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Poland's Energy Mix and Energy Security of the Country

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ABSTRACT

The article presents the basic factors determining the level of Poland's energy security. The energy mix of our country was analysed, as well as energy security indicators for energy carriers used in Poland. The indicators used allow to determine the level of security, but also indicate whether Poland is pursuing the objectives of the country's energy policy. Indicators such as the Stirling Index, Herfindahl-Hirschman index, import dependency ratio, energy self-sufficiency and the index of the share of renewable energy in the national balance sheet were used. The results of the analysis were presented and the modifications should be indicated in order to be able to implement the provisions of the energy policy until 2030.

Keywords**:** Energy security, security indicators, energy mix

1. INTRODUCTION

Energy security in the Energy Law Act is defined as the condition of the economy which enables full coverage of the customer's ongoing and prospective demand for fuels and energy in a technically and economically justified manner, with the observance of the environment protection requirements. The main threats to Poland's security include the dependence on imports, the percentage of fuels in the energy mix and the prices of raw materials.

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The increase in the prices of energy carriers entails a decrease in the competitiveness level of the Polish economy. The basis for security is therefore the ability to provide recipients with reliable energy supplies and provide it at a price acceptable to society, diversify the fuel base, ensure the appropriate technical condition of the energy system infrastructure and store fuel as well as the ability to create their stocks. In addition, access to energy is synonymous with economic development [1, 2].

Obsolete technological systems and a high level of wear of generation and transmission infrastructure mean that energy production becomes inefficient [3]. Almost half of the energy units in Poland are more than thirty years old. The condition of power lines also leaves much to be desired, causing energy losses of up to 10%.

2. MATERIALS AND METHODS

The complexity of the problem of energy security causes that various types of indicators are used to characterize it. The selection of appropriate partial components characterizing this type of security will enable its research in the aspect of various methods of impacting on safety [4]. To check the state of energy security in Poland, the following energy security indicators have been used, belonging to different categories:

- Stirling ratio (diversification index),
- import dependency ratio (indicator),
- Herfindahl-Hirschman index (HHI) (diversification index),
- an indicator of energy self-sufficiency (indicator of energy autonomy),
- an indicator of the share of renewable energy in the national balance sheet (substitution ratio).

The import dependency indicator is determined by the following formula [5]:

$$W_{Ij} = \frac{I_j - E_j}{Z_{ij}}\ [\%]$$

The export dependence ratio in turn should be calculated according to the equation:

$$W_{Ej} = \frac{E_j - I_j}{Z_{Kj}}\ [\%]$$

where:

Z_{Ij} – total consumption of j-carrier,
I_j – import of j-carrier,
E_j – export j-carrier,

Indices of import dependence and export dependency determine the level of dependence of the country on the import and export of energy carriers. The indicator has been determined for the primary energy carriers constituting the Polish energy mix. They are coal, oil, natural gas.

The energy self-sufficiency index, in turn, describes the equation [6]:

$$W_s = \frac{\sum_{i=1}^{m} P_i}{A_{ki}}$$

where:

P_i - domestic production of energy carrier,
A_k - annual domestic consumption of i-fuel.

Another indicator of energy security measurement is the so-called Stirling (also called Shannon-Wiener) index [7] determined in the following way [8, 9]:

$$\mathrm{d}_s = -\sum_{j=1}^{m} u_j \ln u_j$$

where:

u_j – share of j-carrier in the country's energy supply structure,
m – number of energy carrier,

The Stirling index is a diversification index describing the degree of fuel differentiation in the country's energy mix.

Herfindahl-Hirschman Index (HHI) [10, 11, 12]:

$$HHI = \sum_{j=1}^{i} u_{ij}^2$$

where:

i - energy raw material index,
j - index of the source of obtaining the energy carrier.

The indicator determines the level of diversification of fuel sources. It can take values from 0 to 10,000, in case the percentage of a given fuel in the market has been measured. The concentration of the fuel market can be considered in the areas:

- unconcentrated market, if the index is below 1000, where there is no market concentration,
- range from 1000 to 1800, defining the medium-concentrated market,
- 1800 to 5000, when the market is described as highly concentrated
- above 5,000 there is a highly concentrated market,
- the value of 10,000 is equivalent to a monopoly.

The ratio of renewable energy in the energy mix [13]:

$$W_o = \frac{P_o}{A_k}$$

where:

P_o - production of renewable energy in a given period of time,
A_k- primary energy consumption in a given period of time.

Indices of import dependency have been set for natural gas, crude oil and coal. Table 1 contains the results of the calculations made. The dependence on imports is the highest in case of crude oil - at 100%. In case of natural gas, the dependence on imports fluctuates around 70%. The lowest value of the W_{ij} indicator is shown in coal, where the dependence on imports has negative values. It means that Poland's dependence on coal import does not occur. In recent years, coal imports have been growing, which meant that for 2017 the index assumed the value of less than a percent. The decrease in domestic production led to the situation that in order to cover the demand for this fuel, the strategic gap created was filled with coal obtained through importation.

Table 1. Import dependency ratio in the years 2008-2017.

Year	W_{Ij} natural gas	W_{Ij} crude oil	W_{Ij} coal
2008	71%	103%	-3%
2009	66%	103%	-2%
2010	67%	103%	-2%
2011	71%	100%	1%
2012	70%	98%	-2%
2013	71%	93%	-5%
2014	69%	94%	-4%
2015	71%	98%	-5%
2016	76%	95%	-6%
2017	76%	98%	0%

Another indicator used in this work is the energy self-sufficiency indicator (table 2). Poland is self-sufficient in the case of coal, while the lowest level of self-sufficiency refers to oil [[14]]. In case of blue fuel, self-sufficiency in the examined period does not exceed 30%. It should also be noted that the indicator in 2008-2017 is characterized by small changes. The largest decrease in the index size was observed for coal in 2017.

Table 2. Polish energy self-sufficiency indicator in the years 2008-2017.

Year	W_s natural gas	W_s crude oil	W_s coal
2008	27%	3%	99%
2009	28%	3%	100%
2010	26%	2%	92%
2011	27%	2%	93%
2012	26%	3%	101%
2013	25%	4%	97%
2014	25%	4%	97%
2015	25%	3%	98%
2016	22%	3%	95%
2017	21%	3%	92%

The Stirling index for Poland is presented in Table 3 and Figure 1. It is a diversification index, which was calculated as the sum of the ratios of the share of a given energy carrier in the energy mix and the natural logarithm of this share.

Table 3. Stirling ratio in the years 2008-2017.

Year	d_i
2008	0,96
2009	0,97
2010	1,04
2011	1,03
2012	1,09
2013	1,10
2014	1,12

2015	1,14
2016	1,15
2017	1,17

It was noted that the value of the Stirling index is lower than the designated and averaged indicator for all European Union member states. It is caused by a high share of indigenous fuels such as hard coal and lignite. In addition, there is no nuclear energy in the Polish energy mix. Therefore, the level of the indicator fluctuates in the area of one in the examined period. Lowering the share of coal in the energy structure of Poland resulted in a gradual increase of the Stirling index. In 2017, it assumed the value of 1.17, which means that since 2008 it has increased by 20%. The increase in the diversification index will, however, be tantamount to a decrease in the value of the self-sufficiency indicator.

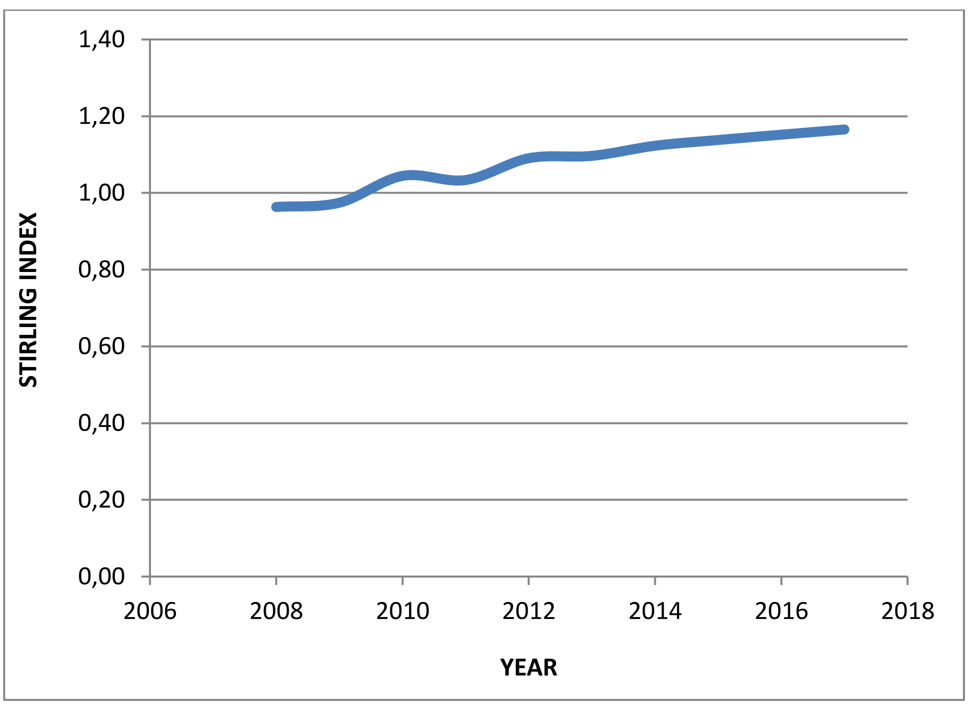

Figure 1. Stirling Index for Poland for the years 2008-2017.

The HHI indicator is also an indicator of diversification. Its value ranges from 1800 to 5000, which means that the market in this case is described as highly concentrated. In other words, we are dealing with the presence of several leading producers of energy raw materials in the energy market in Poland. This is not a surprising statement considering the size of the share of coal in the energy mix of Poland. On the other hand, the dynamics of changes in the designated indicator is interesting. In case of the Herfindahl-Hirschman index, a downward trend is also noticeable.

Table 4. HHI index in the years 2008-2017.

Year	HHI
2008	3 670
2009	3 571
2010	3 283
2011	3 327
2012	3 200
2013	3 249
2014	3 019
2015	2 987
2016	2 927
2017	2 783

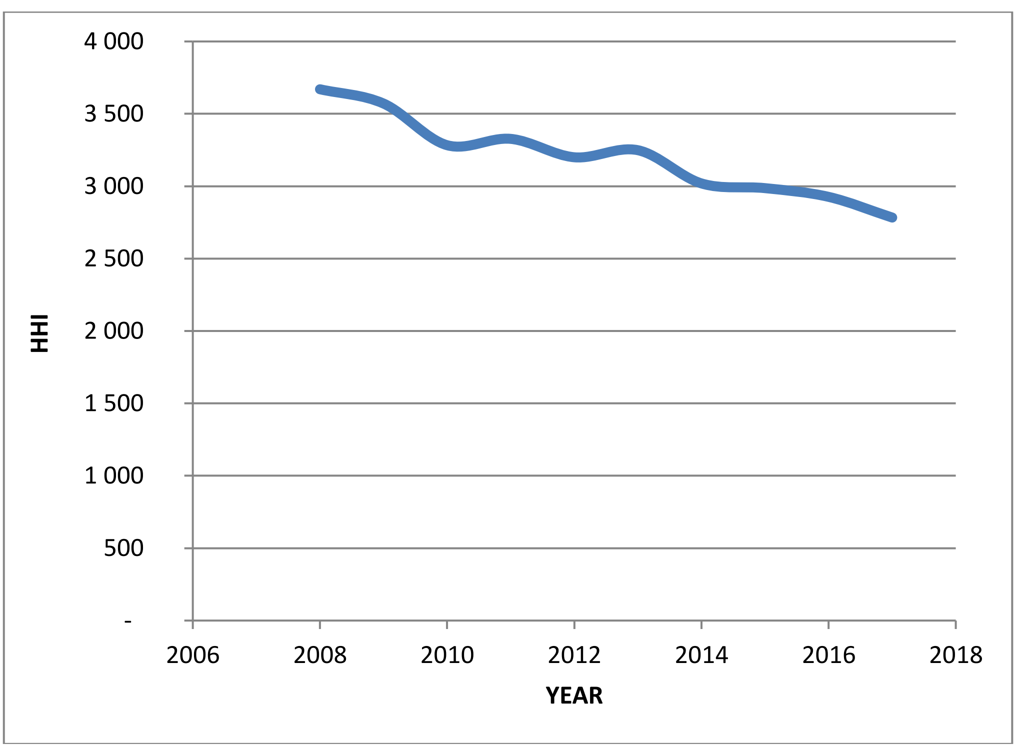

Figure 2. Herfindahl-Hirschman diversification index in the years 2008-2017.

Since 2008, the index has decreased by around 25%. This is a beneficial phenomenon, however, so that the market of energy resources in Poland can be considered as an average concentrated indicator, it must decrease by another 40%.

The ratio of renewable energy in the energy mix of Poland was set to verify the country's progress in the implementation of the European Union's provisions. In the analysed period, the value of the index increased by approximately 4%. The research conducted by the author showed that with the current rate of growth of the share of renewable energy in the energy mix for the next 30 years they will not be able to cover even the current level of demand for energy obtained from coal.

Table 5. The ratio of renewable energy in the energy mix in the years 2008-2017.

Year	R_i
2008	1%
2009	1%
2010	3%
2011	3%
2012	4%
2013	5%
2014	5%
2015	5%
2016	5%
2017	5%

The basic objectives Poland aims at in the area of energy policy are primarily:

- diversification of electricity carriers,
- introduction of nuclear energy to the energy mix,
- diversification of sources of fuel acquisition,
- development of renewable energy sources,
- reduction of the negative impact of energy on the natural environment.

Both the diversification of electricity carriers, the development of renewable energy sources and the introduction of nuclear energy directly refer to the energy mix of Poland. The energy mix that is, the structure of energy production and consumption, broken down into energy carriers, is one of the indicators used to analyse the Country's energy security. In Poland, the energy mix consists of hard coal, lignite, crude oil, natural gas as well as renewable energy sources. Despite long attempts to introduce nuclear energy into the structure since the 1980s, the share of this type of energy will be zero or negligible in the coming years. In Poland, Electricity is produced on the basis of coal. It provides about 77% of energy [15], which is presented in Figure 3. Renewable energy sources contribute about 10%, while natural gas is only less than 4%.

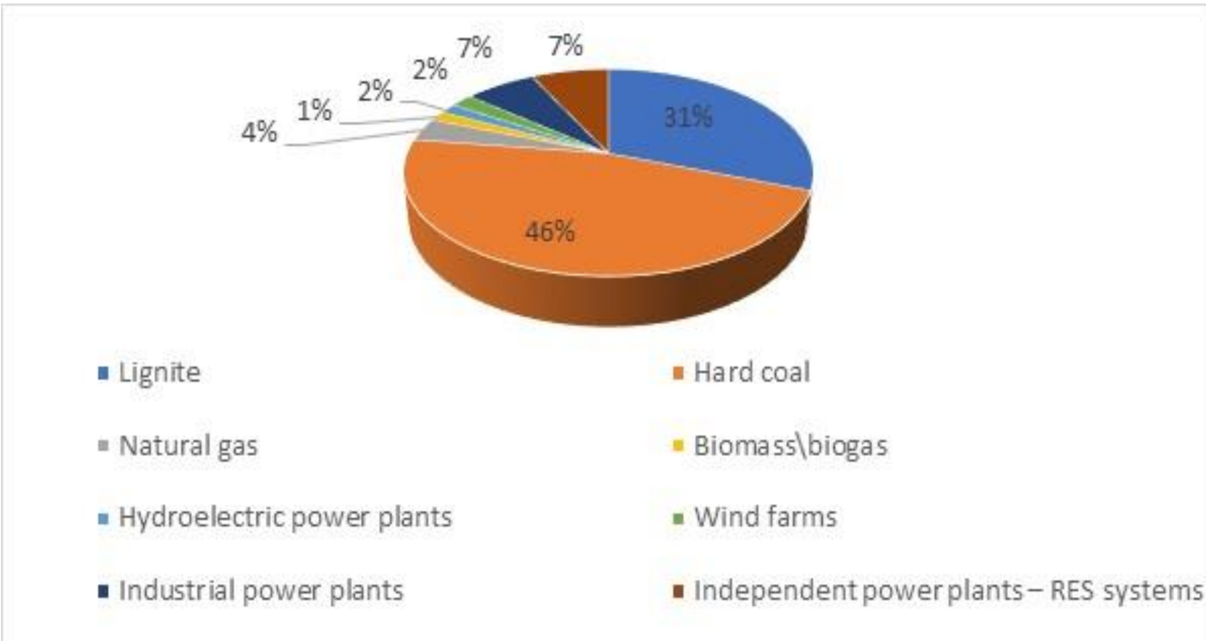

Figure 3. The structure of electricity generation in Poland in the year 2017 [16].

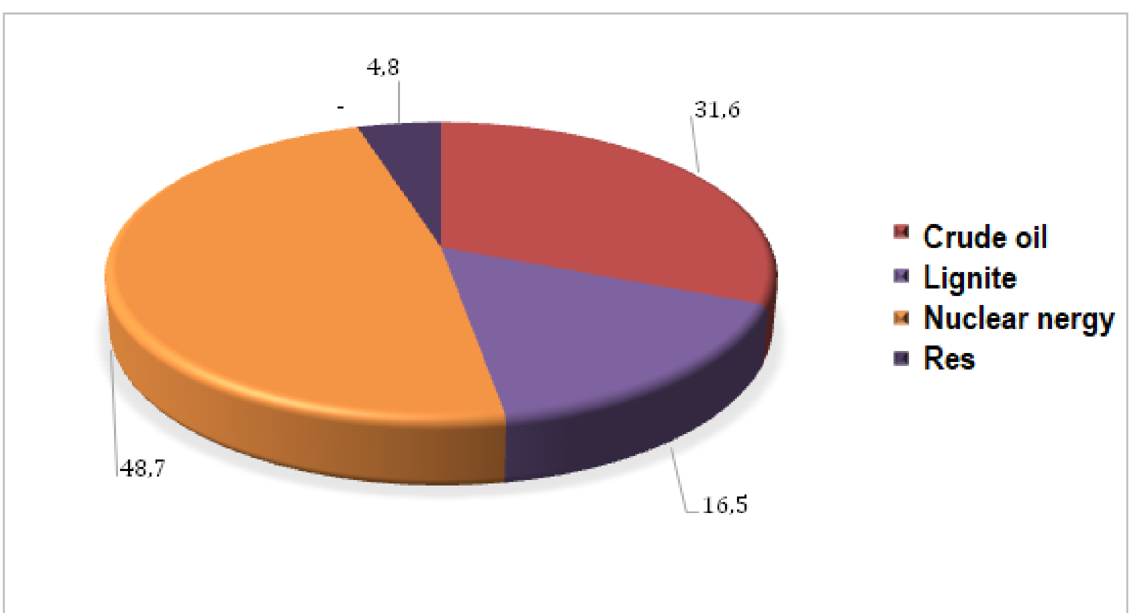

Figure 4. Primary energy consumption in Poland in 2017 (%)

The second indicator to consider in order to characterize the energy mix is the consumption of primary energy. Primary energy is a form of energy that occurs in nature, which has not undergone any process of processing, conversion or transformation. It is, therefore, the energy contained in the raw material constituting the input stream of the energy system. Primary energy is both non-renewable and renewable energy.

In case of primary energy, coal is also the main energy source, but its share is significantly smaller. On the other hand, the participation of natural gas and crude oil is more significant. Primary energy takes into account all uses of energy (not only for production) of electricity. They are also liquid fuels and those used in heating. As shown in Figure 4, the structure of obtaining primary energy is significantly diversified. However, the natural resources of natural gas, and especially of crude oil, are insufficient to cover the demand for these raw materials [17]. Therefore, they are obtained by import. However, there is the problem of insufficient level of diversification of sources of fuels obtained by importing. Natural gas and crude oil imported into Poland come mainly from a single source, namely the Russian Federation. There have been taken numerous attempts to find new suppliers of raw materials and thus increase the level of energy security. However, this is not an easy task considering the costs of transporting raw material by sea. Fuels are also imported from Saudi Arabia, Iran, Iraq and Kazakhstan, and in case of natural gas also from Germany. However, one should remember about the principle of energy security, which assumes that one source should not cover more than 30% of the demand.

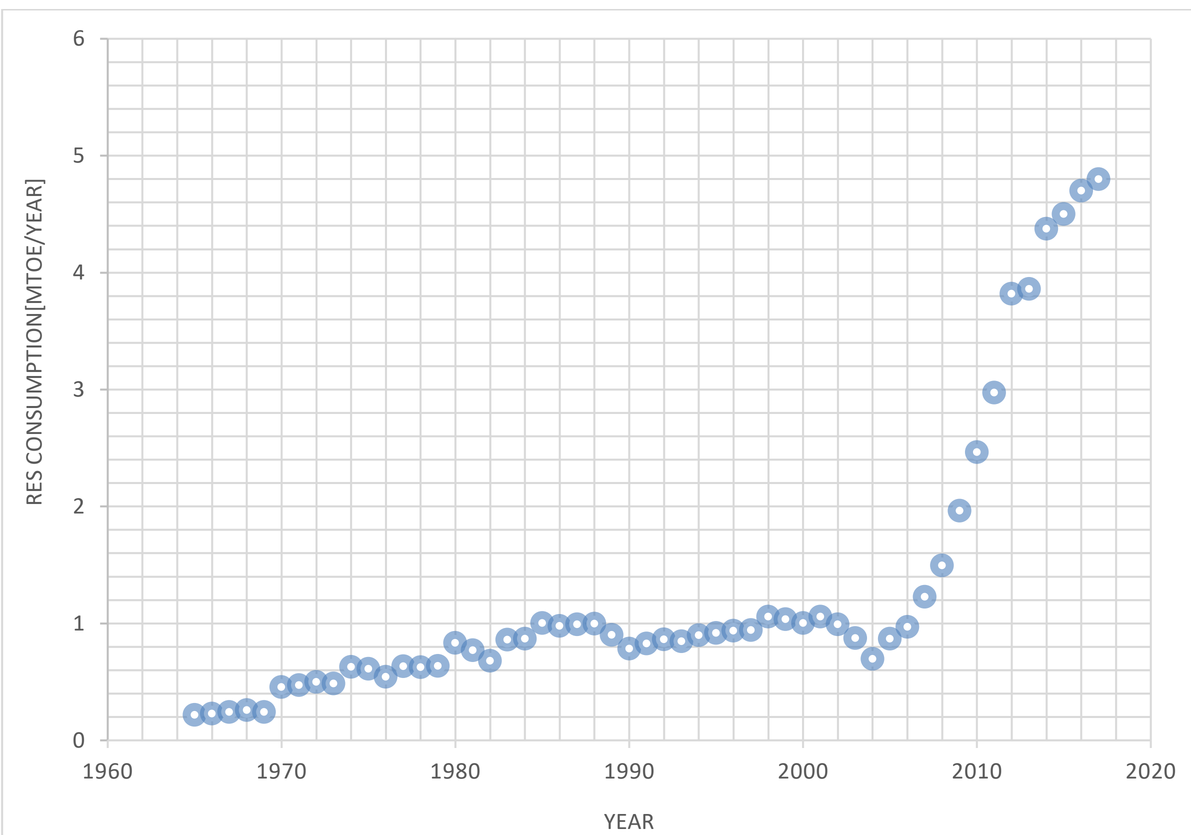

Figure 5. Consumption of renewable energy in Poland in the years 1965-2017.

Renewable energy sources in Poland are developing very intensively. Especially after 2004, we have observed a strong upward trend in the volume of renewable energy demand in our country. It was the year of Poland's accession to the European Union. Therefore, our country committed to comply with the EU guidelines also in the field of renewable energy development. The activities of our country since then have been in line with the general EU objectives, that is primarily Poland strives to achieve a 20% share of renewable sources in gross energy consumption. The Energy Law was also modified. It has been enriched with guidelines on support for renewable energy sources, namely the obligation to purchase RES energy as well as certificates of energy origin. In addition, there were mechanisms such as exemption from excise duty, launching special financial support funds for RES investments and tax reliefs [18].

One of the main factors that has a negative impact on the development of renewable energy sources is the cost of installations that allow the use of green energy, as well as the price of energy itself. However, technological progress allows to eliminate the financial limitations of investments in renewable energy sources. This technology is becoming more and more efficient, and production costs are decreasing, although they are also strongly dependant on the country in which the installation is being made. Another serious obstacle that stands in the way of developing renewable energy sources is problems with its storage. Renewable energy is not generated during unfavourable weather conditions. In turn, in favourable weather conditions its excess it should be stored. Changes to the Energy Law should support the development of the energy storage sector.

Another objective for our country's energy policy is to limit the negative impact on the natural environment. This negative effect applies primarily to hard coal, lignite and crude oil. Factors to consider when examining changes in this impact are mainly emissions of carbon dioxide, but also other greenhouse gases such as sulphur oxides or nitrogen [19, 20]. These substances are released into the atmosphere during the combustion of fuel. Emissions of greenhouse gases in Poland began to decline after 1989. This was due to the economic transformation that took place in the nineties, that is after the fall of communism.

Until 2010, the periods of emission growth and its decline in relation to business cycles were repeated. The greenhouse gas that is produced in the largest amounts is carbon dioxide. The most significant amount of emissions can be registered in the processes of electricity, gas and steam production for air conditioning systems. It accounts for over 50% of total emissions. The total CO_2 emission in 2017 was over 300 million Mg, which accounted for 75% of emissions in 1989 included in the Kyoto Protocol. However, if the year 1990 should be considered the base year, a 20% decrease in emissions would be expected in 2021. This would make it impossible to comply with the provisions of the Kyoto Protocol. The Katowice Package, which was adopted in December 2018, indicates that each country will have the opportunity to choose its own path to reduce carbon dioxide emissions. First of all, the aspect of absorbing CO_2 by vegetation and wooded areas is important.

3. CONCLUSIONS

The ever-increasing demand for energy means that the issue of energy security is an important area of state policy. In addition, the energy sector has a significant impact on the level of greenhouse gas emissions around the world, and therefore in Poland, too. Over 50% of CO_2 emissions in our country are generated in the processes of electricity, gas and steam production for air conditioning systems. Therefore, it is necessary to appropriately plan a strategy aimed at ensuring an adequate level of security and constant monitoring over the carried our activities.

The monitoring process should be carried out systematically, with the use of indicators that can determine whether the direction of undertaken action is appropriate, whether the steps taken bring Poland closer to achieve the set objective or whether the measures should be corrected. For the verification to be reliable and unambiguous, it is beneficial to introduce measurable indicators that will allow to quantify the extent to which the objective has been achieved. The article presents selected energy security indicators. The presented set of measures made it possible to verify the level of safety in terms of the correctness of the composition of the energy mix, dependence on imports, energy self-sufficiency. Analysis of the indicators showed that:

- The degree of diversification of Poland's energy mix is lower than the European average. In case of the Stirling index, an even structure of the energy mix is beneficial. Therefore, its optimal value, in the case of properly diversified energy sources, should be 1.4 (taking into account 4 components of the energy mix: coal, oil, natural gas, RES). In 2017, the indicator was at 1.17.
- Diversification of the energy mix should be optimized mainly by increasing the contribution of renewable energy sources, as indicated by the W_o index. Renewable energy does not require importation.
- The self-sufficiency indicator is satisfactory with regard to hard coal and lignite. In case of natural gas and, above all, crude oil, the level of self-sufficiency indicator is insufficient. Poor deposits of these raw materials in the geographical area of Poland make it impossible for Poland to use only its own resources of raw materials.
- The dependence on imports of blue fuel and crude oil is currently at 76% and 98% respectively. This is therefore unavoidable. However, it is necessary to ensure an appropriate level of diversification of sources of energy.
- Therefore, to increase the level of energy security, there should be:
- Increased the share of renewable energy sources in Poland's energy mix, introduced nuclear energy into the production structure and energy consumption.
- Applied clean coal technologies that will help reduce the negative impact of coal-based energy on the environment.
- Acquired new suppliers of crude oil and natural gas, diversified sources of raw material and delivery routes. It is also possible to look for effective and economically viable shale gas extraction technologies from Polish resources.

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