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Development of the Polish energy sector through transformation and harmonization with the European energy and climate policy

Rozwój polskiej energetyki na drodze transformacji i harmonizacji z europejską polityką energetyczno-klimatyczną

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Keywords: *energy sector transition; energy and climate policy; large-scale low emission power engineering development; method of electricity demand forecasting*

Abstract
The paper presents the development of Polish energy sector European energy policy due to the national way for climate goals achievement. The problems of investing in Polish energy sector effectiveness are significant due to the development of the national economy, analyses are based on recommendations given by the Ministry of Climate expert team. The paper illustrates the dynamics of social changes that determine changes in Polish legislation, they are consistent with the general EU direction. Power engineering, generally understood as a branch of the national economy is a strategic sector for the functioning of the state. The investments play a vital role in ensuring the rational distribution of production, and thus saving social effort, for the comprehensive development of their national economy. As a result of investment activity in the construction of energy facilities, new jobs and conditions for the implementation of the principle of full and rational employment are created. This leads to desired changes in the socio-professional patterns and the development of the national economy. Energy policy determinants in Poland are presented. The Polish energy sector possibilities of the energy transition are describe to determine intra EU harmonization.

Słowa kluczowe: *transformacja sektora energetycznego; polityka energetyczno-klimatyczna; rozwój energetyki niskoemisyjnej na dużą skalę; metoda prognozowania zapotrzebowania na energię elektryczną*

Streszczenie
W artykule przedstawiono rozwój polskiej energetyki w relacji do europejskiej polityki energetycznej w świetle krajowej drogi osiągania celów klimatycznych. Problemy inwestowania w efektywność polskiej energetyki są istotne ze względu na rozwój krajowej gospodarki, analizy opierają się na rekomendacjach zespołu ekspertów Ministerstwa Klimatu. Artykuł ilustruje dynamikę zmian społecznych, które determinują zmiany w polskim ustawodawstwie, są one spójne z ogólnym kierunkiem UE. Energetyka, ogólnie rozumiana jako gałąź gospodarki narodowej, jest sektorem strategicznym dla funkcjonowania państwa. Inwestycje odgrywają istotną rolę w zapewnieniu racjonalnego podziału produkcji, a tym samym zaoszczędzenia wysiłku społecznego, na rzecz wszechstronnego rozwoju gospodarki narodowej. W wyniku działalności inwestycyjnej w zakresie budowy obiektów energetycznych powstają nowe miejsca pracy i warunki do realizacji zasady pełnego i racjonalnego zatrudnienia. Prowadzi to do pożądanych zmian we wzorcach społeczno-zawodowych i rozwoju gospodarki narodowej. Przedstawiono uwarunkowania polityki energetycznej w Polsce. Omówiono możliwości transformacji energetycznej w polskim sektorze energetycznym w celu określenia harmonizacji wewnątrzunijnej.

1. Introduction

One of the significant challenges of modern civilization is the widespread access to energy of adequate quality, at socially acceptable costs and respect for the natural environment. The report of the International Climate Change Panel and the Club of Rome indicates the need to limit the global temperature increase to 1.5°C, which is associated with a radical reduction in emissions: 45% by 2030 and 100% by 2050[1-3]. Therefore, some questions usually do not have the right answers. An example is: what are the three most important trends in the energy sector and what challenges are they related to in Poland? How will the demand for electricity in the world change in the next few decades – and how in Poland? In what direction should the production potential of the Polish energy sector develop? What energy sources will dominate in Poland over a 30-year perspective, and where will they come from? Should the share of gas in the structure of energy sources be increased? Should investments in nuclear energy be made? What benefits should be derived from modern energy technologies, such as digitization – smart metering and smart grid? What is the impact of new technologies on energy efficiency?

Even if the ambitious climate goals advocated by Europe would be politically accepted, what technological solutions must follow, how much will countries economies be burdened by their cost, how will it affect the global economic system, which so far has ignored this problem? There is no doubt that the strategy for the development of energy in Poland should be analyzed from the point of view of European and global economies. It must be taken into account that Europe will achieve nothing without the active participation of such countries as the USA, China, India, Russia, Brazil or Mexico

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. Even if Europe would accomplish what it has stated in the Energy Roadmap 2050 that it will achieve the assumed emission savings, it is not worth the vast expenses that will have to be incurred[4-5]. When it comes to implications the traditional energy structure should and will change with the integration – a convergence of electricity, gas and heating sectors is slowly taking place. Polish electricity and gas transmission and distribution systems and local heat markets also require significant investments. In total, it may add up to ca(300-400) billion Euro until 2050[13].

During the political transformation in Poland, many reform measures were taken in the energy sector. The current impact of the coronavirus causes crisis and recession, but fairly moderate. After the first wave of coronavirus has subsided, large bailouts will stimulate the economy in the form of loans and other relief measures. The basic assumptions of the climate policy leading to the European Union's Green Deal (GD) will be maintained – either they will be incorporated into aid programs (aid for new technologies) or only temporarily suspended, but without changing the dates of the basic objectives of the European climate policy. This means that the implementation of the Green Deal may also be a mandatory pre-requisite for Poland to receive EU aid. Economic and social policy will be under pressure from negative economic indicators and an increase in poverty. Distribution and trading companies, and then the transfer system operators (TSO) and producers, will be exposed to the risk of losing liquidity due to the possible lack of regulation of receivables from their customers, which in extreme cases can even lead to a complete collapse of the energy market[20].

Given the challenges of the EU's climate and energy policy, Poland is in a very difficult situation, because it has coal-fired energy plants. In this context, the following research goals are very important:

- identification of barriers and opportunities for the development of the power industry,
- investigating the possibility of using modern energy technologies in the processes of energy transformation, determining the Polish path useful to achieving climate and energy goals,
- a new method of electricity demand forecasting taking into account the demographic situation, which allows for precise determination of demand in development by the author of this paper.

Power industry as a strategic sector for state security has a significant impact on the development of national economy, stimulating its effective operation and creating sound economic fundamentals of the entire system state.

According to the author, the evaluation of investment effectiveness in market conditions should be based on a complex analysis taking into account different execution conditions, law and regulations, risk and investment uncertainty as well as the integration of investment phases and power engineering, economic and environmental aspects. Thus, methods which can meet the modern requirements of energy markets must be found.

2. Energy policy determinants in Poland

2.1 General remarks

Energy policy, in particular, must not ignore the fact that the energy sector is one of the essential sources of impact on the natural environment on a national and to some extent on a global scale. This involves the use of significant amounts of carbon fuels and the resulting emissions to the environment causing its transformation (waste, etc.), as well as physical and chemical imbalances (acidification of precipitation and soil, greenhouse effect). Stability of goals in the continuation of energy policy, which aims to: ensure the country's energy security, increase the competitiveness of the economy and its energy efficiency. Additionally it should aim to ensure environmental protection against the harmful effects of energy activities related to the production, transmission and distribution of energy and fuels.

It cannot and does not mean satisfaction with the implementation of the reform program, nor even less any agreement on the current pace of change and their socio-economic effects. This creates a specific situation hindering the modernisation/development of the Polish energy sector, which should be implemented in such a way as to strengthen the role and tasks of the transmission system operator and ensure the country's energy security[19].

In general, the definition of a modern development strategy requires consideration of the following issues from a number of aspects:

- changes in the primary energy structure;
- shift to modern, effective energy generation technologies;
- role of prosumer energy generation, especially in conditions of limited transfer capabilities;
- demand for structural heat, with unstable customer portfolio (competition with gas industry, and heat pumps) and general trend of thermomodernisation;
- change in the structure of natural gas consumption, significant fluctuations related to the economic situation and the unstable portfolio of recipients;
- conditions for the development of centralised and dispersed combined economy working for district heating (liberalisation of electricity prices in the European Union – decline in interest in the centralised and dispersed combined economy, impact of integration on the electricity market in Poland, also causing changes on the heat market);
- the unfavourable ratio of electricity to gas prices – impact on the development of district heating based on the gas combined economy.

2.2 Determinants for energy policy

According to general consensus of COP 2018' Conference in Katowice, Poland, the following fundamental issues for Poland may be relevant (including those arising from the work of the Committee for Energy and Climate Policy of the Polish Chamber of Commerce), as described below [16].

To what extent, taking into account the specificity of the Polish energy sector, the fuel resources available and the need to ensure energy security, Poland should shape its energy and climate policy, especially in the context of the EU net-zero carbon emissions by 2050 and commitments made during COP21'.

Polish long-term energy policy should be redefined in such a way that it sets clear priorities, i.e. ensuring secure and stable energy supply at prices that guarantee the economy's competitiveness and do not widen the area of energy poverty among individual consumers. It must take into account the specificity of Poland.

The provisions of the Polish energy policy must be specified to include clear perspectives, enabling the development of a stable strategy of operation.

Representatives of government administration must consider the voice of the Polish economy to a much greater extent during discussions at the European Union level. For its sake, it excludes any further obligations of Poland to tighten the EU climate policy.

The strategy of diversifying Poland fuel structure is slowly becoming obsolete. It seems reasonable to guarantee production capacity using coal fuel that can meet energy demand at any time (for example on a windless winter night – reduced by the possibility of a real reduction in energy consumption through the Demand-Side Management mechanism).

The level of coal consumption must be achieved by evolution while ensuring energy security. It may be necessary to stop further investments for some time while extending the functioning of existing capacities. It is important to be aware that there is currently no and there will not be any commercial coal technology that will meet the stringent EU carbon emissions and other environmental pollution requirements over the next few years. The attempt by the European Union to change the functioning of the energy sector is not feasible in our country.

From the point of view of the economy and the general interest of Poland, integration of the EU energy market requires, first of all, the introduction of the capacity market and ensuring the actual availability for consumers. In the second step, it is necessary to systematize renewable energy support systems. If renewable energy was subsidized, its sale on the integrated EU market requires adding all subsidies allocated to it. Only after these two steps are successfully implemented can an integrated energy market be built within the Union.

In communication with the EU institutions, it should be clearly emphasised that the capacity market is necessary for the integration of renewable energy due to the discontinuous work. Both the economy and individual consumers need reliable and continuous energy supplies, which, together with the increase in the share of renewable energy sources, can only effectively be ensured by the capacity market.

An area that Poland can notably support is cogeneration. We have sufficient potential in Poland in this aspect. It serves to stabilise the work of the power system with the growing share of renewable sources. For the rational development of cogeneration, activities, including industrial cogeneration, should be consolidated.

For the Climate Change Conferences agreements, Poland must emphasise that it implies voluntary of action. In this context, the Polish government administration should focus on defending the goals that are in force today, using all technologies that are now available in Poland. It is also worth mentioning that there are no officially agreed goals of the EU climate and energy policy for 2050. Poland has successfully blocked attempts to adopt the Energy Roadmap 2050 and for now, they are not binding.

The perspective of using coal will be gradually shifted from the energy sector to the chemical sector. Poland must be prepared for the need to shut down the operations of some mines in the next few years, which will cause many social tensions.

The driving force for the development of the sector should be electromobility, in which Poland can be a European leader, in particular in the field of urban electric transport, which will force the need to create a program for the development of bus batteries after 4-5 years of operation. Besides, the agreement of energy distributors on battery charging standards and their chemical composition.

2.3 Forecasting opportunity

Technological innovations should be implemented as soon as possible to guarantee Poland's energy security.

Another very important challenge is the decarbonisation of the power sector in the context of European climate policy. Decarbonisation of the energy sector means gradual replacement of coal fuels by other energy sources. Climate warming is commonly associated with greenhouse gas emissions, especially CO_2[4],[7],[18].

This requires dynamic and long-term structural changes in the energy system. Decarbonisation is a global trend, but its strong idealisation increases the desire to accelerate this process. At the G7 meeting on June 10, 2015, it was recognised that there was a need to decarbonise the world economy by 2050 in order for the global average temperature rise to be below 2^0 C. Public concern about climate change on Earth does not take into account the fact that our planet's climate feature is constant volatility.

The Geological Sciences Committee of the Polish Academy of Sciences in a very balanced way recapitulates the current state of knowledge on this subject in its position from 2009. The committee draws attention to the fact that the periodic increase in the number of greenhouse gases in the atmosphere, up to several times greater than today, has accompanied past warming, including before human appearance on Earth. From 12 thousand years, the Earth is in the next phase of cyclical warming and is near its maximum. In the last millennium, after the warm period, at the end of the thirteenth century, the glacial period began until the mid-nineteenth century, followed by warming again.

The temporary increase in global temperature observed today is due to the natural rhythm of climate change. Despite the apparent lack of global warming, there has been a consensus for more than 15 years on climate change [1],[5] , and long-term forecasts indicate that around 2035, the rate of warming associated with CO_2 emissions will increase . There are even predictions that global warming will continue for the next 1000 years, even if greenhouse gas emissions cease. Translation of complex natural phenomena according to unilateral observations, without taking into account the multiplicity of factors determining specific processes in the geosystem, usually leads to excessive simplifications and erroneous conclusions. The consequence may be the wrong political decisions based on incomplete data. Nuclear power is the primary

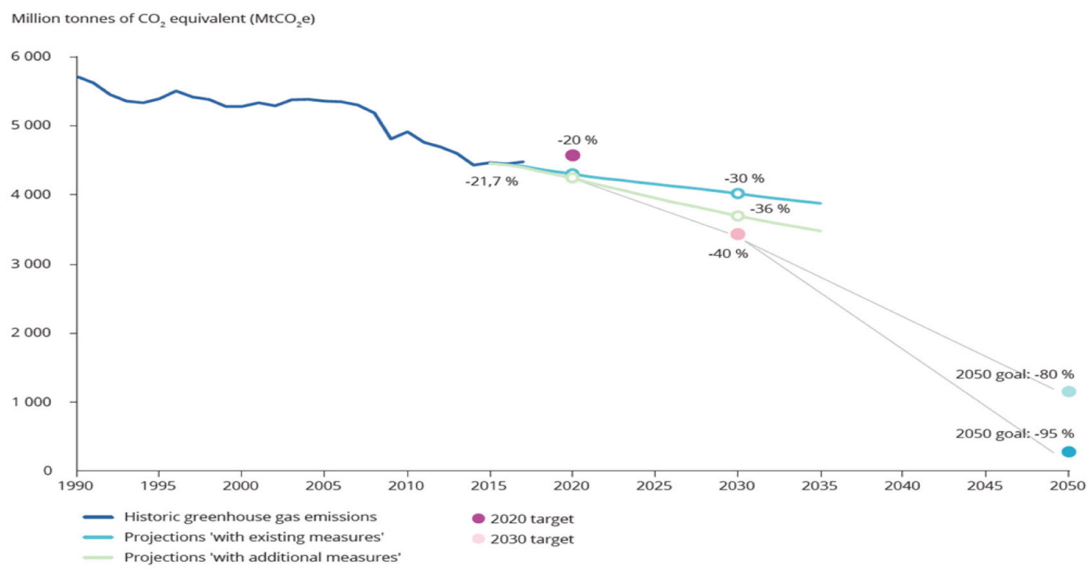

Fig.1.Present status and forecast CO_2 reduction, Source: BP Energy Outlook 2030. London, January 2019, own study

Rys.1.Stan obecny i prognoza redukcji emisji CO_2, Źródło: BP Energy Outlook 2030. Londyn, styczeń 2019, opracowanie własne

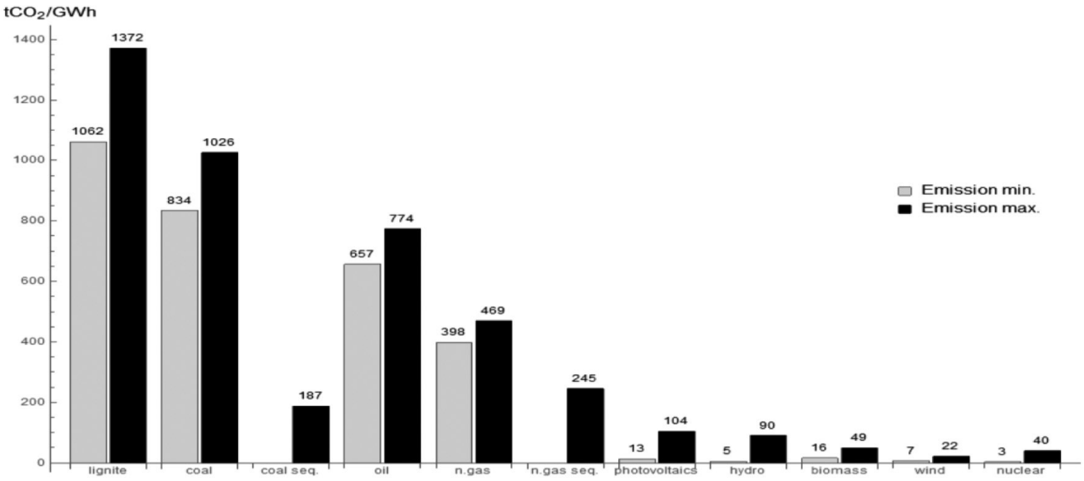

Fig. 2. Greenhouse gas emissions from various sources of electricity, according to data from the World Energy Council; – with exhaust gas sequestration; values for nuclear: minimal – for centrifugal enrichment, maximum – for diffusion, Source: IEA World Energy Outlook 2019—Analysis—IEA; Paris, France, 2019, own study.

Rys. 2. Emisje gazów cieplarnianych z różnych źródeł energii elektrycznej według danych Światowej Rady Energetycznej; – z sekwestracją spalin; wartości dla energii jądrowej: minimalne – dla wzbogacania odśrodkowego, maksymalne – dla dyfuzji, Źródło: IEA World Energy Outlook 2019 – Analiza – IEA; Paryż, Francja, 2019, opracowanie własne.

low-emission source of electricity, ensuring a stable power supply to consumers. This was stated by the World Energy Council (Fig. 2), or by the European Parliament in its resolution of 2007 and subsequent resolution 8, as well as other analyses [5].

The construction of nuclear power plants in Poland with a total capacity of 9,000 MWe, which will generate 60 TWh of electricity per year, will avoid burning 28 million tonnes of coal, i.e. emissions of over 80 million tonnes of CO_2 per year[15]. In this situation, the decision to build nuclear power plants in Poland is justified in the context of the resolution of the COP21 Paris Summit on CO2 reduction, EP in the resolution " European Parliament resolution of 15 Dec. 2015 on Towards a European Energy Union "stressed the importance of NPPs and called on the EC to create conditions for the construction of new NPPs in the EU as a low-carbon source (next to RES, gas and coal from CCS).

Costs require special consideration. In assessing energy costs, it is necessary to take into account the total costs incurred by the society of a given country in connection with electricity generation, including the costs incurred by the National Energy System to ensure reliable power supply to consumers, despite fluctuations in power plant capacity, their planned and unplanned shutdowns, as well as decay of electricity production by RES (when the generation of electricity from solar cells stops at night, or when wind farms on land and sea do not work due to the disappearance of wind). Irregularly working renewable energy sources usually have a maximum power greater than five times (wind on land) to 9 times (PV panels) than their average power per year. Transmission networks must always be designed for maximum capacity, regardless of the type of sources connected to them. The increase in the share of RES in the energy system requires maintaining sufficiently large operational reserves of power, covering the gap in energy production in the absence of wind or lack of sun.

All this causes an increase in investment costs, as well as a reduction in the efficiency of system power plants in periods when they operate with partial power. International analyses have shown that with a significant share of renewable energy sources – the costs of renewable energy cooperation with the network are relatively high. The public bears the third cost component as a result of health losses, environmental damage, destruction of materials and structures and loss of landscapes values. In the case of a nuclear power plant, this means taking into account environmental pollution, accidents when uranium is extracted and enriched, in the production of nuclear equipment and fuel, in the construction of power plants, the transport of fuel to the power plant, during operation and repair periods, during the disposal of radioactive waste and the decommissioning of power plants – to restore the environment as it was before the construction of the power plant. Similarly, these types of problems need to be taken into account

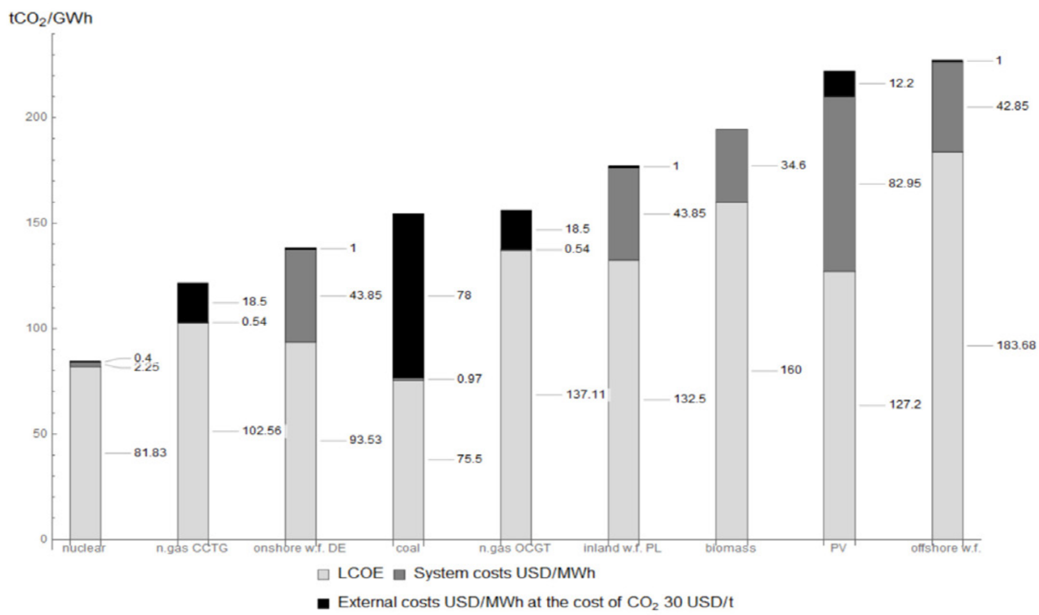

Fig. 3. Investment outlays for 1 MWh of electricity generated by a given energy source, Source: McKinsey Assessment of Greenhouse Gas Emissions Abatement Potential in Poland by 2030, Warsaw, Poland 2009, own study.

Rys. 3. Nakłady inwestycyjne na 1 MWh energii elektrycznej wytworzonej przez dane źródło energii, Źródło: McKinsey Assessment of Greenhouse Gas Emissions Abatement Potential in Poland by 2030, Warszawa, Polska 2009, opracowanie własne.

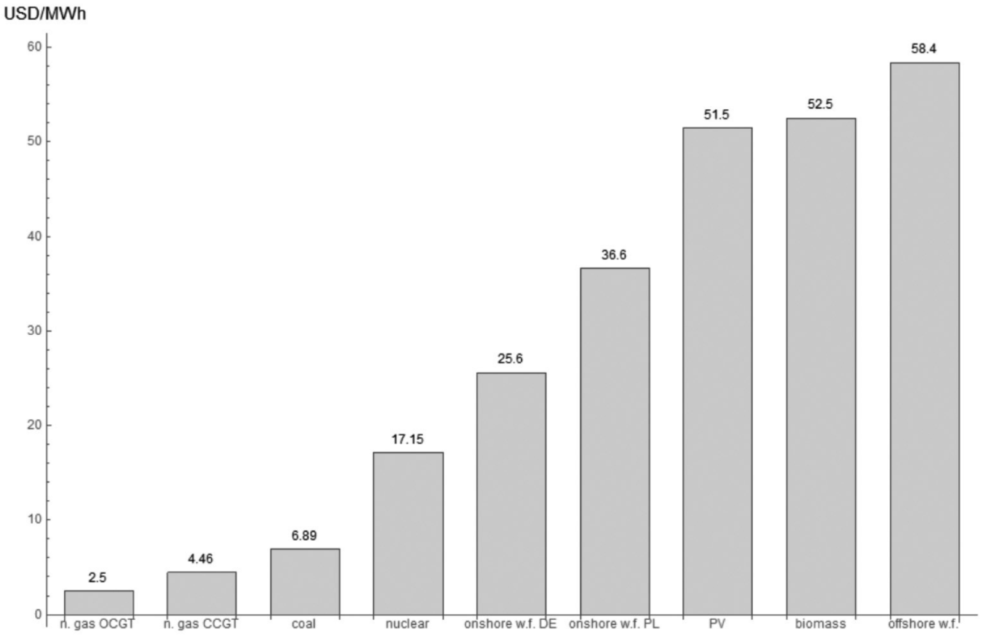

Fig.4. Total costs of generating electricity from various sources including costs in the installation itself, system costs and external costs, Source Central Statistical Office of Poland, own study

Rys.4. Całkowite koszty wytwarzania energii elektrycznej z różnych źródeł, w tym koszty samej instalacji, koszty systemowe i koszty zewnętrzne, źródło: GUS, opracowanie własne

for other technologies throughout their life cycle, e.g. for photovoltaic cells whose impact on the environment during operation is small (except for the loss of agricultural land or meadows), but environmental pollution in the production of aluminium and other materials are significant. For greenhouse gas emissions, it is essential that during the operation of nuclear power plants there is no coal combustion and the emissions are close to zero because they come only from the nuclear fuel cycle outside the power plant and periodic emergency tests of diesel generators at the power plant. The sum of all costs should be as low as possible. The summary of unit investment outlays for various energy sources is shown in Fig. 3. The expenditure shown in Fig. 4 relates to the energy source itself and does not take into account system costs or external costs caused by health losses and environmental damage. The assessment of the costs of delaying the nuclear energy program has two components: financial costs and social costs. Financial costs can be assessed, taking into account subsidies for RES development and construction costs of reserve power plants (e.g. gas). To this, the costs associated with the expansion and strengthening of the power grid must be added[14],[17]. Social costs are the maintenance of high emissions when burning coal and other damage to human health and the environment, assessed in the ExternE program for Europe and Poland.

The total costs of generating electricity from various sources (costs in the installation itself, system operating costs and external costs) are shown in Fig. 4.

The cheapest energy comes from nuclear power plants, taking into account all costs associated with obtaining fuel, disposal of radioactive waste, decommissioning of power plants and costs of cooperation with the power system.

3. Development of large-scale low-emission power engineering in Poland

3.1. General context of the development of the Polish energy sector

With reference to the above-mentioned challenges, opportunities and barriers to development, it should be noted that the dominant role of RES in new energy investments is unquestionable. At the end of 2019 (according to IRENA[11],[12]), the global installed

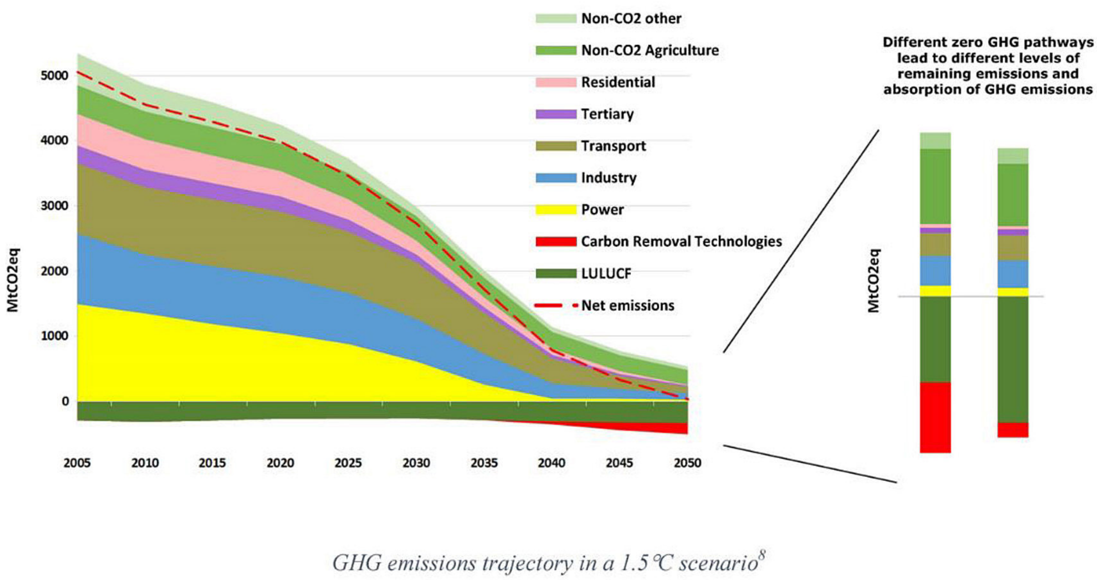

Fig.5. The scenario of the trajectory of GHG emission reduction Source: BP Energy Outlook 2030. London, January 2019, own study.

Rys.5.Scenariusz trajektorii redukcji emisji gazów cieplarnianych Źródło: BP Energy Outlook 2030. Londyn, styczeń 2019 r., opracowanie własne.

capacity in wind and solar energy amounted to 623 GW and 586 GW, respectively, and the corresponding annual power increases were 59 and 97 GW, which together accounted for 89% of the total increase in electric capacity in the world last year.

The EU policy is heading more and more in this direction, regardless of possible future economic crisis, assuming climate neutrality in 2050 in all sectors and consolidating the current trends until 2030 in the European Green Deal formula supported by a new industrial strategy – a more strategic approach to RES and supply chains for this industry[15] (see Fig. 5).

Poland's consent to participate in the policy of "neutrality" becomes a necessity, although one must be aware of all the consequences associated with it. The assumptions of the Green Deal(GD) today include zero CO_2 emissions from the energy sector as early as 2040 (figure above), which is practically technically unattainable in Poland (regardless of the lack of adequate financial resources) – there must be a rational path of changes in the structure of the Polish energy sector in line with the goal of neutrality [13], [20] .

The European Green Deal in 2020 brings various effects for the Polish energy sector and the national economy.

Maintaining the necessity to change the energy-mix is a further necessity of the economy (regardless of the coronavirus problems). The attempt to count on a change in EU policy and some adjustment of GD conditions in the recession and coronavirus is rather illusory – EU changes, if there will be any, can only be short-term. Immediately after the return of relatively stable economic conditions – the issue of neutrality and GD will return even more intensively [13] [20] .

Poland cannot slow down the pace of negotiations with the EU (now is the time to find the key path of transformation) and it certainly cannot count on the fact that due to the crisis or recession the system may "stay as is" with a large role of coal. Coal must be replaced by renewable energy sources, it is only possible to negotiate an appropriate path – when and with what financial support [13], [20] .

There is a need to adopt Poland's energy policy to the European Green Deal and to strategically agree to the European "neutrality" (with the adoption of all positive and negative consequences). The key is to negotiate the most favourable conditions (along with the acceptance of the European Green Deal), which, in simple terms, consists in maximizing aid funds for transformation and minimizing CO_2 reduction obligations (over time). Technologies that will be realistically considered in the time horizon are large-scale offshore energy, onshore energy (in a sense, modernisation of existing facilities and development after the amendment of the 10h Act), large-scale photovoltaic (possibly using post-mining areas). Other technologies do not offer real possibilities (large-scale). By 2030, new generations of reactors, closed-cycle hydrogen economy and certainly the so-called clean coal technologies – should not be considered as investment options. This will cause additional problems in making political and managerial decisions, but it cannot be postponed in the face of other economic problems because it will result in the accumulation of negative phenomena in the energy sector in the future and possibly the complete failure of the sector [13], [20] .

Probably, one should only count on the possibility of transferring part of supplies (production) to our market (new structures of supply chains) and ensuring certain benefits due to the offshore energy and PV photovoltaics development program (and integrate this into investment development programs and negotiations with investors) [13], [20] .

Therefore, the first step to building an offer for locating industry in Poland is to create the own market – an investment plan in renewable energy sources, stable regulations, well-thought-out acts, and only then sector negotiations with selected partners and possible additional incentives for investments.

Soon (certainly by 2025), the manufacturing industry in Poland will have to prove the use of zero-emission energy sources for the production of products (any, not related to the energy sector) if it wants to export them to Western Europe. For this reason, investments in zero-emission sources are important not only for the energy industry associated with them but for industrial production in general.

Until 2030, with the gradual departure from carbon fuels caused by environmental pressure, gas technologies will play a significant role (as a bridge). They can partially replace the shrinking coal fuel base. In addition, employment/use of the constructed gas transmission and distribution system infrastructure will have to be found in view of gaining independence from direct gas supplies from Gazprom[13], [20] .

The role of gas is especially important for heating – cogeneration. In combined heat and power plants operating for the heating sector, an important role will be played by gas and steam units, which, due to their capacity, can be classified as large-scale sources (above 50 MW), taking into account the current legal regulations (up to 50 MW the MCP directive, above – the IED directive).

Following the previous classification, zero-emission energy is more likely to be sources connected to the grid/operating in distribution systems, larger ones – operating on the Polish Power Grid Company (PSE grid) [13], [20] .

3.2. The rational Energy mix 2030 for Poland and the technical conditions of large-scale zero-emission energy sources

With regard to the information presented previously, it appears that, the rational energy mix (electric power/electricity production, %) for Poland in the energy perspective 2040 is as follows (see Table 1):

- coal fuels – 41%/44%,
- gaseous fuels – 16%/20%,
- RES – 43%/36%.

With regard to renewable sources, the shares of individual carriers can be forecast, as follows:

- offshore wind – 20%,
- wind onshore – 28%,
- photovoltaics – 20%,
- biomass – 15%,
- biogas – 15%,
- water – 2%.

Table 1.Energy mix 2040, according to Polish Energy Policy PEP – 2040 in %, Source: own study

Tabela 1.Miks energetyczny 2040 według Polityki Energetycznej RP PEP – 2040 w %, Źródło: opracowanie własne

No.	Specification	Electric power,%	Electricity production,%
1.	Fossil fuels	41	44
2.	Gaseous fuels	16	20
3.	Wind onshore	19	17
4.	Wind offshore	10	12
5.	PV	12	6
6.	Others	2	1
7.	Total	100	100

Concerning the so-called hybrid technologies, due to the constant price pressure of zero-emission technologies in the energy sector and the low market price of energy, all hybrid concepts in Poland are unlikely to achieve the level of competitiveness in strictly generation energy applications, and certainly not in the perspective of 2030.

Extensive introduction of renewable units into the energy system is not neutral for the current network infrastructure – there is a need to expand it, and it also affects the operation of the network. In general – the new concept of the energy system – the transition towards a decentralized grid – is currently being implemented in the conceptual form and the first pilot experiments of microgrids. As a result, the energy system still operates as centralized (with all requirements – security, central management, reliability), but at the same time must bear the costs of reconstruction to take into account new types of sources.

It is not possible to freely connect new sources to the system – they must obtain a connection agreement. The number of units connected to the system is limited by the current state of the network and the operating state of the network.

3.3. Forecast summary

In July 2019, four legal acts entered into force, which are part of the EU's Clean Energy for All Europeans package, which is extremely important for the functioning of the common energy market. The regulations also significantly influenced the scope of competences and the role of regulators in creating the common market. From mid-2019, intensive work began on the implementation of individual provisions of the ordinances, in which the President of ERO actively participated both at the European Association for Energy Regulatory ACER level and fulfilling his competences with regard to the domestic market. A detailed description of the condition of the Polish energy market and the Regulator's activities for the development and proper functioning of the market and promoting competition is presented in detail in this report, submitted to the European Commission and ACER : Regulation (EU) 2019/941 of the European Parliament and of the Council of 5 June 2019 on risk preparedness in the electricity sector and repealing Directive 2005/89 / EC (Journal of Laws EU L 158/1) – Regulation 2019/941; Regulation (EU) 2019/942 of the European Parliament and of the Council of 5 June 2019 establishing the European Union Agency for the Cooperation of Energy Regulators (Journal of Laws UE L 158/22) – Regulation 2019/942; Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market in electricity (Journal of Laws UE L 158/54) – Regulation 2019/943; Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market in electricity and amending Directive 2012/27 / EU (Journal of Laws EU L 158/125) – Directive 2019/944 [5],[21].

The above-mentioned legal acts have very serious implications in setting directions for the development of the Polish power industry. Therefore, the issues presented in this section allow for a thesis that there is currently a need for energy market development the forecast of energy demand in a long-term perspective, preferably until 2050. Such a demand forecast should take into account the demographic situation, i.e. the decline in the population of people in Poland by 2050. As a rule, the current forecasts of electricity demand did not take this condition into account.

In the next part of the paper, the author took up this challenge, developing such a forecast of electricity demand in Poland on the basis of the proposed proprietary method and on the basis of available source materials on demographic issues [21].

4.Materials and Method

4.1.General remarks

In the electricity demand modelling processes, extrapolative econometric models can be useful. The idea of extrapolation models is developed by a class of cause-effect models based on the search for relationships between electricity demand and macroeconomic and demographic indicators, such as GDP, population, energy prices, etc. The models have a lengthy bibliography and are therefore not described in this paper. Generally, section 3 presents the original proposal to forecast electricity demand, using the relationship between electricity consumption per capita and the number of people based on the available source data [21].

4.2.Materials

The forecast of energy demand in a long-term perspective for Poland should take into account the demographic situation, i.e. the decline in the population of people in Poland by 2050. The source materials used in the research are presented in the Tables: 2,3 [21].

The forecast of the development of Poland's demography follows the trend visible in other countries of Central and Western Europe. The demand for electricity consumption per capita is significantly increasing, because it is related to the development of civilization in society.

4.3.Method

The method presented in the paper is an author's own method which, unlike previous methods, relates electricity consumption with social development. This enables to simply estimate the effects of social changes on the domestic energy industry in long-term scenarios. According to the assumptions of the proposed model, the factors responsible for electricity consumption are sociological factors that significantly affect the prediction results. The dynamics of electricity prices is of a secondary nature, for the average consumer who passively accepts changes in prices due to the desire to maximize the standard of living.

The method is based on the fact that assuming the forecasts of electricity consumption per capita, population projection(prepared by reliable research centres (CSO, Eurostat, UNO) in the formula

Table 2. Comparison of CSO population projection in Poland with Eurostat and UN projections in period 2020-2050
Tabela 2. Porównanie prognoz populacji GUS w Polsce z prognozami Eurostatu i ONZ w latach 2020-2050

No.	Projection	Population	2020	2025	2030	2035	2040	2045	2050
1.	CSO	million	38,138	37,741	37,185	36,477	35,688	34,817	33,951
2.	Eurostat	million	38,346	37,967	37,403	36,763	36,108	35,415	34,696
3.	UN	million	38,143	37,887	37,383	36,629	35,750	34,858	33,994
4.	Average	million	38,209	37,865	37,323	36,623	35,848	35,031	34,213

Table 3. Forecasting of electricity consumption per capita in Poland period 2020-2040
Tabela 3. Prognozowanie zużycia energii elektrycznej per capita w Polsce w latach 2020-2040

Year	Population, mln	Electricity consumption, kWh/per capita	Remarks
2020	38,209	4800	
2025	37,865	5000	
2030	37,323	5833	Slovenia level in 2018
2035	36,623	6448	EUR area level countries in 2018
2040	35,848	6553	EU average level countries in 2018
2045	35,031	6700	Ireland level in 2018
2050	34,213	6850	

of five-year time series, it is proposed to approximate these forecasts with the use of exponent functions, so that in the end (by convolution of component functions) one obtains the electricity demand function. The approximation model formulated in this way allows for the preparation of a forecast of electricity demand for a long-term perspective for each year.

It is assumed that the function of forecasting the electricity consumption per capita is an exponentially increasing function at the time t and can be determined by the formula:

$$F1(t)=A\cdot a^{\alpha t} \quad (1)$$

where: t – time, A – scale range parameter for the function of electricity consumption per capita,
a – basis to exponential increasing function (a> 1),
α – growth factor.
Substituting the data, one gets the following formula:

$$F1(t)=4{,}8\cdot 1{,}2^{0{,}07t} \quad (2)$$

It is assumed that the function of forecasting the population is an exponential declining function at the time t and can be determined by the formula:

$$F2(t)=B\cdot e^{-\beta t} \quad (3)$$

where: B – scale range parameter for the function of population projection,
β – reduction factor.
Substituting the data, one gets the following formula:

$$F2(t)=38{,}2\cdot e^{-0{,}004t} \quad (4)$$

Then, it is assumed that the functions for the function of electricity demand can be determined by the formula:

$$F(t)=F1(t)\cdot F2(t) \quad (5)$$

$$F(t)=A\cdot a^{\alpha t}\cdot B\cdot e^{-\beta t} \quad (6)$$

Substituting the data, one gets the following formula:

$$F(t)=4{,}8\cdot 1{,}2^{0{,}07t}\cdot 38{,}2\cdot e^{-0{,}004t} \quad (7)$$

$$F(t)=183{,}4\cdot 1{,}2^{0{,}07t}\cdot e^{-0{,}004t} \quad (8)$$

For the correctness of the approximation, it is required to use the least-squares method (LSM) based on the data in the Tables: 4-6, where calculational version v.1(as a result of simple component multiplication) and approximation version v.2 (as a result of approximation of previously determined functions) are presented.

Table 4.Electricity consumption per capita for calculational and approximation versions, Source: own study.

Tabela 4.Zużycie energii elektrycznej na mieszkańca w wersji obliczeniowej i przybliżonej, Źródło: opracowanie własne.

Year	Electricity consumption calculational version v.1, MWh/per capita	Electricity consumption approximation version v.2, MWh/per capita
2020	4,800	4,800
2025	5,000	5,100
2030	5,833	5,500
2035	6,448	5,800
2040	6,553	6,200
2045	6,700	6,600
2050	6,850	7,000

Table 5.Population projection for calculational and approximation versions, Source: own study.

Tabela 5.Prognoza populacji dla wersji obliczeniowej i aproksymacyjnej, Źródło: opracowanie własne.

Year	Population, calculational version v.1, mln	Population, approximation version v.2, mln
2020	38,209	38,200
2025	37,865	37,400
2030	37,323	36,700
2035	36,623	35,900
2040	35,848	35,300
2045	35,031	34,600
2050	34,213	33,800

Table 6. Electricity consumption for calculational and approximation versions, Source: own study.

Tabela 6. Zużycie energii elektrycznej dla wersji obliczeniowej i aproksymacyjnej, Źródło: opracowanie własne.

Year	Electricity consumption calculational version v.1, TWh	Electricity consumption approximation version v.2, TWh
2020	180,7	183,4
2025	189,3	191,6
2030	217,7	200,2
2035	236,1	209,1
2040	233,3	218,5
2045	243,7	222,3
2050	234,4	238,5

As a result of the usage of analytical algorithms, the results from Table 5 and 6 were obtained.

For the data compiled in the tables, the previously defined functions were verified using the LSM method procedures. As a result, high convergence was confirmed (high level of the correlation coefficient), which means that the functions were well chosen. The r squared computation was done ad hoc in the Gretl software.

4.4.Results and Discussion

Treating the calculation version v.1 and the approximation version v.2 as respectively: series 1, series 2, for the functional dependencies defined in this way, an approximation and calculation were made and the following results were obtained(see: Fig.6-8):

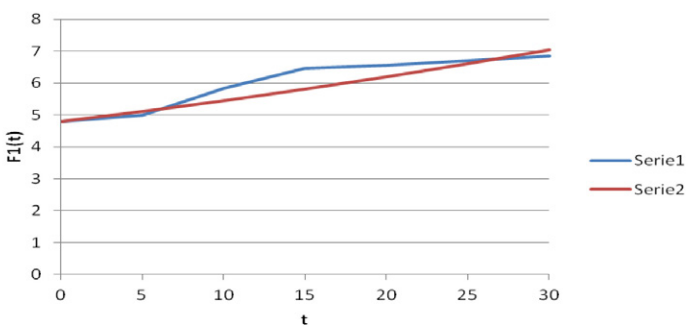

Fig.6. Forecasting of electricity consumption per capita in Poland, 2020-2040, Source: own study.

Rys.6. Prognozowanie zużycia energii elektrycznej per capita w Polsce w latach 2020-2040, Źródło: opracowanie własne.

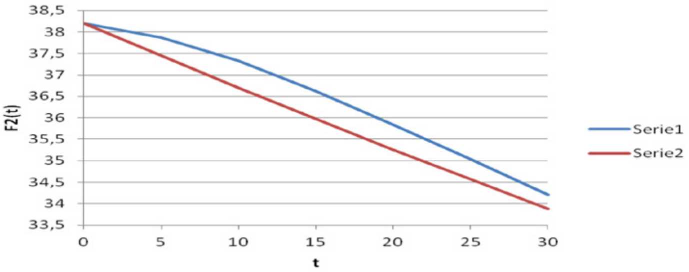

Fig.7. Population projection in Poland , 2020-2040, Source: own study.

Rys.7. Prognoza demograficzna w Polsce, 2020-2040, Źródło: opracowanie własne.

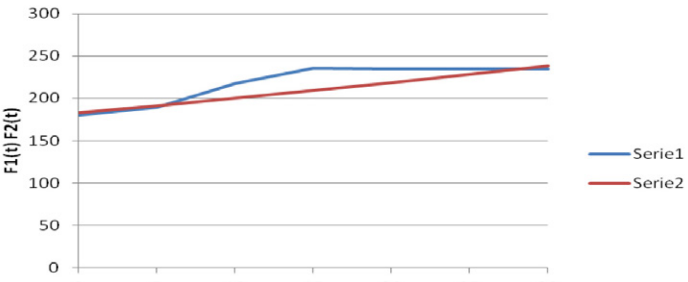

Fig.8. Forecasting of electricity demand in Poland, 2020-2040, Source: own study.

Rys.8. Prognozowanie zapotrzebowania na energię elektryczną w Polsce w latach 2020-2040, Źródło: opracowanie własne.

The electricity balance forecasting in Poland for 2020-2040 for calculational version v.1 and approximation version v.2, are presented in the Tables: 7,8.

In line with the development trend of the Polish energy sector presented earlier in the literature, the slow harmonization of Polish development plans with the EU is constantly observed, the following analyzes are extension of former considerations.

As it results from the presented results, the application of the proposed method allows to forecast electricity demand and electricity balance (according to version v.2) taking into account the demographic conditions for a long-term perspective, year to year. Thanks to this, one can more accurately make better plans for the development of the power industry.

5. Policy Implications and Conclusions

The paper presents the results of research on the main issues and dilemmas in planning the development of the power industry in the perspective of 2050. The electricity demand forecasting method was developed and positively verified, taking into account demographic conditions. This allows for better and more accurate planning of the development of the power industry, especially with regard to low-emission technologies.

Development of large-scale zero-emission energy in Poland should be made only in proven technologies e.g.:

- offshore wind energy program – realistic and crucial for achieving zero-emission shares in technologies and RES (4-6 GW up to the year 2030);
- increasing the possibilities of building onshore wind farms (realistic – 12 GW, optimally – even 18 GW);
- continuation and further rapid development of photovoltaics PV (both local and multi-system), possibly development and conversion of post-energy areas (12-16 GW);
- maintaining gas-fired energy as a transition technology to replace coal and necessary in heating.

It is necessary to be realistic without the strategy distracting:

- reactivation of coal or "clean coal technologies" (without this idea) is not possible;
- it is impossible to deny the Green Deal (without this idea);
- the possible development of nuclear energy is beyond the scope of consideration in the PEP 2040 (before 2035);
- there is no SMR/HTR capability before 2030 ;
- there is no possibility of significant development of the hydrogen economy (before 2030);
- it is not possible to develop energy storage on a larger scale – possibly after 2025;
- investments in transmission networks are required;
- the overall strategy must be linked to a realistic carbon transition programme.

One plan should be implemented paying attention to the key elements – here the OWF, timely investments and increasing the potential of the LFW and the continuation of PV.

Concerning the national context, this requires a significant improvement in the condition of the Polish energy sector. It will help strengthen the independence and international position of Poland, accelerate the economic development of the country, as well as increase the well-being of all citizens and future generations of Poles. The Polish raison d'etat requires that all activities related to the implementation of the state's energy policy be conducted with great prudence, determination and consistency, avoiding cyclical changes under the pressure of various internal and external factors. The recently announced Polish Energy Policy project until 2040 (PEP-2040) is of particular importance. It should be recognised

Table 7. Forecasting of electricity balance in Poland for 2020-2040 version v.1, Source: own study.

Tabela 7. Prognozowanie bilansu energii elektrycznej w Polsce na lata 2020-2040 wersja v.1, Źródło: opracowanie własne.

No.	Specification	Measure units	2020	2025	2030	2035	2040	2045	2050
1.	Production	TWh	170,2	179,1	187,9	229,7	237,7	239,7	240,1
2.	Imports (+)/ exports (-) credit	TWh	10,5	10,2	5,3	– 1,3	– 4,4	– 5,0	– 5,7
3.	Consumption	TWh	180,7	189,3	217,7	236,1	233,3	234,7	234,4

Table 8. Forecasting of electricity balance in Poland for 2020-2040 version v.2, Source: own study.

Tabela 8. Prognozowanie bilansu energii elektrycznej w Polsce na lata 2020-2040 wersja v.2, Źródło: opracowanie własne.

No.	Specification	Measure units	2020	2025	2030	2035	2040	2045	2050
1.	Production	TWh	171,5	182,5	212,4	237,4	239,5	243,9	261,6
2.	Imports (+)/ exports (-) credit	TWh	11,9	9,1	-12,2	-28,3	-21,0	-15,2	-23,1
3.	Consumption	TWh	183,4	191,6	200,2	209,1	218,5	228,7	238,5

that this is a document proposing a rational strategy for the development of the Polish energy sector. In the author's opinion, new rational methods of energy demand forecasting will be needed in the planning processes and strategic studies of the Polish energy sector development. The dilemmas discussed and the new forecasting method presented in the paper may be useful and beneficial for the implementation of the power industry development program in Poland.

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