise they are required to pay a substitution fee).

In Poland, the current Act of 20 May 2016 on Energy Efficiency and the amendment to the Act of 20 April 2021 introduce a national final energy savings target to be achieved by the end of 2030. From 2021 to 2030, energy savings should amount to 5.58 Mtoe. The target set for 2030 will be implemented through a system of energy efficiency certificates and the so-called alternative measures. The system of energy efficiency certificates is commonly known as white certificates and imposes an annual obligation on obliged entities to save energy. An alternative method of fulfilling the statutory obligation is the payment of a substitute fee by the obliged entity. Alternative measures were introduced as a way to achieve the national final energy savings target for 2030. There are programs and instruments to improve energy efficiency. The obligation to achieve certain energy savings was imposed on energy companies operating in the field of production or trade in electricity, heat or natural gas.

Statistical data

The statistical data in the publication [3] are prepared by the Polish National Energy Conservation Agency and Statistics Poland, Enterprises Department according to the Eurostat methodology (ODYSSEE database).

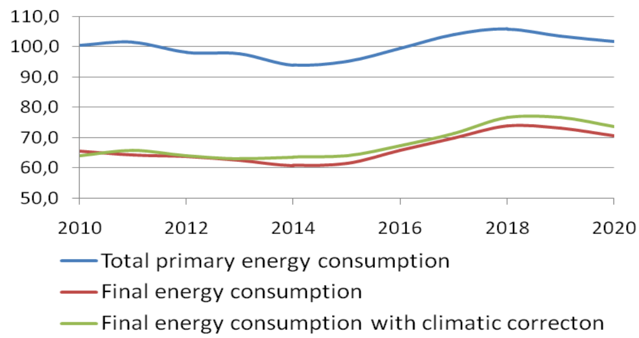

Fig.1. Total primary energy consumption and final energy consumption in Mtoe (Source: [3])

The data includes total primary energy consumption and final energy consumption by economy sectors (Fig.1.). The growth rate of total primary energy consumption in 2010–2020 in Poland was small and amounted to 0.1%/year and increased during this period from 100.5 Mtoe to 101.8 Mtoe. This consumption peaked at 105.9 Mtoe in 2018. A slight increase in total primary energy consumption, coupled with economic growth, is a trend that will continue in the future. The final energy consumption is characterized by a similar trend, with the average annual growth rate amounting to 0.7%. Final energy consumption increased in the analyzed period from 65.6 to 70.5 Mtoe.

The climatic correction takes into account the influence of the outside temperature, characterized by the number of degree days *Sd*, on the energy consumption for heating. Final energy consumption with ZEF^{kk} climatic correction is determined from the formula:

$$ZEF^{kk} = \frac{ZEF}{1 - 0{,}9\alpha\left(1 - \frac{Sd}{Sd_{sr}}\right)} \qquad (1)$$

where: *ZEF* - final energy consumption, *Sd* - number of degree days, Sd_{sr} - long-term average number of degree days, *α* - share of heating energy consumption in total energy consumption in the housing sector.

The number of degree days is the product of the number of heating days and the difference between the average temperature of the heated room and the average outdoor temperature. The heating days are those with the average daily outdoor temperature below 15ºC. The average long-term number of Sd_{sr} calculated for the years 1980-2004 is 3615.77.

The analysis of GDP energy consumption (Fig.2) shows favorable changes, because in relation to 2010, the energy intensity of GDP in 2020 decreased by 24.7% (primary) and 20.3% (final). Taking into account the climatic correction, the rate of efficiency improvement was slightly lower. Primary energy consumption with climatic correction decreased by 21.1% and final energy consumption with climatic correction decreased by 14.5%. A worrying symptom is the slowdown in the rate of improvement in 2016–2020 compared to 2010-2015.

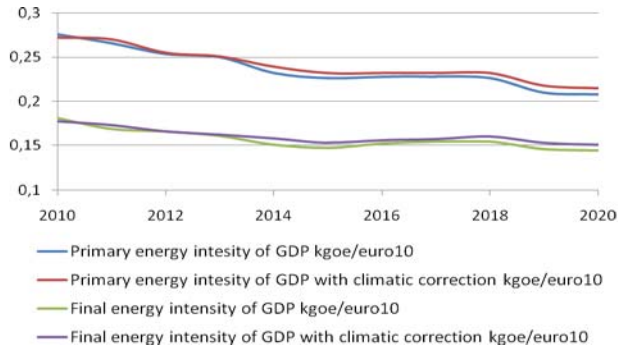

Fig.2. Energy intensity of GDP (Source: [3])

The energy intensity of sector was defined as the final energy consumption in this sector in relation to its added value. The statistics [3] also compiled the so-called energy consumption in a constant structure, determined using the Divisia method. The energy intensities are also calculated using the Divisia method. The dynamics of energy consumption in the Divisia method is determined as the product of the dynamics of energy consumption in a constant structure and the effect of structural changes. The effect of structural changes was calculated as the weighted sum of the growth rates of individual elements, in this case sectors of the economy. Growth rates are defined as the natural logarithm of the change in the relative value added in a given sector relative to the total in subsequent years, and the weights are the shares of the average energy consumption in a given sector in the total consumption of the economy in subsequent years.

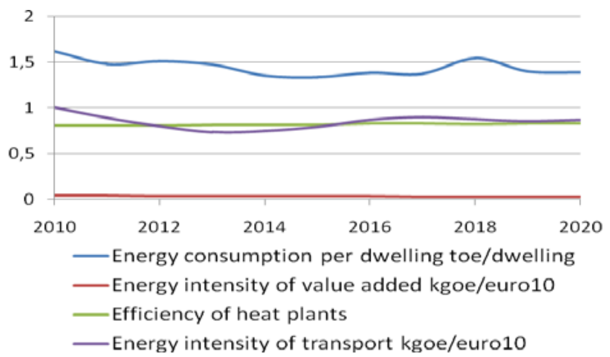

Fig.3 Selected energy efficiency indicators for Poland (Source: [3])

Selected energy efficiency coefficients are presented in Fig. 3, and in detail in Table 1. The coefficients well describe the ongoing changes in the improvement of the efficiency of economic sectors. These are examples of coefficients, e.g. used to determine ODEX indicators.

In the period 2010-2020, in general, an improvement in the energy efficiency of the sectors can be observed, as energy efficiency indicators are falling and the efficiency of heating plants is increasing (Table 1). In the course of these processes, periodic fluctuations can be observed, e.g. the analysis of energy consumption per dwelling shows that the downward trend is generally maintained in 2010-2020, with an average annual decrease of approx. 1.5%, although consumption increased in 2015-2018.

Table1. Selected energy efficiency indicators in economy sectors (Source: [3])

Year	-	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Energy consumption per dwelling	toe/dwelling	1,621	1,479	1,511	1,473	1,355	1,336	1,385	1,374	1,544	1,401	1,388
Energy intensity of value added	kgoe/euro10	0,043	0,04	0,039	0,037	0,035	0,034	0,035	0,031	0,029	0,027	0,026
Efficiency of heat plants	%	80,9	81,0	81,0	81,3	81,6	81,7	82,8	82,8	82,2	82,9	83,1
Energy intensity of transport	kgoe/euro10	1,005	0,888	0,803	0,736	0,744	0,792	0,871	0,898	0,874	0,857	0,869

The analysis of energy consumption is enriched by the ODEX energy efficiency indicators, which are characterized by changes in efficiency in relation to the base year (2000=100). The ODEX indicator shows the progress in the energy consumption compared to the base year. The ODEX indicator is calculated for each year as the quotient of the actual energy consumption in a given year to the energy consumption calculated assuming the current energy consumption of the production processes of the given sector. Additionally, to reduce the impact of random fluctuations, a 3-year moving average of the ODEX is calculated in [3]. A decrease in the ODEX indicator value means an increase in energy efficiency.

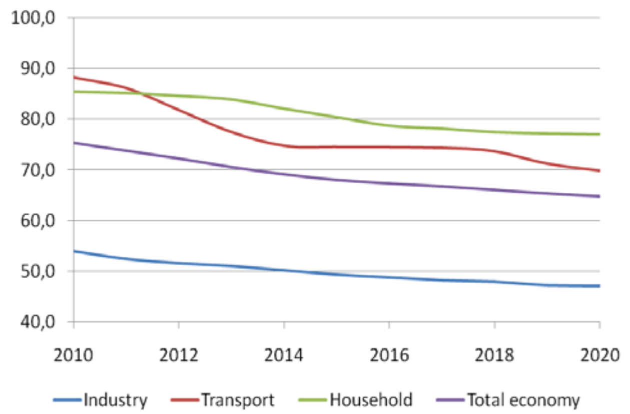

Fig. 4 Total economy and sectoral ODEX indicators for Poland (2000=100) (Source: [3])

According to [3], the ODEX indicator for Poland decreased in the years 2010–2020 from 75.4 to 64.8 points. The average efficiency growth rate was 1.5 %/year. Energy savings in the sectors were achieved in all the years presented in Fig.4, although changes have slowed down. The highest total savings were achieved in 2014 and amounted to 1.2 Mtoe.

Simulation of ODEX indicators described by stochastic differential equations

A series of dynamic processes in economy and energy, in which random disturbances occur, can be modeled using stochastic equations of the Ito type [7]. The application of the Euler method [8] to solve stochastic differential equations (SDE) enables the simulation of the future development of ODEX indicators. The stochastic process of many continuous variables over time can be described by differential equations of the general form:

(2) $$dX_t = F(t, X_t)\, dt + G(t, X_t)\, dW_t$$

where: X - state variable, W - Wiener process variable (Brownian motion), F - trend determining function, G - random variable distribution function.

Based on the general form (2), it is possible to define special variants of the model. The analysis uses the form of the SDE model, in which the state variables are the annual relative increases in the ODEX indicators of the basic sectors of the economy. The Geometric Brownian Motion GBMC model takes into account the correlations between the ODEX indicators of the sectors in the Wiener processes. The GBMC formula:

(3) $$dX_t = \mu X_t\, dt + \sigma X_t\, dW_t$$

where: μ - mean value of the variable X_t, σ - standard deviation of the variable X_t.

The measure of uncertainty is the standard deviation in the SDE model.

The simulations of the energy efficiency indicators in economy sectors and the ODEX indicators were performed using the SDE model with the GBMC formula (3). The simulation results are shown in Fig. 5 and Fig.6.

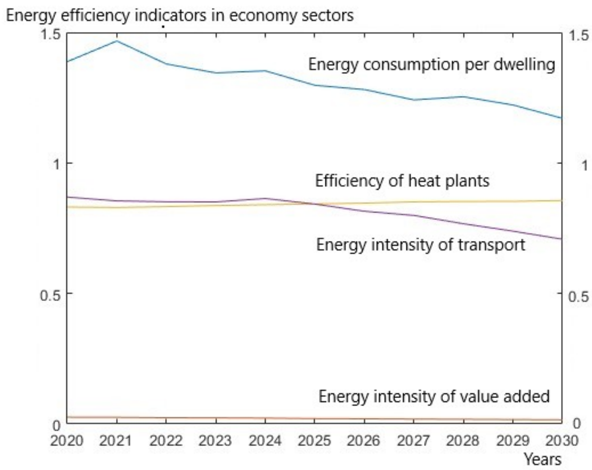

Fig.5. Simulation results of energy efficiency indicators in economy sectors

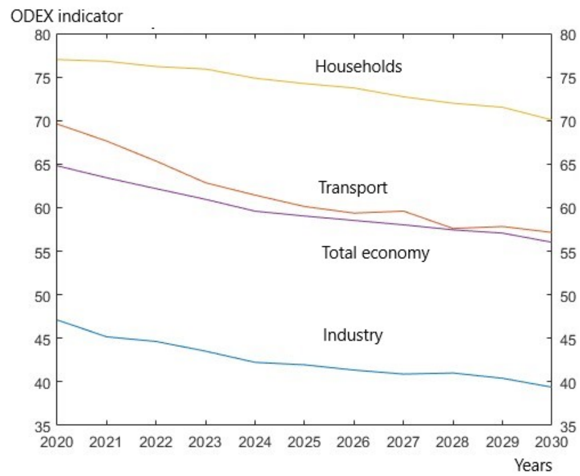

Fig.6. Simulation results of total economy and sectoral ODEX indicators for Poland (2000=100)

The simulation curves of energy efficiency indicators continue the trends from the historical period. The energy consumption per dwelling (1.32 %/year) and the energy intensity of transport (1.34 %/year) are noticeably reduced, while the increase in the efficiency of the heating plant is very small (1.12 %/year), which proves that the technical possibilities are used. As a consequence, the energy intensity of the value added decreases (1.44 %/year).

The simulations of the ODEX indicators in the horizon until 2030 indicate a decrease in the energy consumption. The results of the analyzed GBMC model can be treated as a future scenario for the changes of the ODEX indicators.

Conclusions and final remarks

In Poland, in the years 2010-2020, there has been and continues to be a significant improvement in energy efficiency. The average annual rate of decrease in primary energy intensity in this period was 2.8%, and in final energy consumption - 2.2%. In the case of the basic sectors of the economy, a differentiated improvement in energy intensity was noted. For sectors, it was respectively 0.4% per year for households, 1.3% per year for industry and 2.3% per year for transport.

The ODEX indicator of total economy calculated to the base of 2000 = 100 decreased in the years 2009–2020 from 76.9 to 64.8 points. The average efficiency growth rate was 1.57%/year. The simulation result in 2030 is the ODEX value of 56.0 points, which means an annual increase in energy efficiency by 1.32%.

The fastest rate of improvement (2.29%/year) was recorded in transport, for which the value of the index was 69.9 points in 2020. Estimation in 2030 from the SDE model is 57.2, so the average improvement rate in the years 2020-2030 is 1.36%. The slowest improvement took place in the household sector, where the annual efficiency increase in 2010–2020 amounted to 1.01%. But the value in 2030 is equal to 70.1 that's why the improvement rate is 1,26%/year. In the industry, the rate was 1.67%, and the value of the indicator in 2020 is equal to 47.1 points. Simulation model calculated the value 39.4 in 2030, so the improvement rate is 1.35%/year.

The decrease in the demand for primary energy in the period 2009-2020 was mainly due to the improvement in the efficiency of thermal power plants (decrease by 3.3 Mtoe) and the increase in the use of energy from renewable sources (decrease by 2.5 Mtoe).

According to presented analysis it seems possible to reach the target in 2030 (savings 5.58 Mtoe in the period 2021-2030).

The conducted research shows that the Euler method enables the determination of a simulation of the course of stochastic variables described by differential equations, taking into account the uncertainty of the shaping of energy processes resulting from the influence of the model environment.

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