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ENERGY SECURITY AND EFFICIENCY – POLAND'S POWER SECTOR CASE

Abstract

Ensuring a nation's energy security is crucial to its overall functioning. The current geopolitical realities have clearly undermined the energy stability of many European countries, including Poland. Moreover, the complicated international situation has made the process of modernization and energy transformation difficult. Poland has been implementing decarbonization for many years, which involves the gradual abandonment of hydrocarbons in favor of low- and zero-emission energy sources. One of the initiatives strengthening energy security is also increasing the efficiency of the power sector. In this case, not only the modernization and reconstruction of the electricity generation structure, but also the transmission grids are necessary. Reducing the energy intensity of the economy remains an important priority of the energy policy not only for Poland but also for every developing country. This paper aims to explore the Polish electricity sector in relation to its significance for national security and the urgent requirement to boost energy efficiency in the years ahead. The findings suggest that establishing new energy sectors is essential; without dynamizing modernization and decarbonization of the power sector, achieving a stable and efficient energy system will be difficult to achieve.

Keywords: energy security, energy efficiency, Poland, power sector, energy transformation

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INTRODUCTION

Energy transformation is a serious challenge not only for Poland but also for many other countries that are characterized by an outdated energy system. In such countries, the energy sector is often based on one dominant source, which is fossil fuels. In Poland, coal has been such a source for decades, and in recent years, it has provided as much as 60-70% of electricity production (Dusiło 2024, 35). Unfortunately, coal is becoming unprofitable, especially in the context of the EU's climate policy being implemented. Poland has been decarbonizing its energy sector for many years now, but these actions are too slow. It must not be forgotten that this is due to the fact that Polish coal resources are very large, and the coal industry is well-developed. Thus, coal was and still is the most important source for the power industry and the country's energy security. Maintaining high coal production is associated with decreasing efficiency, which is why the Polish energy strategy indicates the need for a deep reconstruction of the electricity generation structure. Initially, decarbonization is to take place by increasing the consumption of natural gas, and then coal and other fossil fuels are to be reduced in favor of renewable energy sources. The leading role in this process is to be played by wind energy, especially offshore, but also by another sector that does not exist yet – nuclear energy. Investments under consideration will contribute to improving energy security and promoting energy efficiency in Poland.

This paper aims to explore the Polish electricity sector in relation to its significance for national security and the urgent requirement to boost energy efficiency in the years ahead. The findings suggest that establishing new energy sectors is essential; without dynamizing modernization and decarbonization of the power sector, achieving a stable and efficient energy system will be difficult to achieve.

The first part of the article refers to the theoretical aspect of the energy security and efficiency concepts. Then, the current state of the Polish power industry is discussed, with an emphasis on the structure of electricity generation and challenges resulting from its operation. The next part of the text refers to improving energy efficiency in the context of security in the power sector in Poland. Attention is drawn to key projects aimed at ensuring energy security while increasing efficiency in the process of transformation of the Polish energy sector.

ENERGY SECURITY AND EFFICIENCY – THEORETICAL BACKGROUND

Energy security has recently become an important field of national activity. In this context, we cannot forget that awareness of society increases and, therefore, the pressure on political makers grows. Therefore, authorities in individual countries are taking intensive measures to ensure the proper functioning of the economy. It is obvious that without effective power engineering, the state is unable to carry out its tasks. With the above in mind, it is essential to make a few theoretical remarks relating to energy security. In scientific and specialist literature, one can find many definitions of the above concept, and their differentiation is the result of a multidimensional approach. When short-term perspectives are taken into account, issues related to the risk of interruption of energy carrier supplies by major producers are evaluated, among other things. It is defined differently in the scope of discussions on long-term issues, such as the depletion of raw material reserves and the increase in their prices. In this connection, it should be emphasized at the outset that there is no single universally accepted definition of energy security. This concept is so broad that it would be highly difficult and also pointless to attempt to capture it in some synthetic, universal form. Nevertheless, one can identify many valuable attempts to explain what energy security is. It is most often defined as providing energy in the right quantity and quality at economically justified prices (Yergin 1988, 111; Kalicki and Goldwyn 2005, 9; Bordoff, Deshpande, and Noel 2009, 214; Hebda 2019, 17–24). At this point, it is also worth referring to the definition proposed by the International Energy Agency (IEA), in the light of which energy security is understood through the implementation of the so-called four factors: availability (the ability to ensure constant and sufficient access to energy, both quantitatively and qualitatively), affordability (ensuring that energy costs are at a level that makes it accessible to all social and economic groups), acceptability (the ability to meet social needs and expectations in the field of energy security) and responsibility (ensuring the responsibility of countries and other entities in the energy sector for their actions and decisions in order to ensure security) (Strojny *et al.* 2023, 11).

It is worth noting that in recent decades, special attention has been paid to environmental protection, which also reflects European tendencies to perceive energy security through an ecological prism.

This view is consistent with the European Green Deal, in which energy security is understood as the provision of clean and affordable energy (European Commission [EC] 2019). This is not a universal concept because there are many countries that place particular emphasis on the economics (profitability) of their energy sector, ignoring threats to the natural environment. Undoubtedly, energy security in the 21st century will continue to be understood from the perspective of realizing the vital interests of individual countries, which is why it will be difficult to ensure it from a regional, and even more so global, perspective.

Energy efficiency is defined as the ratio of obtained results, services, goods, or energy to energy input (European Parliament, Council of the European Union [EP, CEU] 2012). Efficient use of energy aims to reduce the amount of energy needed to provide products and services. In other words, reducing energy consumption and reducing energy losses are the main goals of energy efficiency, and improving energy efficiency consists of increasing the use of final energy thanks to technological, economic, or behavioral changes of all energy users (Gillingham, Newell, and Palmer 2009, 597–600). Energy efficiency is a concept with a broad meaning and can apply to both energy consumers and producers. The most popular projects in the field of increasing energy efficiency by energy recipients include, among others, modernization of heating installations, heat recovery from industrial processes, modernization of heating boilers, thermal modernization of buildings, energy-efficient lighting of rooms and public spaces, energy-saving devices, electrification of vehicles. In the case of energy producers, we are talking primarily about electricity, which is why efficiency is understood as reducing losses incurred in the process of its production and distribution. In this context, energy efficiency is associated not only with the modernization of power plants and transmission grids but, above all, with increasing the share of low-emission or zero-emission sources in electricity production (Jaffe, Newell, and Stavins 2004, 79–83). This means decarbonization, i.e., abandoning fossil fuels in favor of renewable energy sources and nuclear energy. As can be seen, similarly to the case of energy security, energy efficiency (especially in highly developed countries) is understood through the modernization of the energy sector towards modern technologies that are conducive to the natural environment.

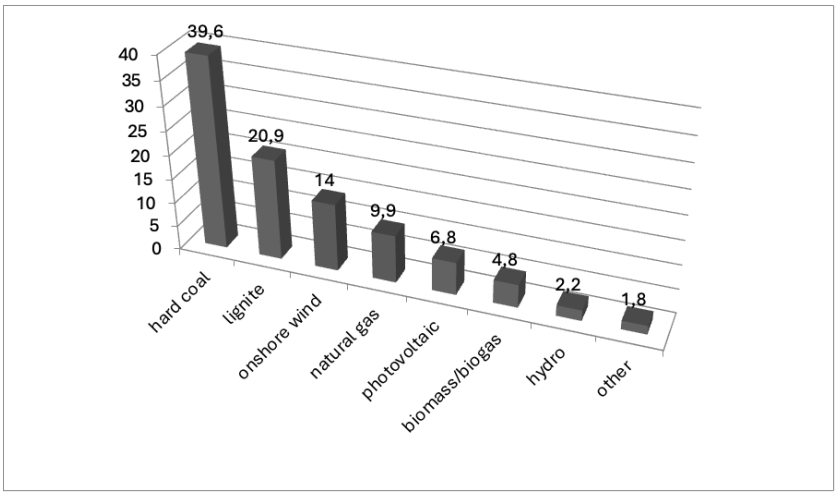
POLAND'S POWER SECTOR – CURRENT STATUS

Poland has been modernizing its power sector for many years, primarily in the direction of increased diversification of strategic fossil fuels (Hebda 2021, 3; Wierzbowski, Filipiak, and Lyzwa 2017, 55–59). During this period, significant dependence on the Russian Federation was noticeable, which is why intensive investments were made in infrastructure that would allow for greater diversification of suppliers of oil and natural gas (Hebda 2022, 177–182). The opening of the LNG terminal in Świnoujście in 2016 and the systematic increase in the transshipment capacity of Naftoport in Gdańsk were certainly of key importance for the diversification of hydrocarbon supplies. Thanks to these investments, Poland could import natural gas and crude oil from any country by sea. Despite the growing number of investments in the fossil fuel sector and renewable energy sources (RES), the Polish power industry at the end of 2023 was still characterized by the dominance of coal. This raw material (hard coal and lignite) accounted for as much as 60.5% of electricity production (Dusiło 2024, 33). However, it should be noted that over the last dozen or so years, the use of coal has generally been decreasing (in 2010: 86.6%, in 2021: 71.2%) (Ministerstwo Klimatu i Środowiska, Agencja Rynku Energii S.A. [MKS, ARE] 2022, 71). The opposite trend can be seen in the natural gas sector, which met about 10% of electricity demand in 2023 (Dusiło 2024, 33). Natural gas consumption has increased significantly compared to previous years, not only in the power industry but also in households (which is a result of intensive gasification and the replacement of coal boilers with gas boilers). Unfortunately, Polish natural gas resources can only meet about 20% of demand, which is why the remaining quantities are imported (until 2022, mainly from Russia, currently from Norway, Qatar, and the USA) (Hebda 2024, 2–4). In terms of fossil fuels, we cannot forget about crude oil, which, although not used by Polish power plants (apart from the CHP plant in Płock), is a key raw material for transport.

Poland's energy transformation is taking place not only through the increased use of natural gas but primarily through renewable energy sources, which are to replace fossil fuels in the next few decades (Hassan, Manowska, and Kienberger 2025, 654–657). The dynamics of the green energy sector are evidenced by the fact that in the energy mix in 2011, it accounted for less than 10% (Główny Urząd Statystyczny [GUS] 2012, 62), while in 2023, it was already 25% (GUS 2024, 30). The largest increase in

generating capacity was achieved in wind energy (especially in the years 2010-2016) and solar energy (after 2018) (GUS 2021, 37). In 2023, onshore wind farms provided 14%, photovoltaics 6.8%, biomass, and biogas (including biomass co-firing) 4.8%, and hydropower plants (including pumped-storage) 2.2% of electricity (Dusiło 2024, 33). Undoubtedly, the greatest contribution to the development of green energy was made by investments in wind energy, which is a consequence not only of technological progress but also of the considerable potential located in Poland (Hebda, Leśniak, and Stolorz 2025, 197–199).

Figure 1. Structure of electricity generation by source in 2023 (in percent)



Source: author based on (Dusiło 2024)

IMPROVING ENERGY SECURITY AND EFFICIENCY IN THE POWER SECTOR OF POLAND

In relation to the climate and energy goals for 2030, the European Union has maintained the priority importance of energy efficiency, committing to 32.5% energy savings at the EU level compared to forecasts, with different contributions from Member States (EP, CEU 2018). Poland belongs to the group of countries that, due to the electricity sector still dominated by the coal sector, need more time to transform. Based on the analysis of the effects and impact on GDP and the savings potential, the Polish energy policy has set a national target for improving energy efficiency by 2030 at the level of 23% in relation to the forecasts of

primary energy consumption developed by the European Commission in 2007 (Ministry of National Assets [MNA] 2019, 29). It is worth noting here that the Polish economy has recorded a reduction in energy intensity by approx. 30% over the last three decades (Ministry of Climate and Environment of the Republic of Poland [MCERP] 2021a, 74).

Improving energy efficiency also indirectly affects energy security due to the reduced demand for fuels and energy and the import of raw materials. The undertaking of pro-efficiency activities has been proven to result in a reduction of energy consumption and more flexible utilisation of energy resources. The priority goal is to minimize the impact of the energy sector on the environment by reducing emissions of pollutants and greenhouse gases, reducing the exploitation of domestic resources, and reducing waste and their reuse in a circular flow (MNA 2019, 21–50). In the power sector, it is assumed that the efficiency of existing conventional sources will be improved, as well as the efficiency of electricity generation and distribution (Khatib 2012, 334–339). In addition, there are plans to increase production from renewable energy sources, but also from distributed energy sources. Energy storage and the use of intelligent solutions will be of great importance (Lepszy 2020).

One of the pillars of Polish energy policy, among others in the scope of improving efficiency, is to achieve a low-emission energy system understood by reducing its emission intensity. Thus, it is planned to implement nuclear energy and offshore wind energy and increase the role of distributed energy while ensuring energy security through the transitional use of energy technologies based on, among others, natural gas (Hebda 2021, 5–6; 17).

In order to implement the above-mentioned process, it is necessary to expand the electricity generation and grid infrastructure. In this respect, Poland will strive to meet its energy demand with its own resources wherever possible. Although domestic coal deposits will remain an important element of Poland's energy security, the increase in demand will be covered by sources other than conventional coal-fired power. "The share of coal in the structure of energy consumption will reach no more than 56% in 2030, and with increased prices of CO_2 emission allowances, it may even drop to 37.5%" (MCERP 2021a, 8). Ultimately, coal will be completely phased out by 2050, but this is dependent on the geopolitical situation. The development of renewable energy sources, with a particular focus on photovoltaic and wind energy, will be key to decarbonisation. The level of RES in the structure of domestic electricity consumption will

be no less than 32% in 2030, but the implementation of this goal must be correlated with the development of network infrastructure, energy storage technologies, and the expansion of gas units (MNA 2019, 26–28). The implementation of nuclear energy in the 2030s will certainly be of great importance in this respect. As a result of the investment, an electricity system will be built based on low- and zero-emission sources (MCERP 2021a, 8).

As mentioned earlier, the implementation of nuclear energy is assumed to be part of the scope of the expansion of the electricity generation infrastructure. Thus, this issue has once again found itself among the goals of the Polish energy policy (previously in the Energy Policy of Poland until 2030). It is worth adding that the first attempts to launch the nuclear sector in Poland date back to the 1970s and 1980s. After the Chernobyl disaster in 1986, the construction of the first nuclear power plant in Żarnowiec was suspended, and this investment was not resumed. The current nuclear energy development program assumes the commissioning of 6 nuclear units by 2043. The planned launch of the first nuclear unit has been set for 2035 (originally, it was supposed to be 2033); however, due to the current delays related to the start of the investment, it is indicated that this date will be postponed to the second half of the 2030s. The launch of new production capacities involving nuclear power plants will allow for balancing Polish electricity needs in connection with the decommissioning of coal-fired power plants. As a result, the stability of electricity generation will be ensured, and importantly, with zero air pollution emissions. A significant part of the nuclear program will be implemented with the participation of Polish companies (Hebda and Mišík 2024, 9–10).

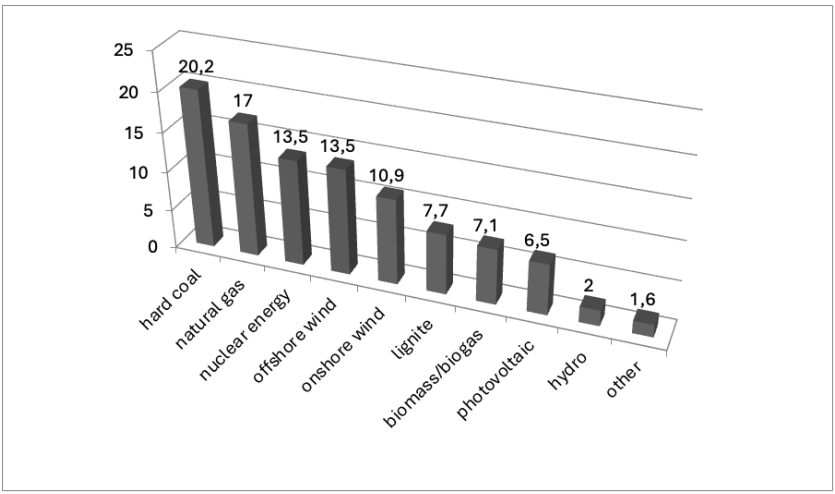
Certainly, another goal, which is the development of renewable energy sources, is of great importance in the context of achieving zero-emission energy. From a technological point of view, the growth in the importance of green energy is to be ensured primarily by offshore wind farms (Sawulski, Gałczyński, and Zajdler 2019) and photovoltaics (Błaszczyk, Matuszak-Flejszman, and Nawrocki 2024). The focus on these two sources is indicative of Poland's potential in the field of wind and solar energy, which is more advantageous than other renewable energy sources, such as geothermal energy. It is also worth mentioning here that thanks to RES, it will be possible to achieve a higher level of distributed energy (through the development of local infrastructure),

which will relieve the currently functioning centralized energy and affect its higher efficiency (MCERP 2021a, 10).

The flagship project will be the implementation of Baltic Power, which involves putting into operation one of the largest offshore wind farms in Europe. This investment includes the construction of 76 wind turbines with a total capacity of 1.2 GW at a distance of approx. 20 km from the coastline of the Baltic Sea. It is worth emphasizing that the generation capacity of offshore wind farms is planned to increase to 11 GW by 2040, which will significantly "increase the share of renewable energy sources in the energy mix" (Nawrot and Manowska 2024, 6). Photovoltaics is being developed in parallel, and its current potential is already over 21 GW, but due to its very large dispersion (micro-installations constitute approx. 19 GW) and low efficiency (resulting from the lack of an appropriate transmission grid and limited energy storage capabilities), it generates relatively small amounts of electricity (Rynek energetyczny 2025). Thus, it is planned to put emphasis on investments in medium and large solar power plants. In addition, taking into account the huge potential of agriculture and forestry, the development of the biomass sector will be accelerated (Wyszomierski *et al*. 2025, 15). Currently, wood biomass and agro biomass are used, among others, in combined heat and power plants, especially in small and medium-sized installations.

The Polish energy policy until 2040 predicts that the power sector will undergo a profound transformation in the next fifteen years. In fact, coal will still be an important source (totalling about 28% of electricity generation) in 2040, but not at the current high level (Sobczyk and Sobczyk 2021, 11). The importance of natural gas will increase (17%); however, considering the current EU policy towards this raw material, it may turn out that the development in this sector will not be as impressive (Hebda 2024, 11). Two emerging energy sectors, namely offshore wind farms and nuclear power plants, are poised to assume paramount significance in the energy transition. These sectors are projected to contribute 13.5% to the total decarbonization efforts, underscoring their potential role in shaping the energy landscape. In the remaining sectors, it is assumed that the potential for electricity generation will be maintained, i.e., onshore wind turbines (10.9%), biomass (7.1%), and PV installations (6.5%) will support the Polish transformation of the power industry (MCERP 2021b, 24). Developing a more diversified structure of electricity generation will ensure the security and stability of the country, but will also significantly increase energy efficiency.

Figure 2. Planned structure of electricity generation by source in 2040 (in percent)



Source: author based on (MCERP 2021b, 24)

The expansion of the transmission infrastructure is also of great importance for the efficiency of the energy sector, which will allow the evacuation of power from existing and new sources (including wind and nuclear power) and improvement of the reliability of supply, as well as the increase of the possibilities of cross-border exchange while maintaining the principle of self-sufficiency of generating capacity in Poland (Dołęga 2018, 95–100). Developments in distribution systems, such as grid reconstruction and medium-voltage network cabling, will improve the quality of supplies to end consumers. This means that energy supply interruptions will be shorter. In addition, investments will contribute to the gradual transition of the passive (one-way) grid into an active (bi-way) network (MCERP 2021a, 9).

In order to enhance the efficacy of operations in emergency scenarios, a digital communication system between distribution system operators is to be established. Furthermore, the infrastructure is to be equipped with control devices. In addition, smart power grids will be implemented to integrate the behaviors and activities of all entities and users connected to them (MCERP 2021a, 9). The necessity for the development of energy storage technologies is becoming increasingly apparent for three principal reasons. Firstly, the volume of RES connected to the distribution and transmission grid is growing. Secondly, the

importance of distributed energy is growing. Thirdly, the profile of electricity consumption is changing, including the development of electromobility (MCERP 2021a, 44). Energy storage is a key component in the integration of RES with the power grid (Denholm *et al*. 2010). Renewable energy, like solar or wind energy, is often unstable and variable depending on weather conditions. Energy storage allows for capturing surplus energy generated during periods of intense sunlight or strong wind. The use of energy storage from renewable sources includes various technologies, e.g., electrochemical batteries (lithium-ion, lead-acid), which store energy in the form of chemical energy in a battery or pumped hydroelectric power plants, which use excess energy to pump water to a reservoir located at a higher level, and when necessary, this water flows back through turbines (Pawłowicz and Jasinowski 2025). Considering the underdeveloped hydropower industry in Poland and the large dispersion of renewable sources, batteries are a more effective source of energy storage.

When considering the issue of energy efficiency, the hydrogen sector cannot be ignored. The Polish hydrogen strategy until 2030, with a perspective until 2040, involves establishing a hydrogen economy from scratch. This will be achieved by implementing hydrogen technologies in the energy and heating sectors, supporting the decarbonisation of industry, and providing an alternative fuel for transport (MCERP 2021c, 3–4). Currently, projects are being implemented to increase the use of hydrogen in transport, including the purchase of hydrogen buses for public transport. In the coming years, the aim of the project will be to create so-called hydrogen valleys, which will allow the construction of a comprehensive hydrogen economy through the production, transport, storage, and final use of hydrogen in industry. Investment projects will be carried out in the valleys, which will contribute to cooperation between local, national and foreign stakeholders (Dowejko 2023, 1922–1926).

CONCLUSIONS

Ensuring energy security in the current geopolitical realities is a significant challenge for most European countries. It should be noted that energy security is associated with the need to transform the power sector, which in the case of many countries is related to decarbonization. This means reducing the consumption of hydrocarbons, i.e., coal, oil, and natural gas in favor of low- or zero-emission energy

sources. Systematic improvement of energy efficiency is certainly also crucial in the modernization process. It will not only reduce energy consumption (energy intensity of the economy) but also reduce energy losses (especially in the distribution of electricity). Poland is one of the countries experiencing profound economic and social changes in recent years. The energy transformation has clearly accelerated, which has increased the threat to maintaining the stability of the power sector. Particular attention is being paid to balancing the generating capacities of Polish power plants. This is the result of the consistent withdrawal from coal in connection with the development of renewable energy sources and planned nuclear power. Hydrocarbons will continue to be an important source for the Polish power industry over the next two decades, but their role will clearly decrease. It seems that investments in wind energy and the launch of a new sector – nuclear energy – are to be the most important undertakings towards ensuring security and increasing energy efficiency. To this end, it is necessary to expand the transmission grids, increase the capacity for energy storage and put hydrogen valleys to use. Achieving the assumed goals will certainly strengthen the Polish power sector, especially in the context of growing social needs and political and economic uncertainty in the region.

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ЕНЕРГЕТСКА БЕЗБЕДНОСТ И ЕФИКАСНОСТ – СЛУЧАЈ ПОЉСКОГ СЕКТОРА ЕЛЕКТРИЧНЕ ЕНЕРГИЈЕ

Резиме

Обезбеђивање енергетске безбедности једне нације је кључно за њено целокупно функционисање. Тренутне геополитичке реалности су очигледно поткопале енергетску стабилност многих европских земаља, укључујући и Пољску. Штавише, компликована међународна ситуација је отежала процес модернизације и енергетске трансформације. Пољска већ годинама спроводи декарбонизацију, што подразумева постепено напуштање угљоводоника у корист извора енергије са ниским и нултим емисијама. Једна од иницијатива за јачање енергетске безбедности јесте и повећање ефикасности електроенергетског сектора. У овом случају, неопходна је не само модернизација и реконструкција структуре за производњу електричне енергије, већ и преносних мрежа. Смањење енергетског интензитета привреде остаје важан приоритет енергетске политике не само Пољске, већ и сваке земље у развоју. Овај рад има за циљ да истражи пољски електроенергетски сектор у односу на његов значај за националну безбедност и хитну потребу за повећањем енергетске ефикасности у годинама које долазе. Резултати сугеришу да је успостављање нових енергетских сектора неопходно; без динамизације модернизације и декарбонизације електроенергетског сектора, постизање стабилног и ефикасног енергетског система биће тешко постићи. Енергетска ефикасност у пољском енергетском сектору је кључни елемент у тежњи ка одрживом развоју и смањењу емисија, али и безбедности у ширем смислу. Тренутни енергетски систем Пољске углавном се заснива на фосилним горивима, посебно домаћем угљу, који задовољава већину енергетских потреба земље. Стога ће се повећање енергетске ефикасности у овом сектору током наредне две деценије одвијати кроз систематско смањење потрошње угља. У случају природног гаса, предвиђа се његова употреба као

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горива за стабилизацију пољског енергетског сектора. Процес декарбонизације повезан је са потребом пуштања у рад нових енергетских капацитета. У овом аспекту, кључна инвестиција биће изградња нуклеарне електране (у 2030-им) и повећано коришћење обновљивих извора енергије. Што се тиче зелене енергије, највећи потенцијал у Пољској представља енергија ветра, стога је стратешка инвестиција изградња приобалне ветроелектране и повећање капацитета копнених ветроелектрана. Од мањег значаја је соларна енергија или биомаса. Горе наведене инвестиције су неопходне не само да би се осигурала стабилност и ефикасност енергетског сектора, већ пре свега енергетска безбедност земље.

Кључне речи: енергетска безбедност, енергетска ефикасност, Пољска, сектор електричне енергије, трансформација енергије[2]

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