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Directions of changes in the structure of electricity production in the world

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Abstract
The article aims to analyze the direction of changes in the world's electricity production structure. The energy balance structure is an important element in the economic development of many countries. The diversity of sources used in different countries or continents to produce electricity affects the diversity of the energy balance structure. So far, raw materials are of strategic importance for the energy security of each country and the competitiveness of their economies. Nevertheless, due to their global importance and the introduced directives related mainly to the integration of energy markets and environmental protection, as well as the pace of reduction (shrinking) of the level of their resources, there is a diversification of energy sources resulting from the shift from fossil sources to renewable energy sources. In line with current trends, energy demand (energy consumption, including electricity) is constantly growing, which increases demand for individual energy sources, including solid fuels. The increasing trend in energy demand increases the importance of an appropriate energy balance and, consequently, the energy security of individual countries around the world.
The authors of the publication asked the following research question: what may be the future trend in the development of individual energy sources? The authors' attempt to answer was based on the analysis of available data on the amount of electricity produced in the world and the amount of its consumption (consumption). The presented analysis is based on individual regions of the world: North America, S. & Cent. America, Europe, CIS, Middle East, Africa and Asia Pacific.

Keywords
energy market, electricity generation/production, energy consumption, energy resources, renewable and sustainable energy, decarbonization, energy transformation, energy forecasting

Introduction

Energy has been of fundamental importance to all sectors of the economy for several centuries. The role of key raw materials has changed at the turn of the century. Coal, the key fuel in the Industrial Revolution (since the 18th century), through crude oil, initiated the development of the automotive industry (the turn of the 19th and 20th centuries). However, as a result of the oil crisis in the 1970s, the direction of energy policy changed, the aim of which was to become independent (reduce dependence) on oil. The 20th century also increased the importance of natural gas (energy, chemical industry) and nuclear energy and also began the dynamic development of renewable energy sources (RES).

Creating an energy policy in the current conditions, responding to new regulations, and introducing tightenings are becoming an increasingly complex problem. Currently, the main goals of energy policy include, above all, ensuring energy security, affordability, sustainability, and economic (economic) development (Fig. 1), as well as reducing carbon dioxide emissions (Manowska, 2018; Kowal and Kustra, 2016).

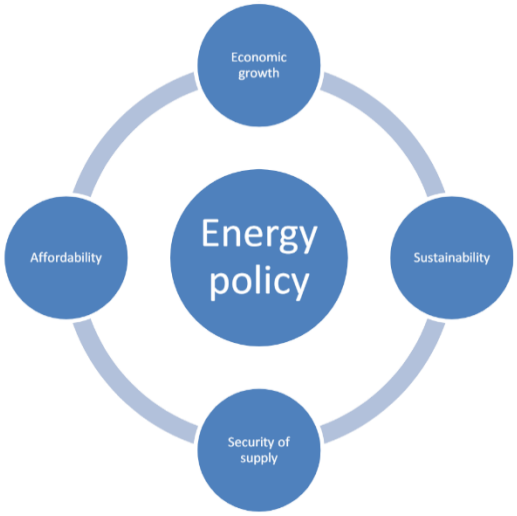


Fig. 1. Energy policy and its goals (Bluszcz, 2020)

In this study, we generally focus on analyzing the direction of changes and the tendency of development of individual energy sources and in the world's electricity production structure. The increasing trend in energy demand increases the importance of an appropriate energy balance and, consequently, the energy security of individual countries all over the world.

Literature review

The individual goals of energy policy remain a subject of interest, which is reflected in numerous publications in which much attention is paid to the impact of electricity on economic growth (Kraft and Kraft, 1978; Acaravcia and Ozturk, 2010; Apergis and Payne, 2011a; Atems and Hotaling, 2016; Kahia et al., 2016; Bluszcz and Manowska, 2019; Ziolo et al., 2019), as well as to growing concerns about climate change and the continued development of alternative sources of electricity (Al-mulali, 2014; Al-mulali et al., 2014; Pao and Fu, 2013; Apergis and Payne, 2010a; Apergis and Payne, 2010b; Apergis et al., 2010; Apergis and Payne, 2011b; Apergis and Payne, 2012; Apergis and Danuletiu, 2014; Halkos and Tzeremes, 2014; Xiaosan et al., 2021; Shahjahan et al., 2021).

The process of implementing individual energy policy objectives is very complex and requires taking appropriate strategic actions that consider the fact that mineral resources (energy, metal, chemical, rock) are useful but non-renewable natural resources (Domaracká ed., 2020). Therefore, to balance the energy demand, individual countries should make an appropriate investment effort in both the production and network sectors, not focusing only on fossil fuels. Energy markets have a strong impact on the economic situation in countries. Therefore, the pace of changes in the energy transformation process should be diversified and adjusted to their capabilities. As a result of the study (Bluszcz, 2020), this process is already noticeable in some EU countries such as Germany, France, Great Britain, Italy, Spain, Poland, and Sweden (the largest energy producers in the EU). These countries are trying to diversify energy sources. One of the reasons for diversifying energy sources is also the need to protect the environment (moving away from fossil sources in favour of renewable energy sources), to some extent regulated by the implementation of new directives in the European Union related to the integration of energy markets and environmental protection (Directive 2003/87/EC; Directive 2009/31/EC; Directive 2009/28/EC;

Directive 2004/8/EC; Directive 2012/27/EU; Bluszcz and Manowska, 2019; Manowska, 2018). The pace of appropriate changes while maintaining the set energy policy goals is a major challenge for mining and energy companies (Manowska and Nowrot, 2019; Grabowska, 2018; Bluszcz, 2016).

Considering the increase in energy demand and environmental protection, focusing attention (financial and intellectual resources) on new technologies and new energy sources is undoubtedly necessary. As indicated by many publications and current trends, global energy demand will double at least by 2050, and the use of renewable energy sources will become even more important and will develop continuously (Atems and Hotaling, 2018; Marks-Bielska et al., 2020; Ruszel, 2017). Although renewable energy sources have been developing significantly in recent years, the world's energy needs are still mainly met by raw materials such as coal, oil, and gas. As studies show (BP, 2017; Gawlik and Mokrzycki, 2017; Statistical Review of World Energy, 2020), the rate of use of these sources is increasing, and as a result, these resources last for less and less time. According to data from 2016, with an unchanged level of extraction, documented reserves of crude oil were to last for 51 years of exploitation, natural gas for 53 years, and coal (hard and brown) for 153 years. The latest data from 2019 (published in 2020) show that crude oil reserves will last for 50 years of exploitation, natural gas for less than 50 years (49.8 years), and coal reserves for 132 years. This means that over these years, the availability of resources has decreased, and the period for which their availability is expected has shortened. This may also indicate that resources are being used faster. It should be noted here that the energy demand is high. Most of the raw materials from which energy is produced are fossil fuels such as oil, natural gas, and coal, and currently, they have no substitutes that would meet the required demand (Gawlik and Mokrzycki, 2017; Ranosz and Kowal, 2020; Kovanič, 2013). However, current trends indicate that renewable energy sources are becoming more efficient in some parts of the world and are slowly starting to compete with other sources (Bluszcz, 2018; Bluszcz, 2017). This development will contribute not only to environmental protection or ensuring the energy security of individual countries but also to the emergence of new technologies in the energy sector and to the creation of new industries (Ranosz, 2014; Kowal et al., 2018; Kowal et al., 2020; Ranosz et al., 2020; Kovanič et al., 2021a; Kovanič et al., 2021b).

Examples of the growing trend of interest in and use of renewable energy sources include already completed investments such as a solar-powered plane - Solar Impulse 2 (Kulik 2015), solar-powered airport in India (Turek, 2016; Pierwsze…2015) or the Eco-capsule, which was supposed to replace camping trailers (Ekokapsuła, 2016, 2017; Propertydesign, 2017, 2018), as well as other planned projects e.g. Solar Mountain (Na pustyni…, 2021).

One of the most visible sectors of the energy transition focusing on environmental protection is the automotive industry, which is mainly focused on the development of electric cars. According to an analysis conducted by the non-governmental organization Transport & Environment (T&E), electric cars will triple their share of the EU market. This is mainly due to EU regulations on CO2 emissions from cars. Already, a noticeable majority of car manufacturers such as BMW, PSA, Volvo, and FCA-Tesla are meeting EU emission reduction targets (W tym roku… 2020). Electric vehicles are now important to achieving global climate change goals (ZEKE, 2020; Perspektywy rozwoju…, 2014). Recently, there has been increasing talk about hydrogen-powered cars, with three main reasons given as to why it is worth switching to them: reducing air pollution, reducing CO2 emissions, and reducing oil consumption (Keith and Farrell, 2003).

Methodology

The justification for the future development trend of individual energy sources is based on the analysis of available data on total energy demand, the amount of electricity produced in the world, and the amount of its consumption in the following regions of the world: North America (3 countries), S. & Cent. America (58 countries), Europe (49 countries), CIS (17 countries), Middle East (16 countries), Africa (63 countries) and Asia Pacific (45 countries).

The research results presented in this article were based on data presented in the BP Statistical Review of World Energy (BP, 2020). This database contains historical data on the demand, consumption, and production of oil, gas, coal, nuclear energy, hydroelectricity, and renewable energy sources. The period for which the individual data is available varies, so the analysis collected data for the years 1985-2019 to compare changes in energy markets in the above-mentioned regions of the world.

In addition, the units of the analyzed data were not standardized. Some of the data taken from the BP database were in Exajoules (consumption, production), others in TWh (generation) or tons (production, consumption of crude oil). Hence, to make comparisons, it was necessary to perform appropriate conversions. The conversion factors (1) and (2) were used.

$$\mathbf{1\ exajoule\ (EJ)\ =\ 1\ quintillion\ joules\ (1E\ x\ 10^{18})} \quad (1)$$

$$\mathbf{1\ kilowatt-hour\ (kWh)\ =\ 860\ kcal\ =\ 3600\ kJ\ =\ 3412\ Btu} \quad (2)$$

The following conversion factor (3) was obtained from the above relations, which enabled data parameterization. It allowed for comparisons of analyzed data expressed in the same units.

$$1\ exajoule\ (EJ) = \frac{(1E\ x\ 10^{18})}{3600000000000000} = 277{,}7777778\ TWh \quad (3)$$

Because the article analyzed various energy sources, including energy production from crude oil, the estimated tons of extracted raw material were also converted to the potential size of Exajoules. This conversion was based on data on the consumption of this raw material, which was given both in tons and Exajoules. Data on the consumption of crude oil from 1965 to 2021 in Exajoules as tons is presented in Fig. 2.

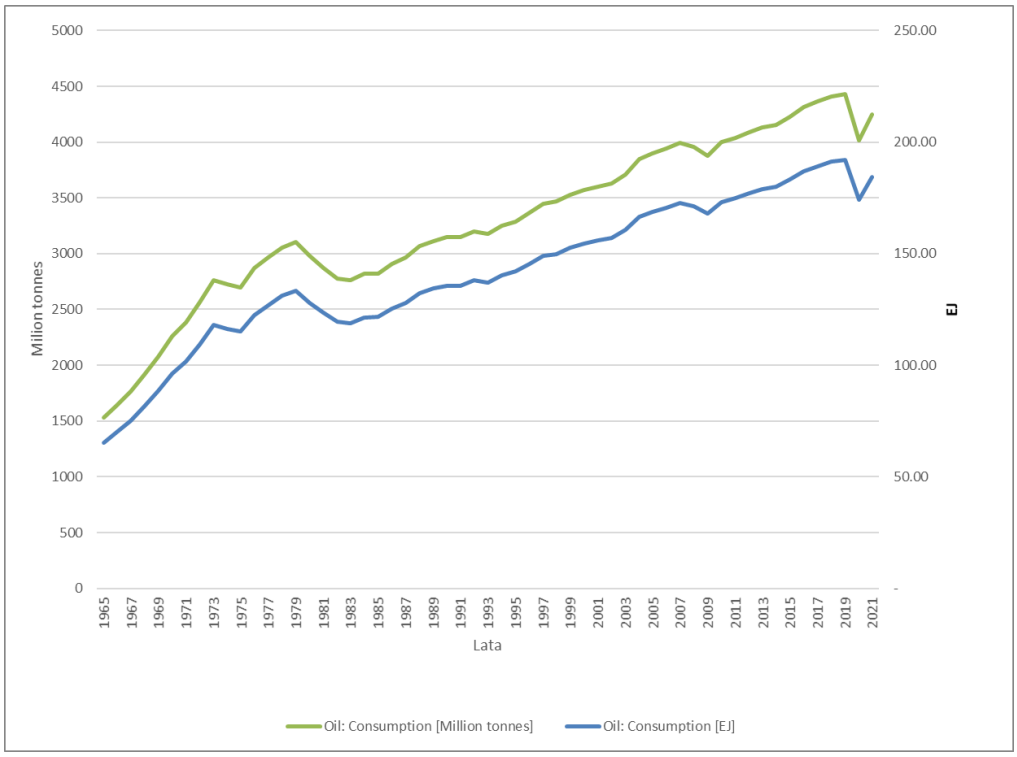


Fig. 2. Crude oil consumption in Exajoules and tons (own study based on BP, 2020)

Based on these relationships, the conversion factor from tons to Exajoules of crude oil consumed was determined according to the relationship (4):

$$P = \frac{\sum_{i=1}^{n} \frac{a_i}{b_i}}{n} \quad (4)$$

Where:
P – conversion factor
a – oil: Consumption [Million tonnes]
b – oil: Consumption [EJ]
$i = 1 \ldots n$
n – number of years analyzed ($n = 55$)

The crude oil production data were given only in tonnes of extracted raw material, so to convert tonnes to Exajoules, the following relationship (5) was used:

$$Oil\ Production\ [EJ]=Oil\ Production\ [Million\ tonnes]\ P \tag{5}$$

Then, the exajoules were revalued to TWh according to formula (3).

In determining the directions of changes in the structure of electricity production in the world in future periods, trend functions were used:

– exponential, defined for each real number *X* by formula (6)

$$fx= ax \tag{6}$$

Where:
a >0
$X \in R$

– linear (7), which is a special case of linear regression where the explanatory variable X is the time variable t. In such a case, we say that we are dealing with a time series, i.e. data that are arranged about time

$$y= a\ X+b$$

Where:

$$a= (ti- X)(Yi- Y)(ti- t)2 \tag{7}$$
$$b= Y-a\ t$$

– logarithmic defined by formula (8)

$$fX= logax \tag{8}$$

Where:
f:0,∞
$a \in 0,1 \cup (1,\infty)$

To match the trend to the empirical data, the coefficient of determination R^2 defined by formula (9) was used. It is a measure of the quality of the model's fit to the training data and takes values from the range [0, 1]. The higher its value, the better the model fit and the more accurate the forecasts will be (Aczel and Sounderpandian, 2018).

$$R^2 = \frac{SS_M}{SS_T} = \frac{\sum_{t=1}^{n} (\hat{y}_t - \bar{y})^2}{\sum_{t=1}^{n} (y_t - \bar{y})^2} \tag{9}$$

Where:
R^2 - coefficient of determination, percentage of variation explained by the model
SS_M - a sum of squares for the model
SS_T - the total sum of squares
y_t - actual value of the dependent variable
$\hat{y}_t$ - predicted values of the dependent variable (based on the trend)
$\bar{y}$ - mean value of the actual dependent variable

Results and discussions

The first stage of the research, immediately after standardizing the units of analyzed data, was the assessment and analysis of demand (extraction) for energy in six regions of the world. Secondly, the structure of sources was analyzed, and then the level of electricity production and consumption was compared. In the last stage, based on previous analyses, an attempt was made to determine the formation of the future trend of development of individual energy sources.

Global energy demand

Initial research results have shown that the world is producing more and more energy. In the initial year of the analysis, global energy production was 30222.8 TWh, and in 2019, it reached 58389.9 TWh, which almost doubled. This change represents an increase of 28167.1 TWh. Over the 34 years, the production volume increased by an average of 854.6 TWh per year. The upward trend visible in Figure 3 continues throughout the analyzed period. Only in 2009 was a decrease noted, when the volume of electricity production decreased by 741.2 TWh compared to 2008.

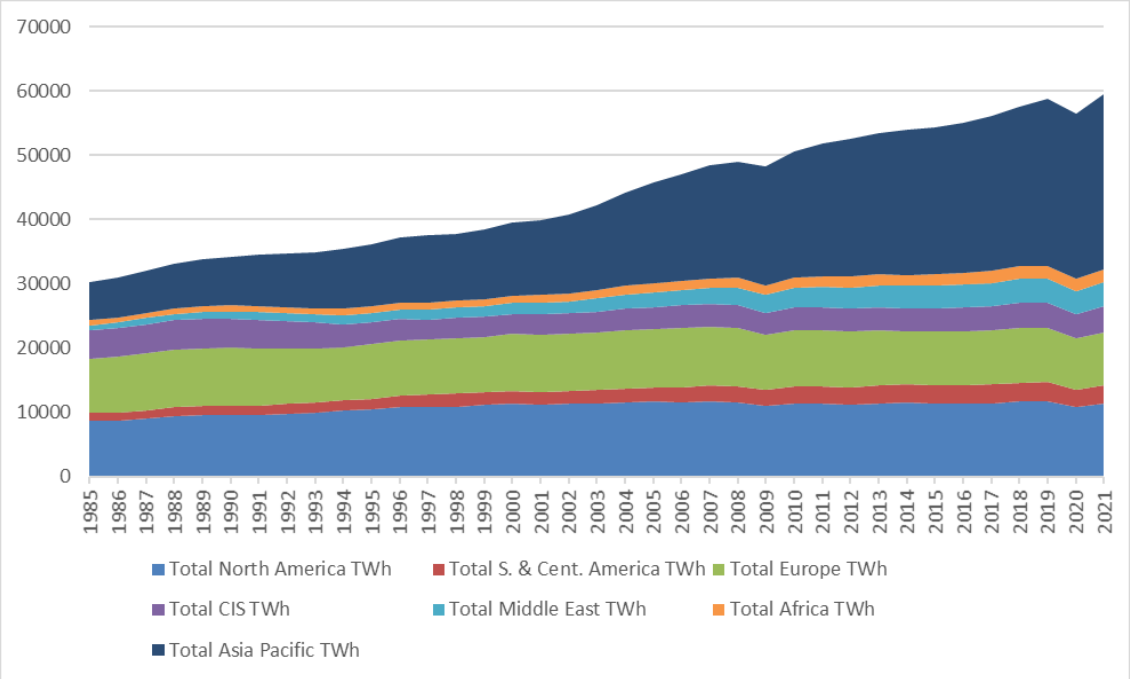


Fig. 3. Total energy demand in the world and six regions in 1985-2021 [TWh] (own study based on BP, 2020)

At the beginning of the analyzed period, the largest share of total energy demand was held by the North American and European regions. Until about 2000, their share was comparable and was estimated between 28.1%-28.9% for North America and 22.2%-28.2% for Europe. The share of the third largest region, Asia Pacific, was much lower: 19.5% in 1985 and 28.5% in 2000. These three regions have played and continue to play the largest role in creating energy demand in the world. After 2000, the situation changed slightly. Energy demand is mainly created by the Asia Pacific region. It increased from 11255.1 TWh in 2000 to 25756 TWh in 2019. Its share in creating demand has been growing very dynamically from 2001 (29.2%) to 2019 (44.1%). The dynamics of this growth, compared to other regions, is astonishing. The average annual growth in demand in the Asia Pacific region (since 2000) was 805.6 TWh, which was only 246.6 TWh less than the average annual growth in total global demand in the same period (1,052.2 TWh).

The share of other regions remained at a similar level over the 34 years analyzed: S. & Cent. America (4%-5.3%), Middle East (2.8%-6.6%), Africa (2.6%-3.4%), and even decreased, as in the case of the CIS region, whose initial share from 14.3% (in 1985) gradually decreased to 6.6% in the last year of the analysis (from 4310 TWh to 3868.3 TWh). It should be noted that only a part of this consumed energy is used for electricity production.

The share of electricity from individual sources in total consumption is shown in Figure 4. In the case of Nuclear Energy and Hydroelectricity (overlapping lines on the graph), all energy generated from them was used in 100%. In the case of renewable energy sources, approximately 80% of the energy generated from them was used to produce electricity, although this level in recent years (since 2016) has been above 90%, and in 2019, even 96.8%. Energy generated from coal was used by 43.3% in 1985 to 62.2% in 2019 to produce electricity, and from gas initially, this level was half as much, but since 1996 it has increased to 44.5%. On the other hand, oil is characterized by an interesting situation - almost none of the energy it generates is used to produce electricity (only 4.3% in 2019).

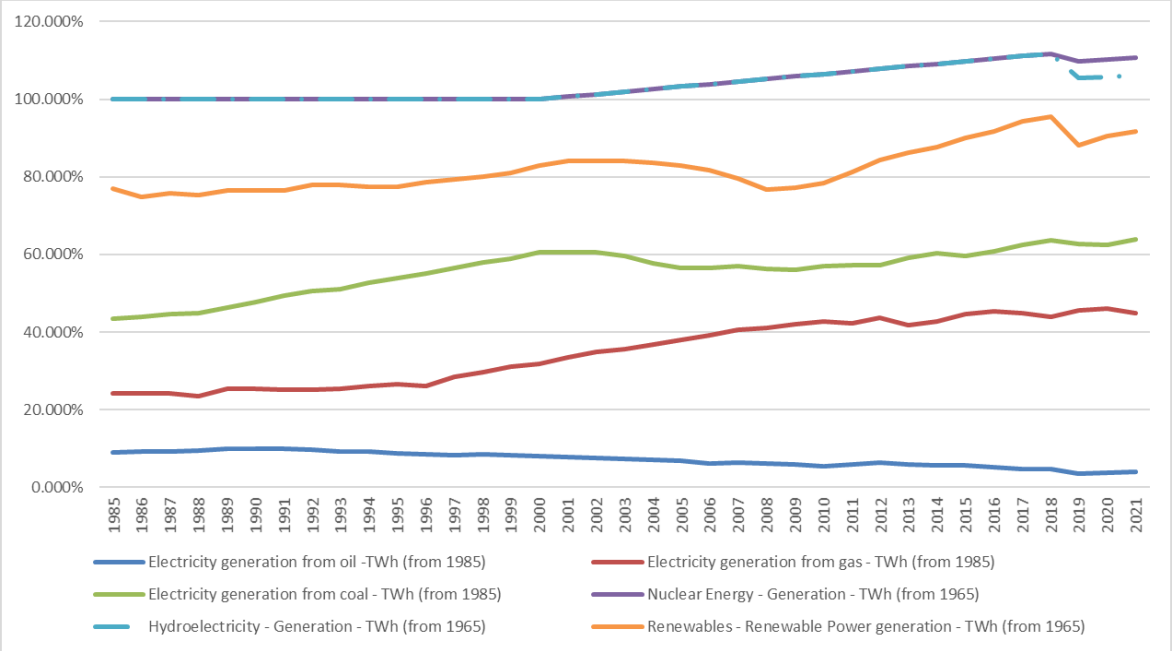
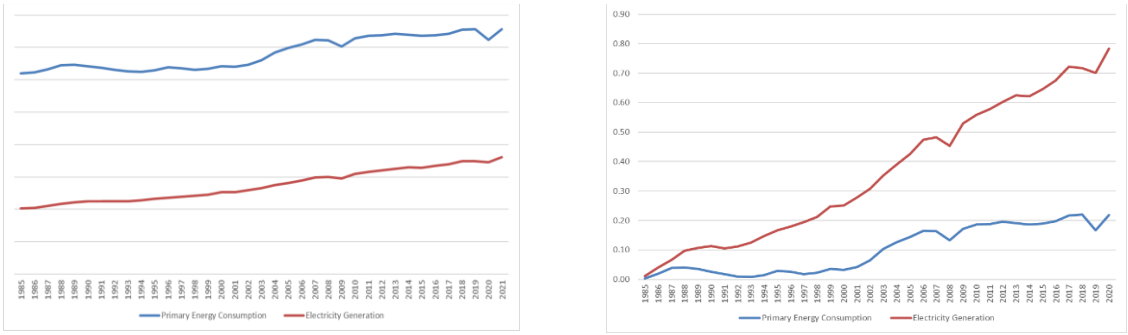


Fig. 4. Development of the level of use of individual energy sources for electricity production (own study based on BP, 2020)

The years analyzed have shown that more and more energy is used per person, and we use more and more raw materials to produce electricity (Fig. 5a). It is also visible that the increase in Electricity Generation per person is much faster than the increase in energy consumption (Fig. 5b).



a) *b)*

Fig. 5. Level of global energy consumption and electricity consumption (a) [TWh/person] and the pace of these changes (b) per capita [TWh] (own study based on BP, 2020)

The growth rate of electricity generation is also visible in its increasing share of energy consumption. In practice, electricity is understood as energy that is transformed into usable energy. We need it everywhere: in industrial production, transport, heating, or lighting. It can be converted into electromagnetic radiation energy (for instance, light bulbs, light-emitting diodes, and heating devices) or mechanical energy (for instance, electric motors and loudspeakers). Thanks to it, the world has achieved development at its current level. Over the years studied, the share of electricity consumption in total energy consumption increased from 32.7% to 46.2% (Fig. 6).

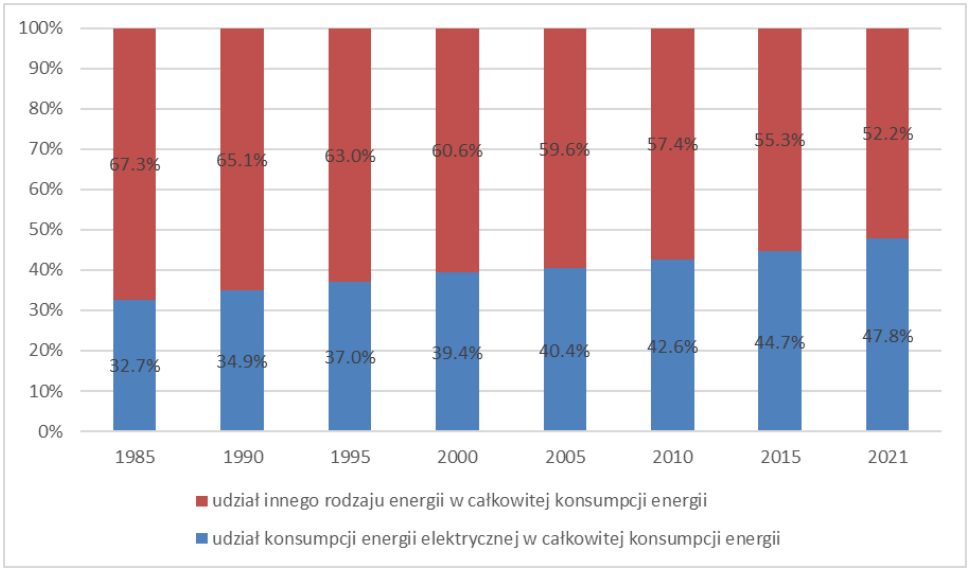
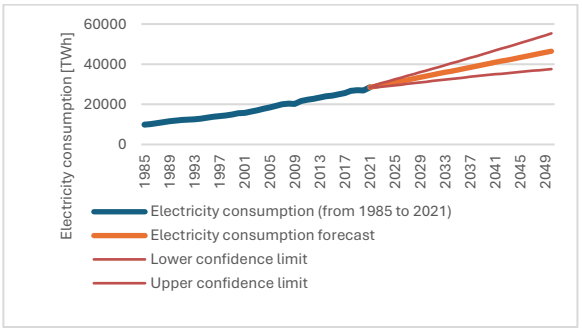
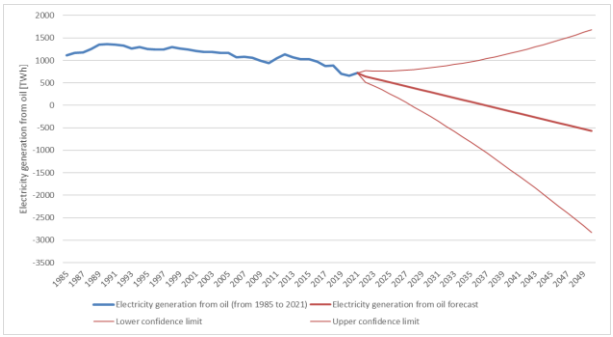


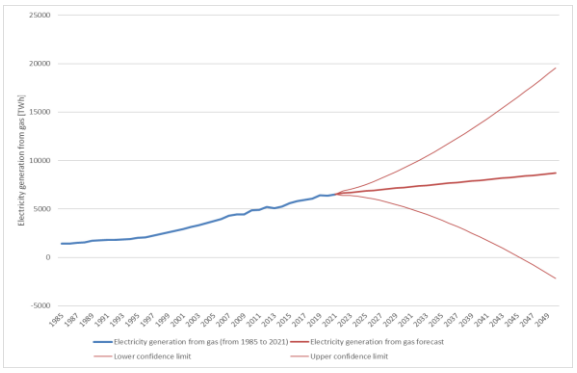
Fig. 6. The share of electricity and other types of energy consumption in total energy consumption [%] (own study based on BP, 2020)

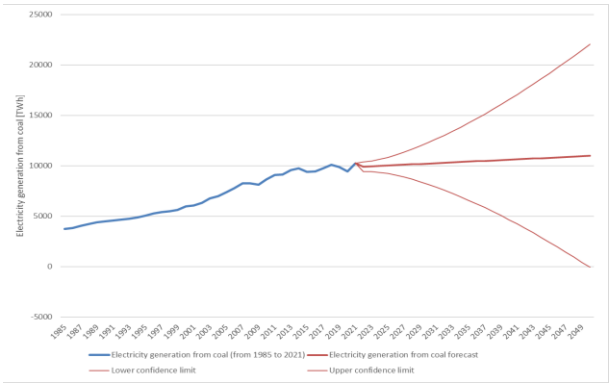
The development trend of individual energy sources and their structure in the world

The next step of the research was to determine the development trend of individual energy sources. Based on actual data from all years, i.e. from 1985 to 2021. Figure 7 shows the actual electricity consumption until 2021 and the prospect of its total consumption for individual energy sources. The trend of electricity consumption for all sources was made using the built-in Excel function "Forecast sheet". Basic statistics are presented in Table 2.









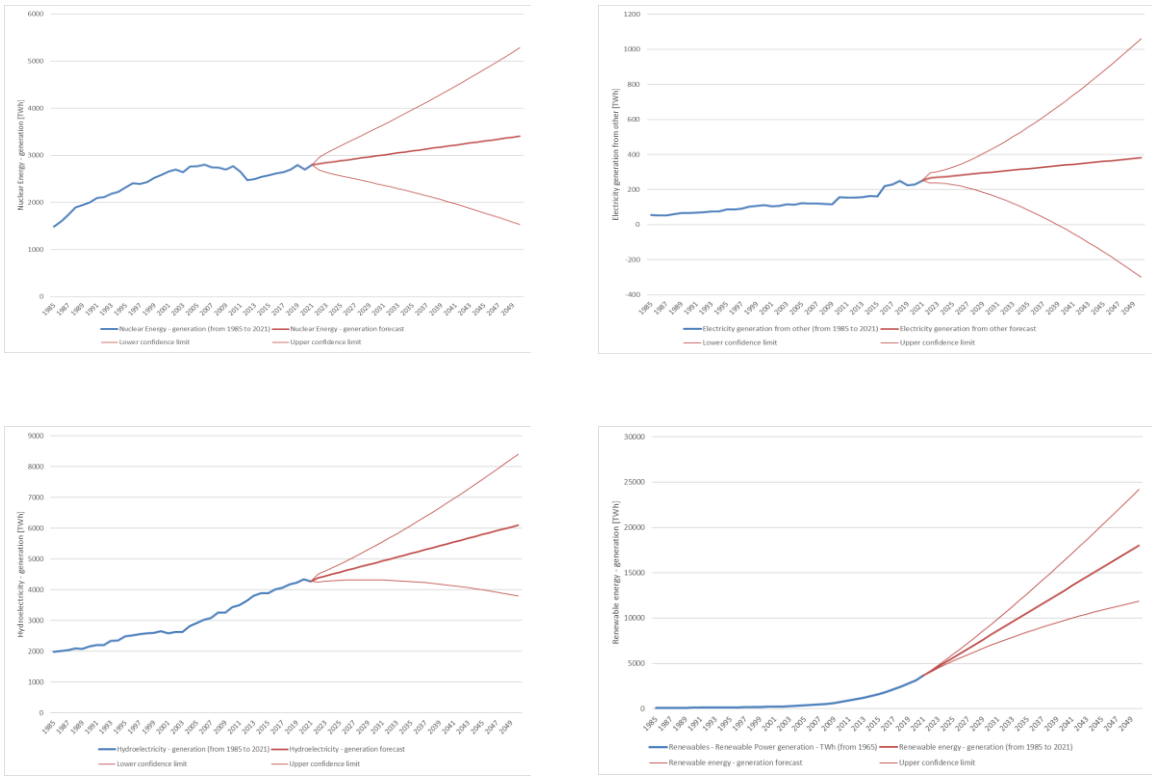


Fig. 7. Prospection of electricity consumption for individual energy sources until 2050 prepared using the Forecast Sheet

Tab. 2. Basic Statistics

Statystyka	energy	oil	gas	coal	nuclear	other	hydro	renewable
Alpha	1	0.67	0.5	0.25	1	0.25	0.67	0.9
Beta	0.1	0.17	0.5	0.25	0.1	0.25	0.17	0.9
Gamma	0	0	0	0	0	0	0	0
MASE	0.66	1.87	1.15	1.36	1.05	3.79	0.8	1.35
SMAPE	0.01	0.08	0.03	0.03	0.03	0.1	0.01	0.02
MAE	319.81	71.83	154.44	293.69	70.32	20.84	52.4	42.85
RMSE	455.42	87.62	177.05	347.51	88.46	24.44	71.39	66.74

Source: own elaboration

As shown in Figure 7, electricity consumption will increase if current trends are maintained. From the perspective of 2050, it can be observed that, on a global scale, we can expect a move away from electricity production from crude oil. Another observation is that energy production from conventional sources (coal, gas, etc.) will remain at an unchanged level, and additional electricity demand will come from water and renewable energy sources. As shown in Figure 7 (oil), the trend in energy consumption from this source indicates that consumption will take on negative values. This is not logical, so it was assumed that zero values would be adopted in this type of phenomenon. Figure 8 compares energy consumption for individual sources.

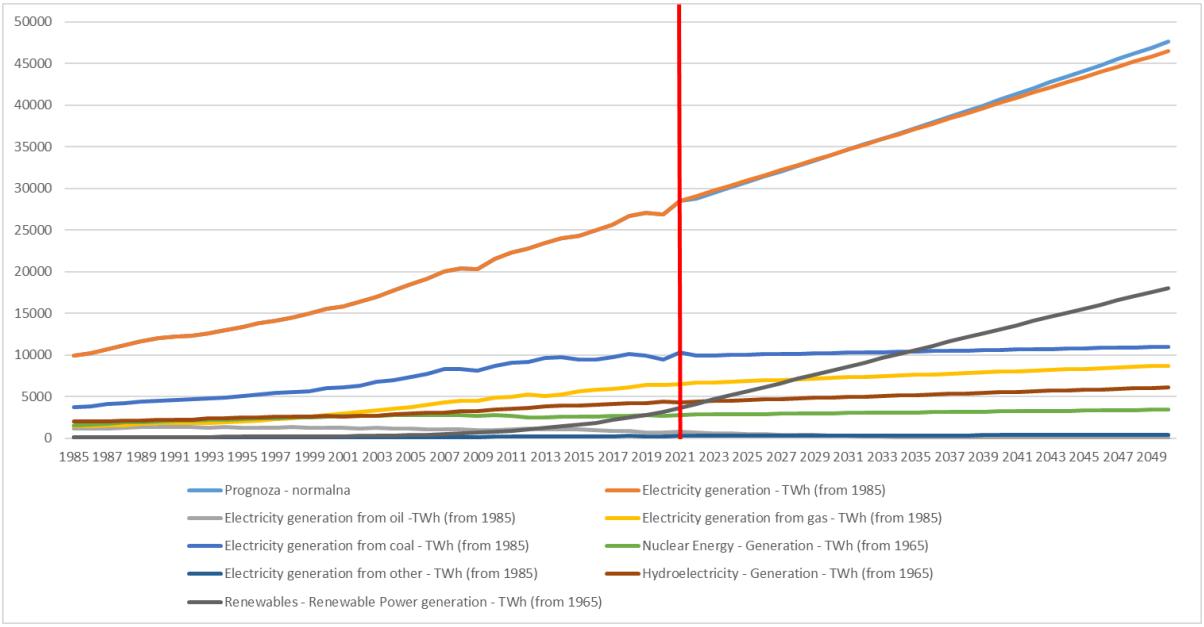


Fig. 8. Electricity consumption and its trend until 2050 for individual energy sources

As shown in Figure 8, renewable energy sources will be the main source by 2050, and oil-based energy will be eliminated by 2037. Figure 8 also shows that the sum of energy consumption from individual sources is not equal to the forecast of energy consumption as a whole – in connection with this fact, it was decided to correct the forecast of energy consumption for individual sources in direct proportion to the following formula (10):

$$EG_{dn} = \frac{EG_{pn} * EG_{p}}{\sum_{i=1}^{m} EG_{pm}} \tag{10}$$

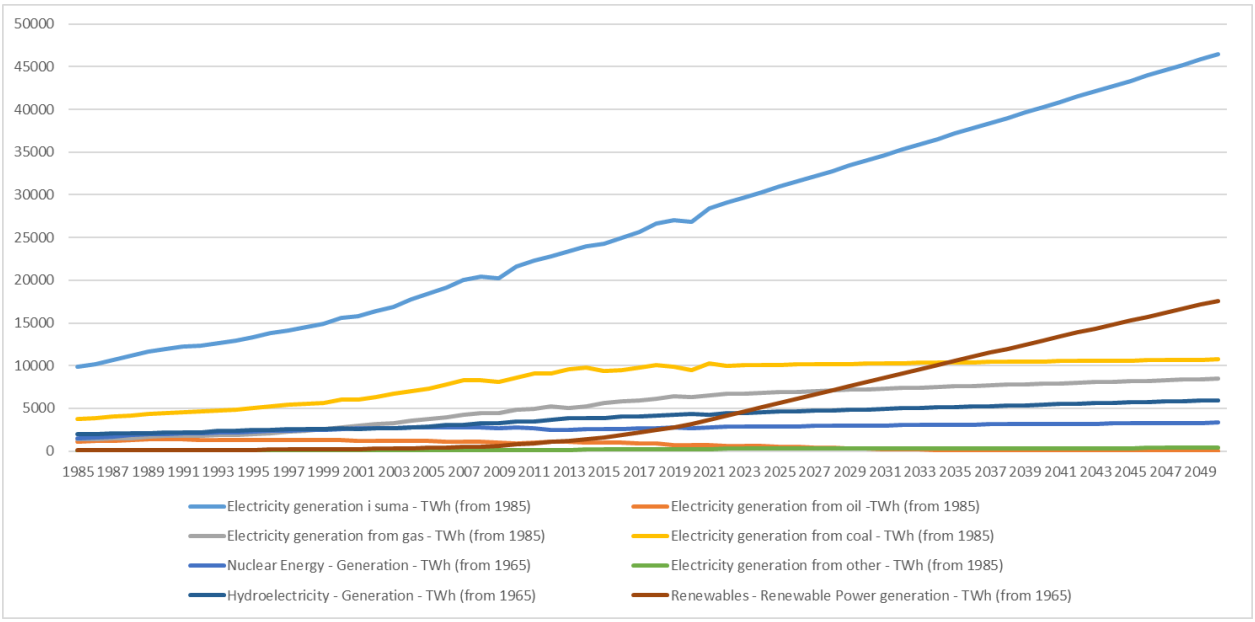


Fig. 9. Electricity consumption and its trend until 2050 for individual energy sources – after correction

As can be seen from Figure 9, the electricity consumption according to the above formula did not change its structure. Both Figure 8 and Figure 9 show the nominal electricity consumption. Figure 10 shows the percentage share of individual sources in the total electricity consumption until 2050.

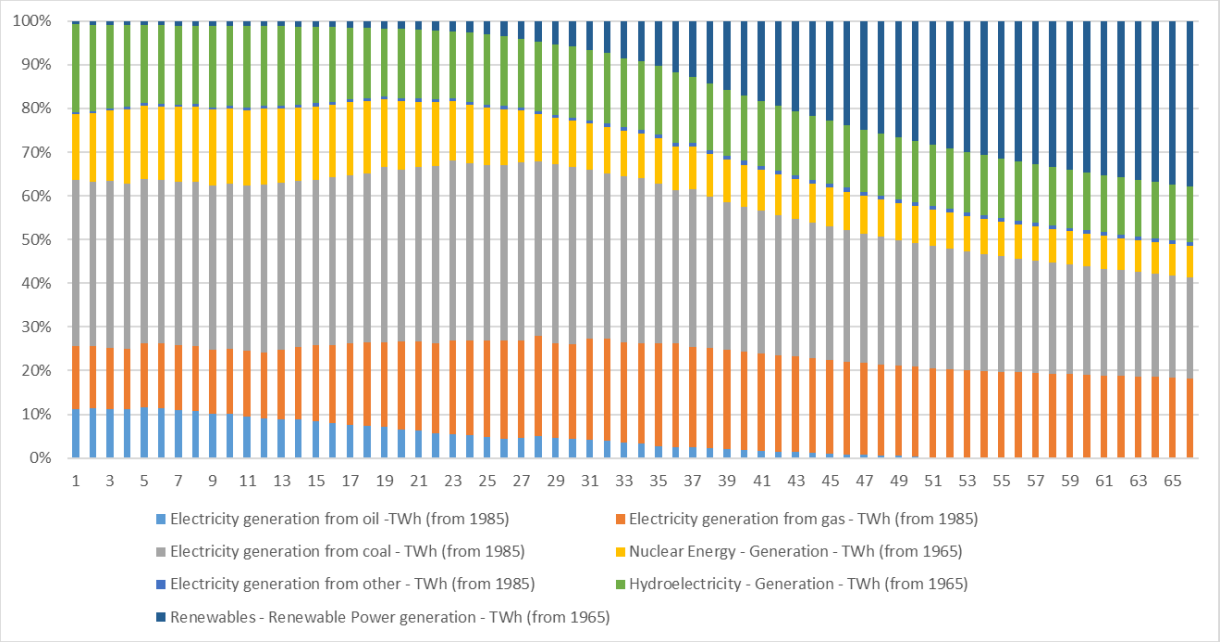


Fig. 10. Percentage share of individual energy sources in total energy consumption by 2050

As a result of the above prospects, the share of renewable energy sources significantly increases its share of total energy consumption in the context of the whole world. Within the framework of the article, renewable energy sources are treated as energy from the following sources: wind energy, solar energy, and others, i.e. primarily geothermal energy and biomass. Based on the available data, it was checked which of the above renewable energy sources, if current trends are maintained, will have a dominant role in the future (Fig. 11).

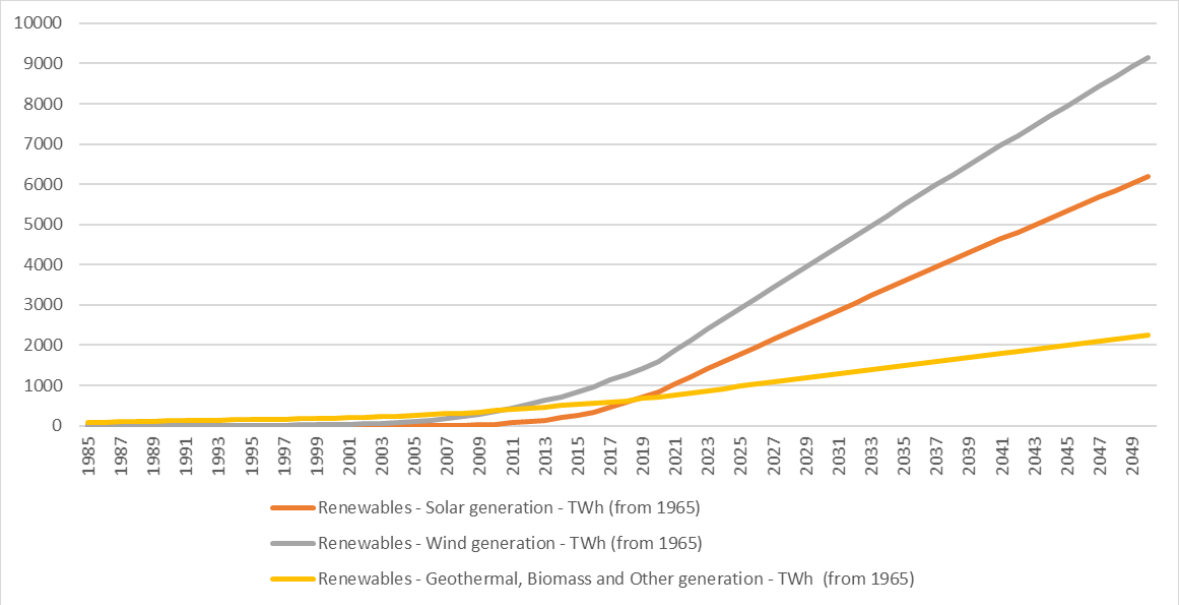


Fig. 11. Historical and forecasted electricity consumption (production) until 2050 from individual sources

In 2021, in the context of the whole world, most electricity will be produced from wind farms, and the growth dynamics of this energy source will be the highest. In this context, the production of solar energy is not much worse. This situation is completely different from that observed at the beginning of this century when the dominant renewable energy sources were geothermal energy and biomass. In 1985, the share of geothermal energy and biomass within renewable energy sources was 99%. At the beginning of this century, it exceeded 80%. In 2021, this share will be slightly over 20%. In contrast, the share of wind energy is over 50%, and solar energy is 28% (Fig. 12). Of course, the decrease in the share of energy from biomass and geothermal energy does not mean that this energy source is disappearing completely and the world will give it up - as can be seen in Fig. 10, the amount of electricity produced from this source is increasing.

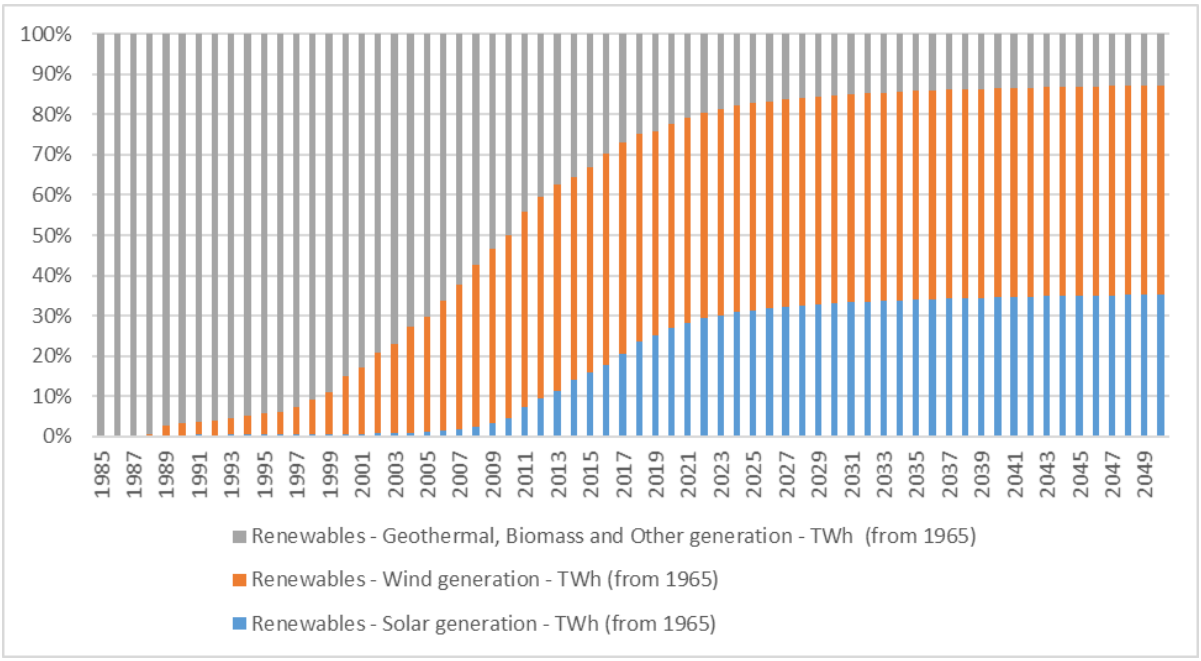


Fig. 12. Historical and forecasted electricity consumption (production) until 2050 from individual sources

Considering the above graphs (forecasts) – it should be clearly stated that the increase in demand for electricity will be largely covered by energy from renewable energy sources (especially solar and wind energy). However, the dynamic development of RES does not mean that conventional energy sources will completely disappear. In the case of coal energy, the current state should be expected to be maintained. In the case of energy from gas, a small increase can be expected, similar to the case of hydro and nuclear energy.

Conclusion

Nowadays, energy is an important element in the daily functioning of humanity. It is also an indispensable factor and one of the most important factors influencing the development of all economies of the world. The research presented in the article on the directions of changes in the structure of electricity production in the world expands knowledge about the formation of the structure of energy markets in the next few decades.

Based on the analysis of empirical data for the years 1985-2021 regarding the volume of electricity production from these sources (TWh) for 7 regions of the world and matching trends to empirical data, future directions of changes in the structure of electricity production in the world were determined.

As a result of the research presented in the article, the energy demand will increase over time both in nominal terms and per person. From this point of view, it is important to manage the resources from which we obtain energy properly. Developing individual technologies to use primary energy sources efficiently is also important. Although in recent years, much emphasis has been placed on environmental protection and consequently on renewable energy sources, from a global perspective, the main resources from which energy is produced are still fossil fuels, i.e. coal, oil, and gas. Nevertheless, as the graphs show, it is impossible not to notice the very dynamic development of renewable energy sources. As the analysis in the presented article showed, in the 1940s, renewable energy sources could become the dominant source of energy from a global perspective. According to the authors, this is not improbable and even almost obvious - especially considering the development of technology and the willingness of financial institutions to participate in such ventures. The programs announced by individual countries promoting this type of energy source are also important.

Another aspect highlighted in the article is that the global trend is towards using primary energy resources (regardless of their type) to convert them into electricity. Currently, primary resources are used by about 40% to generate electricity, and in about 10 years, this share may exceed 50%. As the analysis shows, this trend is constant. Such a situation may have its advantages and disadvantages. The advantages include mainly the fact that, for example, households will significantly reduce the emission of pollutants into the atmosphere (low emission), while the disadvantage, on the other hand, maybe too much "monopolization" of primary energy resources, which may negatively affect, for example, energy prices, but may also increase the probability of new economic crises.

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