GOSPODARKA SUROWCAMI MINERALNYMI – MINERAL RESOURCES MANAGEMENT

2019 Volume 35 Issue 4 Pages 113–134

DOI: 10.24425/gsm.2019.128538

PRZEMYSŁAW KASZYŃSKI[1], ALEKSANDRA KOMOROWSKA[2], JACEK KAMIŃSKI[3]

Regional distribution of hard coal consumption in the power sector under selected forecasts of EUA prices

Introduction

An increase in the volume of electricity generation has recently been observed in Poland (Fig. 1). The total production grew from 162.5 TWh in 2013 to 165.21 TWh in 2018. Hard coal-fired power plants play a key role in the domestic power generation system. Although their share has decreased, 49.86% of electricity was produced in hard coal-fired power plants and 29.7% in brown coal-fired units in 2018 (PSE 2019). Steam coal consumption in the domestic power generation sector amounted to approximately 40 thousand Mg, including hard coal consumed in public power plants of 27 thousand Mg in 2017 (ARE 2018). The remainder is used in:

✉ Corresponding Author: Aleksandra Komorowska; e-mail: komorowska@min-pan.krakow.pl
[1] Mineral and Energy Economy Research Institute of the PAS, Kraków, Poland; ORCID iD: 0000-0002-0600-4374; e-mail: kaszynski@min-pan.krakow.pl
[2] Mineral and Energy Economy Research Institute of the PAS, Kraków, Poland; ORCID iD: 0000-0002-9604-1071; e-mail: komorowska@min-pan.krakow.pl
[3] Mineral and Energy Economy Research Institute of the PAS, Kraków, Poland; ORCID iD: 0000-0001-7514-8761; e-mail: kaminski@min-pan.krakow.pl

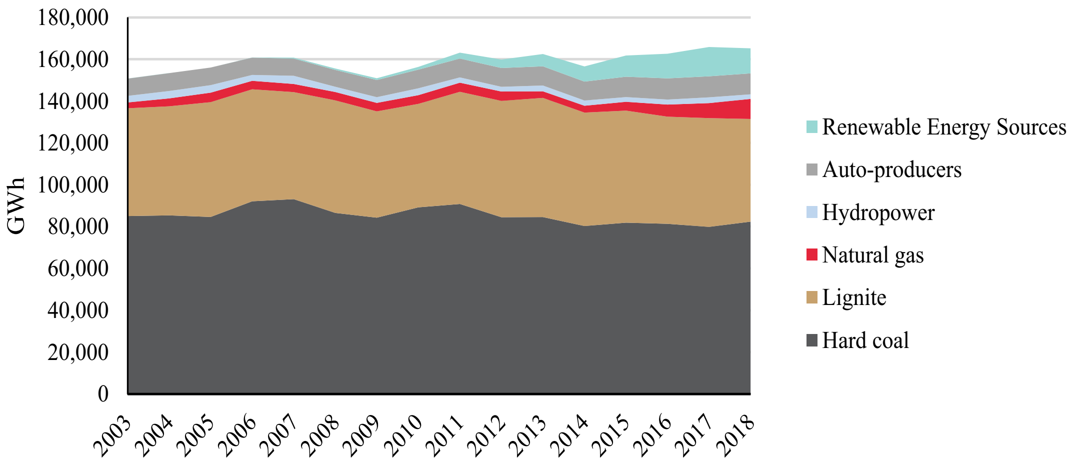

Fig. 1. Power generation mix in Poland in 2003–2018, GWh
Source: Own analysis based on (PSE 2004–2019)

Rys. 1. Produkcja energii elektrycznej w latach 2003–2018, GWh

- public combined heat and power plants,
- public and non-public heating power plants,
- industrial power plants.

The detail information on the current state of the energy sector and hard coal mining sector in Poland is presented in (Gawlik 2018).

Due to the fact that hard coal plays a key role in power generation, changes in the power sector have a direct impact on the coal-mining sector (Chiodi et al. 2013; Fereira et al. 2012; Gawlik and Mokrzycki 2019; Kamiński 2009; McGovern and Hicks 2004). The main changes that take place in the power sector can be classified in the following groups: technological, economic, environmental.

However, as the power generation sector is a complex system, all changes that can be classified into one category affect others. The main changes in the Polish power generation system affecting the mining sector are as follows: global fuel prices (Kamiński 2019), renewables development (Augustyn and Kamiński 2018), the introduction of the capacity market (Komorowska and Kamiński 2018; Zamasz et al. 2014), development of energy storage technology (Augustyn et al. 2019; Lezynski et al. 2019), development of electromobility (Drożdż and Starzyński 2018), policy regulations (Kamiński 2014; Szurlej et al. 2013), etc.

One of key elements of the environmental category that directly affects the volume of coal consumption in the power sector is the EU Emission Trading System (EU ETS) that obliges power generators to purchase allowances for emitted greenhouse gases. Consequently, the change in prices of European Emission Allowances (EUAs) affects the power sector, in an economic, as well as a technical and environmental way. An analysis of global experience leads to the conclusions that the research on this impact has been already carried out in various countries. Rečka and Ščasný (2016) pointed out that EUA prices have a significant impact on the energy mix in the Czech Republic. Falbo et al. (2013) discussed the results of analysis based on the modelling approach and proved that the grandfathering of allowances may change the fuel-mix towards more polluting technologies in Italy and Germany. Jaskólski (2016) analyzed the impact of the EU ETS on technologies deployed in the Polish power generation system.

As the level of hard coal consumption in Poland is significant and mostly region-dependent, it is worth examining the long-run implications of changes in EUA prices on its regional distribution. In this context, the main objective of this paper is to estimate the regional distribution of hard coal consumption in the long-term perspective (2020–2040) under selected forecasts of EUA prices. This analysis aims to identify regions where coal-fired units may be mothballed due to high EUA prices earlier than it is forecasted based on an expected technical lifetime. Three scenarios are developed for this study:

- the first scenario mimics low EUA prices (average price of EUAs in 2014–2017),
- the second scenario reflects a slight increase in EUA prices (accordingly to the NPS scenario published in the World Energy Outlook (IEA 2018)),
- the third scenario that simulates a significant increase in EUA prices (accordingly to the SDS scenario published in the World Energy Outlook (IEA 2018)).

The results contribute to the literature in the following ways: methodology of the impact assessment of EUA prices on hard coal consumption, methods based on a model approach to develop a regional distribution of hard coal consumption, analyses of long-run hard coal consumption in fossil fuels-based power sectors.

In this study we consider only existing, modernized, under-construction and announced coal-fired power generation units.

The remainder of the paper is organized as follows. Section 1 presents the design of the EU ETS. The model employed, scenario assumptions and data used in this paper are described in Section 2. The results are presented and discussed in Section 3. The last section draws main findings and conclusions.

1. European Emissions Trading System

The European Emissions Trading System is the most wide-reaching carbon market in the world. It has been in place since 2005 and the main objective of its operation is the effective reduction of greenhouse gases (GHG) emission by 20% until 2020 (compared to the 1990 level) (Directive 2003/87/EC). This market covers thirty-one countries (all Member States, Iceland, Liechtenstein and Norway) and approximately 45% of greenhouse gas emissions produced in these countries.

The EU ETS is a ‘cap and trade’ system; the magnitude of the cap is set as the volume of GHG that may be emitted (the volume of emission allowances is reduced over time).

Generators and other companies receive or buy allowances, which can then be traded on the competitive market. At the end of each year, every generator is obliged to surrender such a number of allowances that covers the total volume of its emissions. Companies that fail to comply with this obligation are obliged to pay a fine.

The operation of the EU ETS can be divided into four phases (Fig. 2). The first phase was considered the pilot phase. Its main objective was to develop appropriate infrastructure, monitoring and testing tools and to examine the functioning of the market. Approximately 95% of emission allowances were grandfathered to the companies. Due to the fact that: the number of EUA allocated was too high, the companies could not transfer them to the next phase,

the EUA price reached zero at the end of the first stage. In the second phase, the total number of emission allowances was reduced by 6.5% compared to the first phase. However, approximately 90% of allowances were also grandfathered. The end of the second phase was also characterized by an oversupply of allowances, which resulted in a significant drop in prices. The design of the third phase was shaped on the basis of conclusions drawn from the two previous phases. The main changes were as follows:

- the abolition of national emission limits and their replacement by a common cap at the EU level,
- purchasing all allowances in the auction system.

Free allowances are allocated only in the case of modernization of power generator systems. Poland is one of the eight countries that benefit from this derogation; 70% of the average annual volume of emissions in 2005–2007 are grandfathered in the third phase. The European Commission confirms that the operating of EU ETS will continue after the third phase (EC 2015).

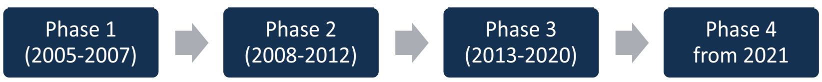

Fig. 2. Duration of phases of the EU ETS

Rys. 2. Czas trwania poszczególnych faz Europejskiego Systemu Handlu Uprawnieniami do Emisji CO_2

The prices of EUA in the third phase are presented in Fig. 3. A sharp increase has been observed since 2018. The maximum price in 2019 has amounted to EUR 29.46/Mg CO_2.

The Polish power generation system is particularly sensitive to changes in the EU ETS because the energy sector generates a large volume of greenhouse gases, especially carbon dioxide. Fig. 4 presents the production of carbon dioxide in Poland in 2008–2017 and the average CO_2 emissions in the European Union. In this case, approximately 93% is emitted by the energy sector. The volume of carbon dioxide generated in Poland significantly exceeds the EU28 average. The presented results confirm the validity of research on the impact of EUA prices on hard coal consumption in the Polish power generation system.

Fig. 3. EUA prices in 2013–2019, EUR/Mg CO_2
Source: own analysis based on (CIRE 2019)

Rys. 3. Ceny uprawnień do emisji CO_2 w latach 2013–2019, EUR/Mg CO_2

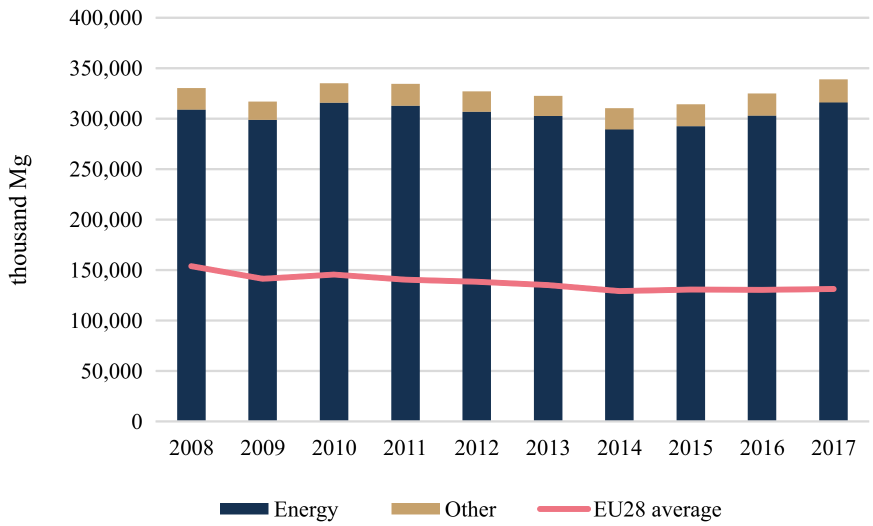

Fig. 4. CO_2 emissions in Poland in 2008–2017, thousand Mg
Source: own analysis based on (Eurostat 2018)

Rys. 4. Emisja CO_2 w Polsce w latach 2008–2017, tys. Mg

2. Methodology

2.1. Model description

The methodology that was applied to investigate the regional distribution of hard coal consumption in the Polish power generation system under selected forecasts of EUA prices originates from the systems analysis and operational research. Two long-run models are applied for this investigation in order to:

- estimate the level of hard coal consumption in the power sector under various EUA price forecasts,
- calculate hard coal supplies to different regions of Poland (NUTS-3 level), based on both, hard coal consumption of individual power generation units (estimated in the previous stage), as well as the fuel quality requirements of these units.

In the first stage, the PolPower_LR is applied, which is a bottom-up, long-run model of the Polish power generation system, developed with the employment of the Linear Programming (LP) approach. The model allows one to flexibly change the time horizon of analysis (e.g. 2020–2040). The time resolution of the model is one year, divided into a number of reference time slices. The objective function is the minimization of the total discounted costs of power generation in the Polish power generation system. The input data is adjusted to the current state of the power generation system in terms of technical parameters of power units, fuel and EUA prices, demand for electricity and power, the potential of primary energy supplies, a minimum renewables share in total electricity production, etc. All conventional power plants and combined heat and power plants are implemented at the level of power generation units. The remaining plants (non-public heating power plants, industrial power plants, renewables, demand side response and import) are implemented at the aggregated level. The existing units are described by the technical and economic parameters, such as installed capacity, net efficiency, emissions factors, availability factor, capacity factor, variable and fixed unit costs, etc. One of the key features of the model is the implementation of the expected decommissioning year of existing power units as well as commissioning year of the power plants under construction. The thorough description of the PolPower_LR model can be found in Kamiński et al. (2015), Kamiński (2018) and Kaszyński (2019).

The second one, the Fuel Supplies Model (FSM_LR) is applied for the optimization of the distribution of hard coal supplies in Poland. This model represents both:

- the supply side of the coal market – individual domestic coal mines, traders and importers,
- the hard coal demand units or sectors, i.e. power generation sector, heating sector, industry, households, etc.

For the purpose of this study, public coal-fired power plants are considered as individual power generation units and then aggregated at the NUTS-3 level. These units are characterized by various economic, technical and environmental parameters. Consequently, the cost of electricity production is different for these units. The objective function of the model is the minimization of the total cost of hard coal supplies (including purchase prices and transport costs) to public power generation units. Key assumptions and input data to the model are as follows: forecast of coal producers' capacities, quality parameters of produced/imported coal, coal prices, the distance (from suppliers to consumers) matrix, transportation cost, required (by the public power units) coal quality parameters and demand for chemical energy of each power unit. The last input parameter is the outcome of the PolPower_LR model. As a result of model computation for the assumed input data and implemented constraints, the volumes of hard coal supplies meeting the quality requirements of each public power generation unit are obtained. The detailed description of the long-run Fuel Supply Model can be found in Kamiński (2019).

Both models are implemented in the General Algebraic Modeling System (GAMS) and solved with the employment of CPLEX solver. Fig. 5 illustrates the research methodology applied and the soft linkage of two models.

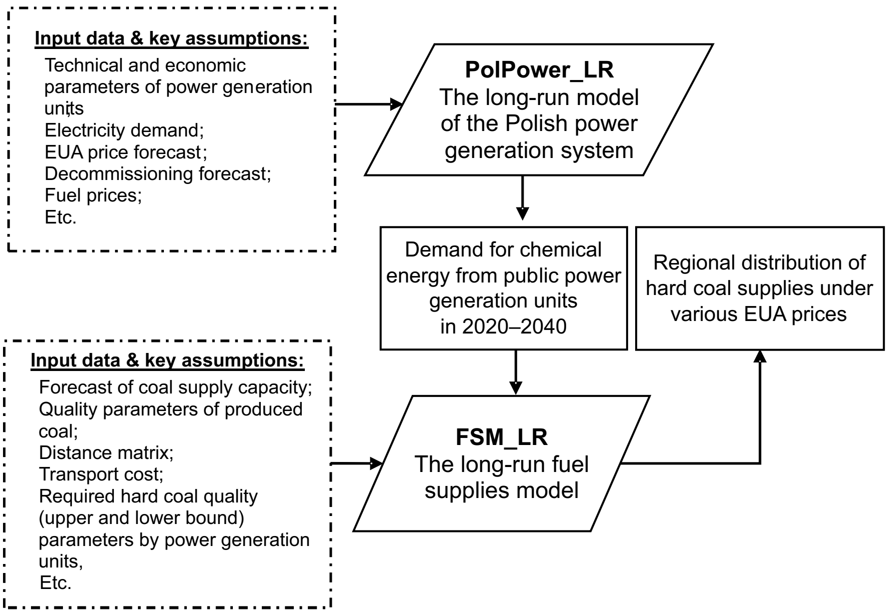

Fig. 5. Methodology applied

Rys. 5. Zastosowana metodyka badawcza

2.2. Scenario and data assumptions

The application of mathematical models described in the previous section requires the development of research scenarios, therefore appropriate data assumptions are needed.

In this case, the forecast of the EUA prices is the most important one (Fig. 6). In our study, three scenarios of the long-run development of EUA prices are proposed (Table 1). Two of them are based on the World Energy Outlook (IEA 2018), namely the New Policy Scenario (NPS) and the Sustainable Development Scenario (SDS). These scenarios assume price increase from the current level (of approx. EUR 25/Mg CO_2) to 42.5 and EUR 123.9/Mg CO_2 in 2040 respectively. The last scenario assumes a return to very low EUA prices, i.e. to the level of EUR 6.6/Mg CO_2 (average price in 2014–2017).

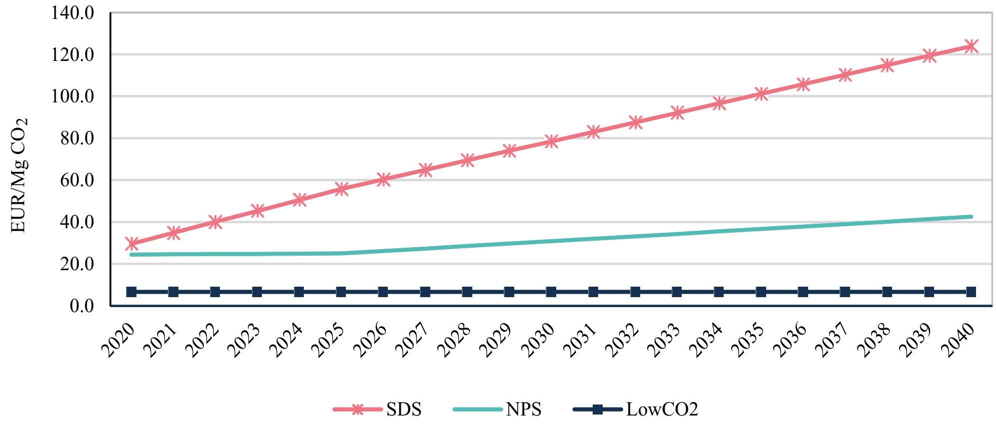

Fig. 6. Forecasts of EUA prices in 2020–2040, EUR /Mg CO_2
Source: own analysis based on (IEA 2018)

Rys. 6. Prognozy cen uprawnień do emisji CO_2 w latach 2020–2040, EUR /Mg CO_2

Table 1. Comparison of research scenarios

Tabela 1. Porównanie scenariuszy badawczych

Scenario name	Description
LowCO2	Assumed EUA price: LowCO2 forecast as in Figure 6. The EUA price of EUR 6.6/Mg CO_2 throughout the entire period analysis.
NPS	Assumed EUA price: NPS forecast as in Figure 6. Minimum price equals EUR 24.4/Mg CO_2 in 2020 and increases to the maximum level of EUR 42.5/Mg CO_2 in 2040.
SDS	Assumed EUA price: SDS forecast as in Figure 6. Minimum price equals EUR 29.6/Mg CO_2 in 2020 and increases to the maximum level of EUR 123.9/Mg CO_2 in 2040.

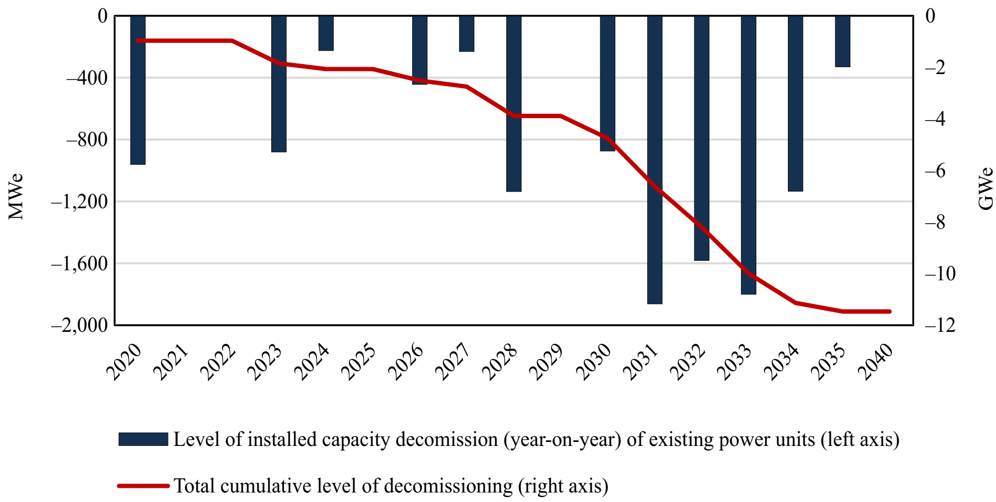

Fig. 7. Forecasted decommissioning level of existing hard coal-fired power units
(due to technical and environmental reasons) in 2020–2040

Rys. 7. Prognozowany wolumen odstawień mocy istniejących jednostek wytwórczych na węgiel kamienny
(z powodów technicznych i środowiskowych) w latach 2020–2040

The schedule of decommissioning of the public power generation units in 2020–2040 is assumed as presented in Figure 7. The data is based on

- publicly available information of power companies and Transmission System Operator, which also includes decommissions caused by environmental regulations i.e. Industrial Emissions Directive and BAT conclusions,
- information on age and degree of technical condition of boilers and turbines.

The level of total decommissioning of existing coal-based units is almost 11.5 GWe in 2020–2040.

3. Results and discussion

As previously mentioned, in this study we consider only existing, modernized, under-construction and announced coal-fired power generation units. The results of our analysis provide volumes of hard coal consumption by power generation units in specific regions of Poland under various scenarios of EUA prices in 2020–2040. Figure 8 presents the cumulative results for the entire analyzed period. In the first year, a drop in hard coal consumption is observed. This is due to the fact that almost 1 GW of hard coal-fired units is phased-out. It should be noted that hard coal consumption is not higher than in 2019 during the entire analysis period for the NPS and the SDS scenario. In the following years, an increase in hard coal consumption is observed (slight in the case of the LowCO2 and the NPS scenario, and sharp in the SDS scenario). This is due to the following reasons:

- increase in electricity demand,
- phase-out of brown coal-fired power plants due to much higher EUA prices resulting in increased production in hard coal-fired units.

The maximum volume of hard coal consumption under the LowCO2 scenario (of 26 million Mg) is noticed in 2029. After this year, the decrease is observed under all the analyzed scenarios. This stems from the following facts: further increase in EUA prices, decommissioning of several hard coal-fired units.

In the last year of the analysis, under the scenario of the highest price of EUA, hard coal consumption is lower by about 11 million Mg than in the case of the other two scenarios.

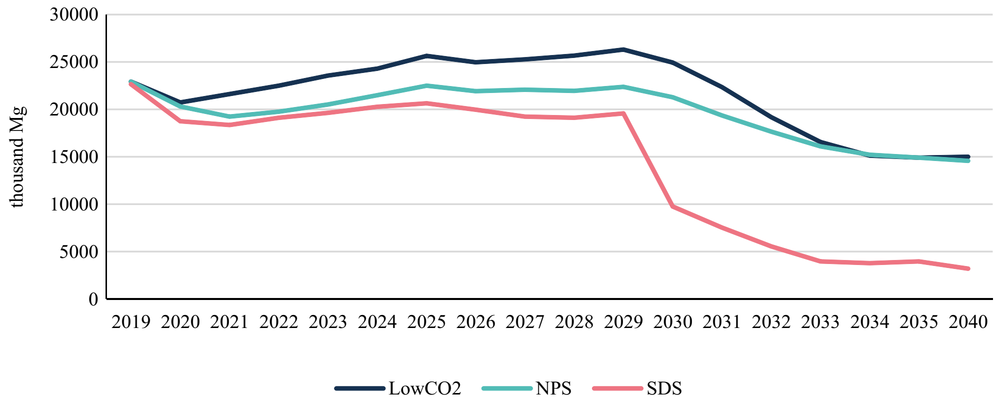

Fig. 8. Hard coal consumption in Poland in 2019–2040, thousand Mg

Rys. 8. Zużycie węgla kamiennego w Polsce w latach 2019–2040, tys. Mg

The total hard coal consumption in the various regions of Poland in 2020–2040 is presented in Figure 9. Regardless of the scenario, the largest volume of hard coal consumption is observed in the *Opolski* region. The difference between the highest (the LowCO2 scenario) and the lowest consumption (the SDS scenario) amounts to almost 20 million Mg within twenty years. The consumption in the *Poznań*, *Szczeciński* and *Tyski* regions is almost at the same level under all scenarios.

Initially, the lignite-fired power units are mothballed due to environmental regulations. Therefore, the total hard coal consumption increases until 2025. Then, the hard coal-fired units that have lower efficiency and higher emission factors reduce their production. They are replaced by gas-fired units and renewables. In 2030 and 2032, the two units of nuclear power plants are commissioned. As a result, the less profitable hard coal-fired units especially in the *Sosnowiecki*, *Radomski* and *Opolski* regions, reduce their electricity production

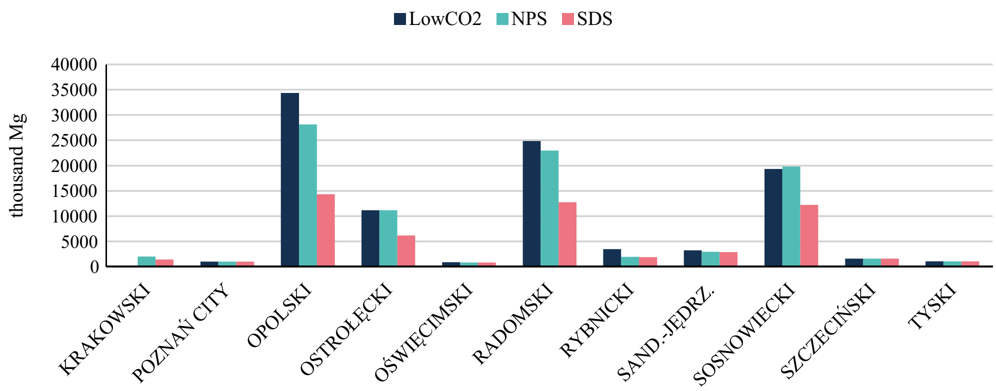

Fig. 9. Total hard coal consumption in specific regions of Poland in 2020–2040, thousand Mg

Rys. 9. Zużycie węgla kamiennego w poszczególnych regionach Polski w latach 2020–2040, tys. Mg

under all scenarios in these years. Under the SDS scenario, the reduction of generation in coal-fired units begins earlier in *Radomski* (in 2025) and *Opolski* (in 2026). With the commissioning of the first nuclear power unit, the production in the *Krakowski*, *Radomski*, *Sosnowiecki* and *Ostrołęcki* regions is halved. The commissioning of the second nuclear unit results in mothballing of some units located in the *Krakowski*, *Radomski* and *Sosnowiecki* regions.

Fig. 10 illustrates the hard coal consumption in specific regions of Poland in 2020. The highest volume is observed in the *Opolski* region under each scenario and totals respectively 7.8 million Mg under the LowCO2 scenario, 5.7 million Mg under the NPS scenario and 5.3 million Mg under the SDS scenario. In the *Radomski* region, the consumption is the highest under the NPS scenario, because the electricity production in units located in this

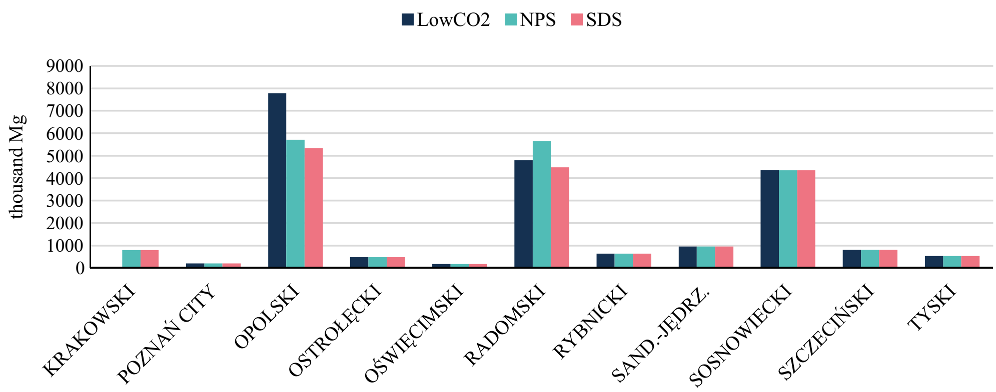

Fig. 10. Hard coal consumption in specific regions of Poland in 2020, thousand Mg

Rys. 10. Zużycie węgla kamiennego w poszczególnych regionach Polski w 2020 roku, tys. Mg region is more profitable than in others. This stems from the fact that power generation units located in this region have higher efficiency and lower emission factors. For the same reasons, the consumption in the *Krakowski* region totals 0.03 thousand Mg under the LowCO2 scenario. The consumption in other regions (*Poznań*, *Ostrołęcki*, *Oświęcimski*, *Rybnicki*, *Sandomiersko-Jędrzejowski*, *Sosnowiecki*, *Szczeciński*, *Tyski*) is almost at the same level under all the analyzed scenarios. The difference between EUA prices under all the scenarios is rather slight, therefore the EUA prices have no impact on the hard coal consumption in these regions in 2020. The total volume of consumption hard coal amount to respectively 20.73 million Mg under the LowCO2 scenario, 20.29 million Mg under the NPS scenario and 18.74 million Mg under the SDS scenario in 2020.

Figure 11 presents the hard coal consumption in specific regions of Poland in 2025. The highest volume is observed in:

- the *Opolski* region under the LowCO2 and the NPS scenario and totals 7.4 million Mg and 5.8 million Mg respectively and
- the *Radomski* region under the SDS scenario and amounts to 5.4 million Mg.

The consumption in the *Krakowski* region is as low under the LowCO2 scenario as in 2020. Since the power plant located in the *Ostrołęcki* region is commissioned in 2023/2024, the consumption in the *Ostrołęcki* region increases when compared to the previous year. In the *Radomski* region, the consumption under the SDS scenario is higher than under the NPS scenario. This stems from the fact that power generation units located in this region have a slightly higher efficiency and lower emission factors. Therefore, the production in these units is less expensive than in others. The total volume of hard coal consumption totals 25.63 million Mg under the LowCO2 scenario, 22.49 million Mg under the NPS scenario and 20.65 million Mg under the SDS scenario in 2025. As previously mentioned, the increase in consumption in comparison to 2020 stems from the fact that brown coal-fired units are decommissioned and their place is taken by hard coal-fired units.

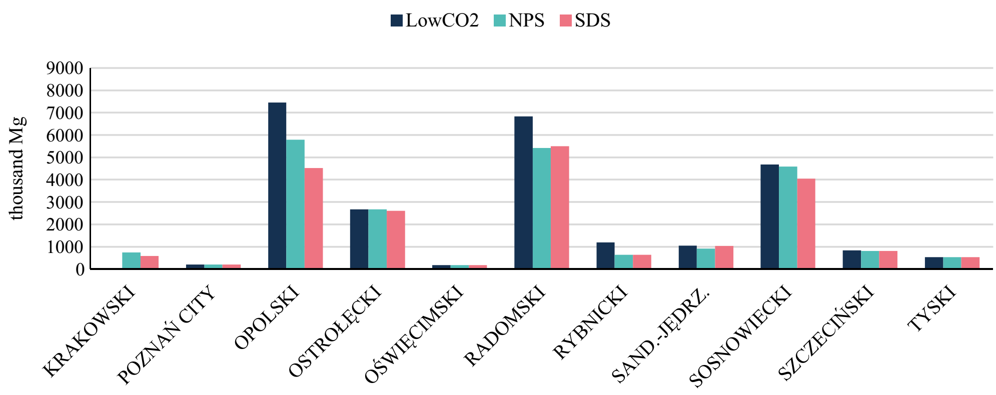

Fig. 11. Hard coal consumption in specific regions of Poland in 2025, thousand Mg

Rys. 11. Zużycie węgla kamiennego w poszczególnych regionach Polski w 2025 roku, tys. Mg

The hard coal consumption in specific regions of Poland in 2030 is shown in Figure 12. The highest volume is observed in:

- the *Opolski* region under the LowCO2 and the NPS scenario and totals 7.7 million Mg and 6.1 million Mg respectively and
- the *Sosnowiecki* region under the SDS scenario and amounts to 2.4 million Mg.

Due to the fact that some hard coal-fired units will be decommissioned between 2025–2030, there is no consumption in the *Szczeciński* and the *Tyski* region. In the *Ostrołęcki* region, the consumption under the SDS scenario is much lower when compared to other scenarios. In the *Rybnicki* region, the consumption under the LowCO2 scenario is the highest because some units become profitable only when there are very low EUA prices. The total volume of hard coal consumption totals 24.94 million Mg under the LowCO2 scenario, 21.28 million Mg under the NPS scenario and 9.78 million Mg under the SDS scenario in 2030.

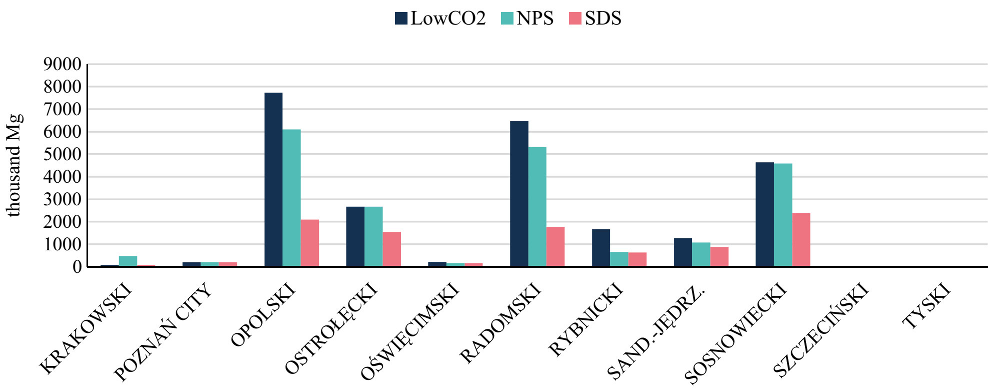

Fig. 12. Hard coal consumption in specific regions of Poland in 2030, thousand Mg

Rys. 12. Zużycie węgla kamiennego w poszczególnych regionach Polski w 2030 roku, tys. Mg

The hard coal consumption in specific regions of Poland in 2035 is presented in Figure 13. The consumption of coal is observed in only six regions. Under the SDS scenario, the units that are located in other regions are mothballed. The decommissioning of some units in the *Krakowski*, *Radomski* and *Sosnowiecki* regions happen earlier than it is forecasted based on their expected technical lifetime. Regardless of the scenario considered, the highest consumption takes place in the *Opolski* region and totals 5.8 million Mg under the LowCO2 scenario, 5.3 million under the NPS scenario and 1.3 million Mg under the SDS scenario respectively. In 2035, the difference between consumption under the LowCO2 or the NPS scenarios and, the SDS scenario can be clearly observed.

The total volume of hard coal consumption totals 14.91 million Mg under the LowCO2 scenario, 14.93 million Mg under the NPS scenario and 3.96 million Mg under the SDS scenario in 2035.

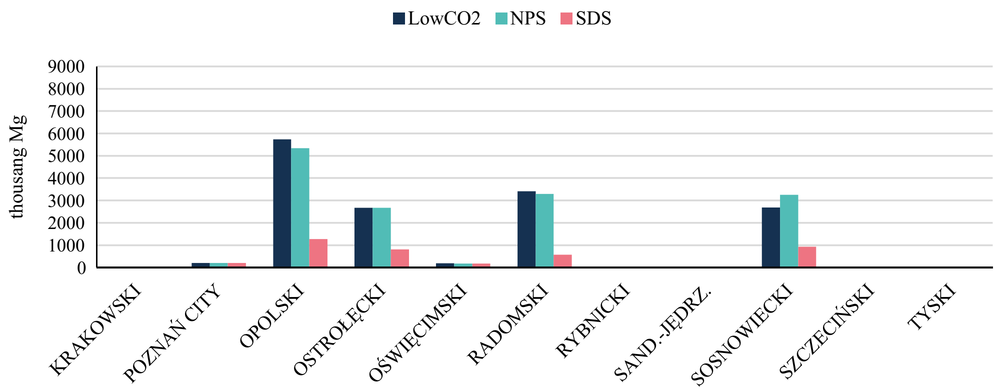

Fig. 13. Hard coal consumption in specific regions of Poland in 2035, thousand Mg

Rys. 13. Zużycie węgla kamiennego w poszczególnych regionach Polski w 2035 roku, tys. Mg

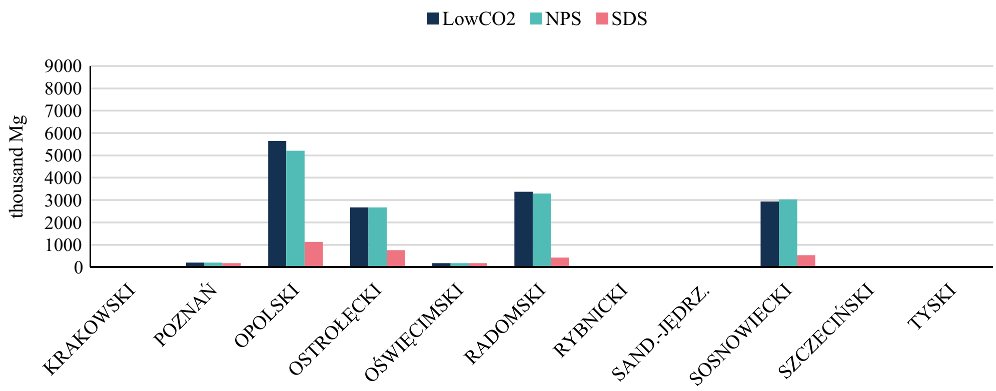

Fig. 14. Hard coal consumption in specific regions of Poland in 2040, thousand Mg

Rys. 14. Zużycie węgla kamiennego w poszczególnych regionach Polski w 2040 roku, tys. Mg

Figure 14 illustrates the hard coal consumption in specific regions of Poland in 2040. The consumption is observed in the same six regions as in 2035. The highest volume is observed in the *Opolski* region under each scenario and amounts to 5.6 million Mg under the LowCO2 scenario, 5.2 million under the NPS scenario and 1.1 million Mg under the SDS scenario respectively. The total volume of hard coal consumption totals 15 million Mg under the LowCO2 scenario, 14.57 million Mg under the NPS scenario and 3.20 million Mg under the SDS scenario in 2040. The difference in consumption between 2040 and 2035 is unnoticeable.

The regional distribution of steam coal consumption in Poland in 2018 is presented in Figure 15. The cartogram presents the current state and serves for comparing the consumption in further years under the NPS scenario (Fig. 16–18). The cartograms illustrate

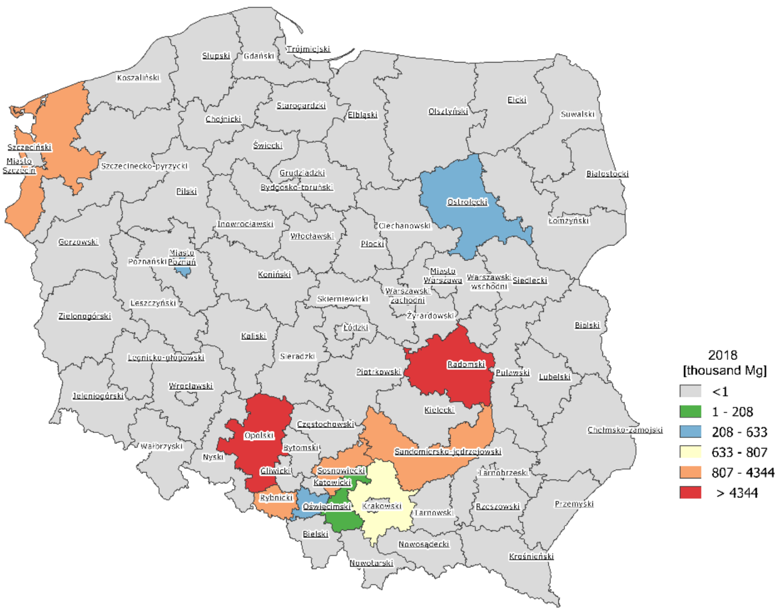

Fig. 15. Estimated hard coal consumption in existing power plants in 2018

Rys. 15. Szacunkowe zużycie węgla kamiennego w istniejących elektrowniach w 2018 roku

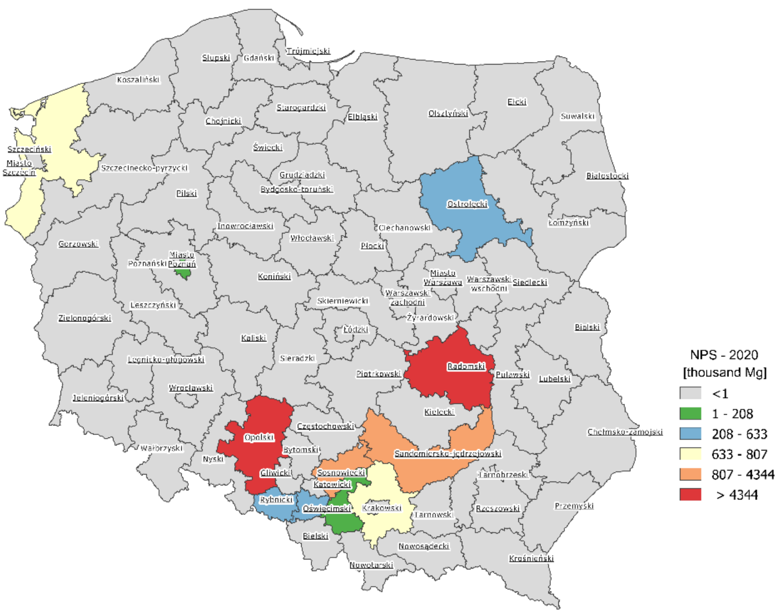

Fig. 16. Hard coal consumption in existing and planned power plants in 2020 under the NPS scenario

Rys. 16. Zużycie węgla kamiennego w istniejących i planowanych elektrowniach w 2020 roku dla scenariusza NPS

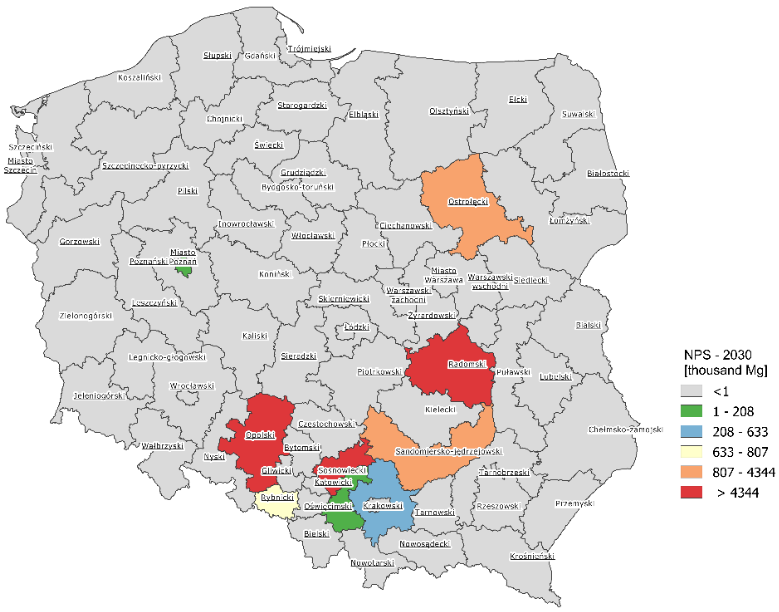

Fig. 17. Hard coal consumption in existing and planned power plants in 2030 under the NPS scenario

Rys. 17. Zużycie węgla kamiennego w istniejących i planowanych elektrowniach w 2030 roku dla scenariusza NPS

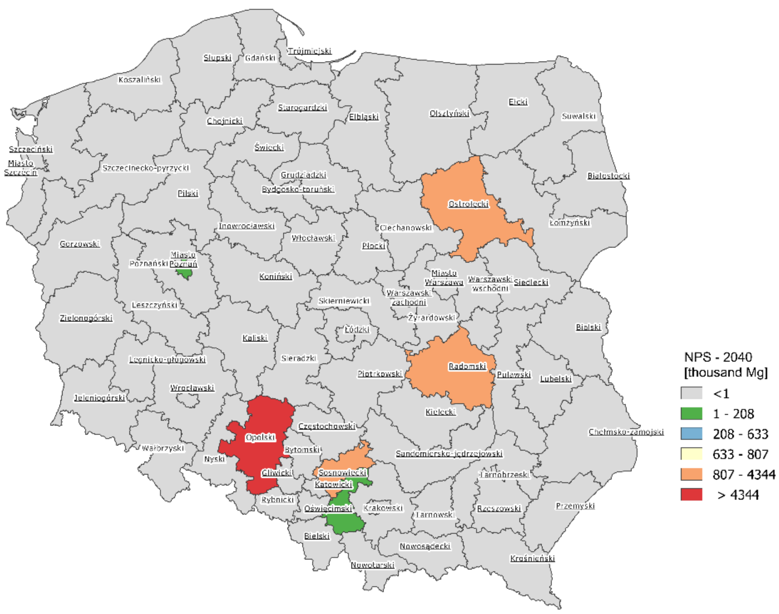

Fig. 18. Hard coal consumption in existing and planned power plants in 2040 under the NPS scenario

Rys. 18. Zużycie węgla kamiennego w istniejących i planowanych elektrowniach w 2040 roku dla scenariusza NPS seventy-three Polish regions according to the statistical classification at the NUTS-3 level. The intensity of the colors used in the maps indicates the volume of hard coal consumption in each region. The results indicate changes in hard coal consumption throughout the entire period of analysis.

Conclusions

The objective of this study was to examine hard coal consumption in various regions of Poland under selected scenarios of EUA prices' forecasts. In order to achieve this purpose, two models were employed:

- the PolPower_LR model, that represents the Polish power generation system,
- the FSM_LR model, that represents both the supply and demand side of the coal market.

Three scenarios were considered in this study:

- the LowCO2 scenario that reflects the prices of EUA at the level of EUR 6.6/Mg CO_2 in the entire period (average price in 2014–2017),
- the NPS scenario that mimics EUA prices accordingly to the NPS scenario of the World Energy Outlook (IEA 2018),
- the SDS scenario that simulates EUA prices accordingly to the SDS scenario of the World Energy Outlook (IEA 2018).

The results of the study indicate that regardless of the scenario a drop in hard coal consumption by power generation units is observed in the entire period of analysis. However, the dynamics of these changes differ. Under the LowCO2 scenario, hard coal consumption initially increases (to reach the maximum volume in 2029) and then slightly decreases to reach 15 million Mg in 2040. The pattern of changes under the NPS scenario is similar. However, the total volume of consumption is lower until 2033. Then, it resembles the LowCO2 scenario. Under the SDS scenario, hard coal consumption is much lower and changes in consumption are sharp, especially in 2030 and 2033. Finally, the consumption under this scenario totals around 3.2 million in the last year of analysis.

The highest cumulated volume of hard coal consumption is observed in the *Opolski*, *Radomski* and *Sosnowiecki* regions, regardless of the scenario. The difference between the LowCO2 and the SDS scenario amounts to 28 million Mg in the *Opolski*, 12 million Mg in the *Radomski*, and 7 million Mg in the *Sosnowiecki* region. The results of the study indicate that in the case of commissioning of nuclear power plants, the hard coal-fired units reduce their production in the *Sosnowiecki*, *Radomski* and *Opolski* regions under the LowCO2 and the NPS scenarios. Under the SDS scenario, the reduction of generation in coal-fired units begins in 2025 in *Radomski* and in 2026 *Opolski* region. The commissioning of nuclear power plants results in the decommissioning of some hard coal-fired units located in the *Krakowski*, *Radomski* and *Sosnowiecki* regions in this case.

The results of this study confirm that an increase in EUA prices drastically changes the fuel-mix of electricity production in Poland. The mothballed hard coal-fired power generation units may be replaced by:

- new high efficiency, low emissions coal-fired power plants,
- gas-fired units,
- nuclear power units commissioned in 2032 and 2032 or,
- renewables.

The thorough analysis of the changes in the fuel-mix should be considered in further studies.

The results of this analysis prove that the volume of hard coal consumption may differ by even 136 million Mg (in total, over the analyzed period) depending on the EUA prices scenario and may have various regional directions of distributions, as presented in this paper. The findings of the study provide reliable information for policymakers, coal mining companies, suppliers and shipping companies.

The work was carried out as part of the statutory activity of the Mineral and Energy Economy Research Institute Polish Academy of Sciences.

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REGIONAL DISTRIBUTION OF HARD COAL CONSUMPTION IN THE POWER SECTOR UNDER SELECTED FORECASTS OF EUA PRICES

Keywords

fuel and energy sector, hard coal, EU ETS impact, EUA price, hard coal mining industry

Abstract

The Polish power generation system is based mostly on coal-fired power plants. Therefore, the coal mining sector is strongly sensitive to changes in the energy sector, of which decarbonization is the crucial one. The EU Emission Trading System (EU ETS) requires power generating companies to purchase European Emission Allowances (EUAs), whose prices have recently soared. They have a direct impact on the cost efficiency of hard coal-fired power generation, hence influence the consumption of hard coal on the power sector. In this context, the objective of this paper is to estimate the hard coal consumption in various regions of Poland under selected forecasts of the EUA price. To investigate this question, two models are employed:

- the PolPower_LR model that simulates the Polish power generation system,
- the FSM_LR model that optimizes hard coal supplies.

Three scenarios differentiated by the EUA price are designed for this study. In the first one, the average EUA price from 2014–2017 is assumed. In the second and third, the EUA prices are assumed accordingly to the NPS and the SDS scenario of the World Energy Outlook. In this study we consider only existing, modernized, under construction and announced coal-fired power generation units. The results of the study indicate that regardless of the scenario, a drop in hard coal consumption by power generation units is observed in the entire period of analysis. However, the dynamics of these changes differ. The results of this analysis prove that the volume of hard coal consumption may differ by even 136 million Mg (in total) depending on the EUA prices development scenario. The highest cumulated volume of hard coal consumption is observed in the *Opolski*, *Radomski* and *Sosnowiecki* region, regardless of the considered scenario.

KIERUNKI DYSTRYBUCJI WĘGLA KAMIENNEGO W ENERGETYCE W ZALEŻNOŚCI OD WYBRANYCH PROGNOZ CEN UPRAWNIEŃ DO EMISJI CO_2

Słowa kluczowe

sektor paliwowo-energetyczny, węgiel kamienny, wpływ EU ETS,
ceny EUA, górnictwo węgla kamiennego

Streszczenie

Polski system wytwarzania energii elektrycznej wciąż bazuje przede wszystkim na jednostkach węglowych. W związku z tym sektor górnictwa węgla kamiennego jest wrażliwy na zmiany zachodzące w energetyce, z których istotną jest zachodzący proces dekarbonizacji. Unijny System Handlu

Uprawnieniami do Emisji nakłada na emitentów obowiązek zakupu i przedstawienia do umorzenia uprawnień do emisji, których ceny w ostatnich miesiącach znacznie wzrosły. Ceny te mają wpływ na efektywność ekonomiczną produkcji energii elektrycznej z węgla kamiennego, a zatem bezpośrednio wpływają na jego zużycie w energetyce. W świetle powyższych uwarunkowań, celem niniejszego artykułu jest oszacowanie zużycia węgla kamiennego w poszczególnych regionach Polski w zależności od wybranych prognoz cen uprawnień do emisji. W tym celu wykorzystane zostały dwa modele:

- PolPower_LR, który jest długoterminowym modelem krajowego systemu wytwarzania energii elektrycznej,
- FSM_LR, który optymalizuje dostawy węgla kamiennego.

Opracowano trzy scenariusze badawcze różniące się ścieżkami cen uprawnień do emisji. W pierwszym z nich założono stałą cenę na poziomie średniej z lat 2014–2017. W drugim i trzecim założono ceny zgodnie ze scenariuszami NPS i SDS opublikowanymi w World Energy Outlook. W badaniu uwzględnione zostały jedynie jednostki węglowe: istniejące, modernizowane, w budowie oraz ogłoszone do realizacji. Wyniki analizy wskazują, że niezależnie od scenariusza, w całym okresie analizy obserwowany jest spadek zużycia węgla kamiennego w energetyce. Jednak dynamika tych zmian jest różna, a łączny wolumen zużycia węgla kamiennego może się różnić nawet o 135 mln Mg w zależności od scenariusza. Największy wolumen zużycia węgla kamiennego obserwuje się w powiecie opolskim, radomskim oraz sosnowieckim.