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Competitiveness of the Polish hard coal mining sector as a fuel supplier for heat and power generation

Introduction

Countries and regions where hard coal plays a dominant role in heat and power generation currently face substantial challenges (Osička et al. 2020; Sivek et al. 2020). Climate policy leads to the decreasing consumption of fossil fuels in the power sector (ÓhAiseadha et al. 2020). In particular, the decarbonization process and energy transition, which are intended to produce a zero-emission economy, are taking place in the countries of the European Union (Barrett et al. 2018; Tvinnereim and Mehling 2018). Although many mechanisms have been implemented in member states, such as supporting renewable energy sources or the European Emissions Trading Scheme, the power generation sectors of several countries are still based on coal. A study conducted in 2018 indicated that 24 EU countries depend on

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fossil fuel at a minimum level of 60% (Martins et al. 2018). One of these countries is Poland (Gawlik and Mokrzycki 2019), where the share of fossil fuels in electricity generation was 75.4% in 2019 (PSE SA 2019). It is expected that the level will be maintained in the immediate future because of the introduction of the capacity market, which is supporting coal-fired units until 2025 (Komorowska et al. 2020).

The significant share of fossil fuels in the energy-mix is a direct consequence of the existence of large coal deposits in Poland and the historical development of the power sector based on domestic resources. Given the fact that there are a significant number of mines in Poland, the competitiveness of domestic vs imported coal is a critical factor that determines the future of the Polish hard coal mining sector (Kamiński 2009).

The prices on global steam coal markets have been fluctuating over recent years (Figure 1). The CIF ARA price decreased from PLN 379.6/Mg in 2011 to PLN 179.8/Mg in 2016. The sharp drop was caused by a high level of global coal supplies and the demand for steam coal being lower than predicted in the emerging economies (RBA 2019). Over this period of time coal prices also decreased on the Polish market. The price in 2016 was 30% lower than in 2012–2013. Then the CIF ARA prices for steam coal increased over the years 2016–2018.

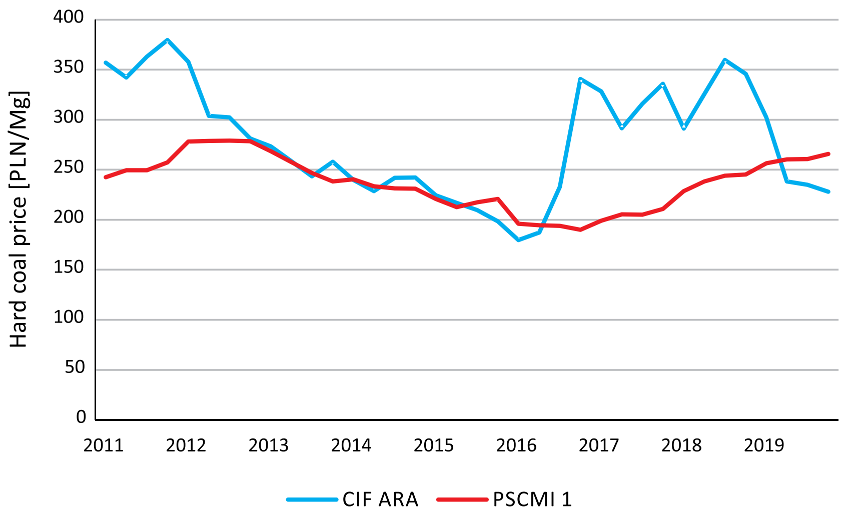

Fig. 1. Steam coal price sold to the power generation sector in 2011–2019
Source: own analysis based on: ARP SA 2020; WNP 2020

Rys. 1. Ceny węgla energetycznego sprzedawanego do energetyki w latach 2011–2019

Substantial declines in coal prices over the years 2011–2015 resulted in decreasing production in some companies with the aim of cutting costs. Some mines were also mothballed or closed. In consequence, the increase in demand and the simultaneous decrease in supply resulted in a growth in global coal prices (RBA 2018; RBA 2019). The sharp growth was also a consequence of developments on the Chinese coal market. Production was reduced by 140 million Mg when compared to 2015. Chinese companies reduced the number of working days in mines and increased the level of coal imports. Then prices began to decrease again. At present, they are lower than the price of coal produced in Poland (expressed via the Polish Steam Coal Market Index (PSCMI 1)). Current energy policies are directed towards low emission economies. The governments of most countries have changed their energy mixes through supporting power generation from renewable energy sources and production in combined cycle gas-fired units. As a result, global coal consumption has decreased as has its price as well.

However, the decline in coal prices is not observed in Poland. On the contrary, the prices in the local market have been increasing in recent years. This is a result of the Polish energy policy and the specific rules of trade in the domestic steam coal market. The price of coal is often determined through long-term contracts between producers and power generation companies. Both partners are partially State-owned (Kamiński 2009).

In conclusion, the lack of a high correlation between CIF ARA and domestic coal prices in recent years can be explained by a difference in the way they are determined. While global prices are determined through the employment of a typical market-clearing price approach, domestic prices are mostly based on long-term agreements that are only partially driven by international coal prices. The impact of the fluctuations of coal prices on the international markets on the volatility of domestic fuel and electricity prices is discussed in Malec (Malec 2017).

Since most domestic generation units are fired with steam coal, the relationship between the prices of imported and domestic coal is important for the competitiveness of Polish coal mines. Additionally, the distance between power plants and coal supply enterprises (such as domestic mines, seaports, and railway border crossings) influences the profitability of electricity and heat generation. Naturally, the difference between prices is not the only element of competitiveness in domestic hard coal mining. For example, Tilton (Tilton 1992) pointed out the role of public policy, which is very important and is very often neglected in the analysis. The impact of environmental regulations and the competitiveness of mining in the broad sense is discussed in Kaszyński et al. (Kaszyński et al. 2019) and Söderholm et al. (Söderholm et al. 2015).

The competitiveness of domestic coal production is a crucial issue for every country or region in which coal is widely consumed. However, the cost of coal exploited in domestic mines must not lead to losses in power generating companies. Ultimately, the main objective of these companies is profit maximization. Therefore, if imported coal prices are lower, power companies will purchase coal from other countries. As a result, it is important (for mining companies, generating companies, and also for policymakers as well) to understand at what price ratio purchasing coal from domestic mines is more cost-efficient than from import sources. In this context, the paper further develops the investigation published in Kamiński (Kamiński 2019), where there is an analysis of the impact of potential changes in the price relationship between domestic and imported coal and its influence on the volume of coal imported to Poland.

The study analyzes the impact of the domestic vs imported coal price ratio on the consumption of domestic fine coal in the heat and power generation sector. This issue is critical not only for Poland but also for other countries in which domestic coal production still has an important share in coal supplies. These countries are currently facing challenging conditions since they have to react and undertake activities related to energy transition and the decarbonization process. The methodology applied in this study allows one to find the optimal supplier of coal for each power generation unit (or power plant).

The study was conducted by employing a computable model of the Polish steam coal market. The model reflects key elements and relationships between coal suppliers and power generating units. The mathematical formulae are implemented in the General Algebraic Modelling System (GAMS) as a Mixed Integer Linear Programming (MILP) problem and solved with the CPLEX solver. The results are then aggregated to the appropriate NUTS-3 level that allows one to specify the level and structure of steam coal demand in each region of Poland.

The remaining sections of this paper are as follows. Section 2 describes the methodology applied. Data assumptions and the development of scenarios are presented in Section 3. The results are discussed in Section 4. Section 5 concludes the study and draws out the policy implications.

1. Methodology

In order to quantify the impact of the price relationship between domestic and imported steam coal, the application of the appropriate methodology is required. To the best of our knowledge, mathematical modelling – which is one of the methods of systems analysis and operational research – is the most appropriate approach (Lopion et al. 2018; Rademeyer et al. 2019; Ventosa et al. 2005). This approach enables one to depict the key elements of the sector in question and relations between them as mathematical formulae.

A long-term mathematical model of the Polish steam coal market was developed and employed to achieve the research objective. The conceptual model is presented in Figure 2. The supply side is reflected at the level of individual mines and quality classes of the coal produced. Suppliers of imported coal are described in a similar manner; various quality classes were identified for the import of coal by sea (from the US, Colombia, South Africa), as well as the import of coal by rail (from Ukraine, Russia, Kazakhstan). The model takes account of the locations of seaports and of rail border crossings (Figure 3) which are described by the volume of coal import capacity.

Steam coal demand is reflected at the level of individual units or groups of consumers. Public power plants are represented at the level of individual power generating units that can be aggregated to the level of representative unit classes or individual power plants. Public CHPs are reflected at the level of entire plants. For other consumers of steam coal (industrial CHPs, public and non-public heating plants) aggregate demand was adopted at

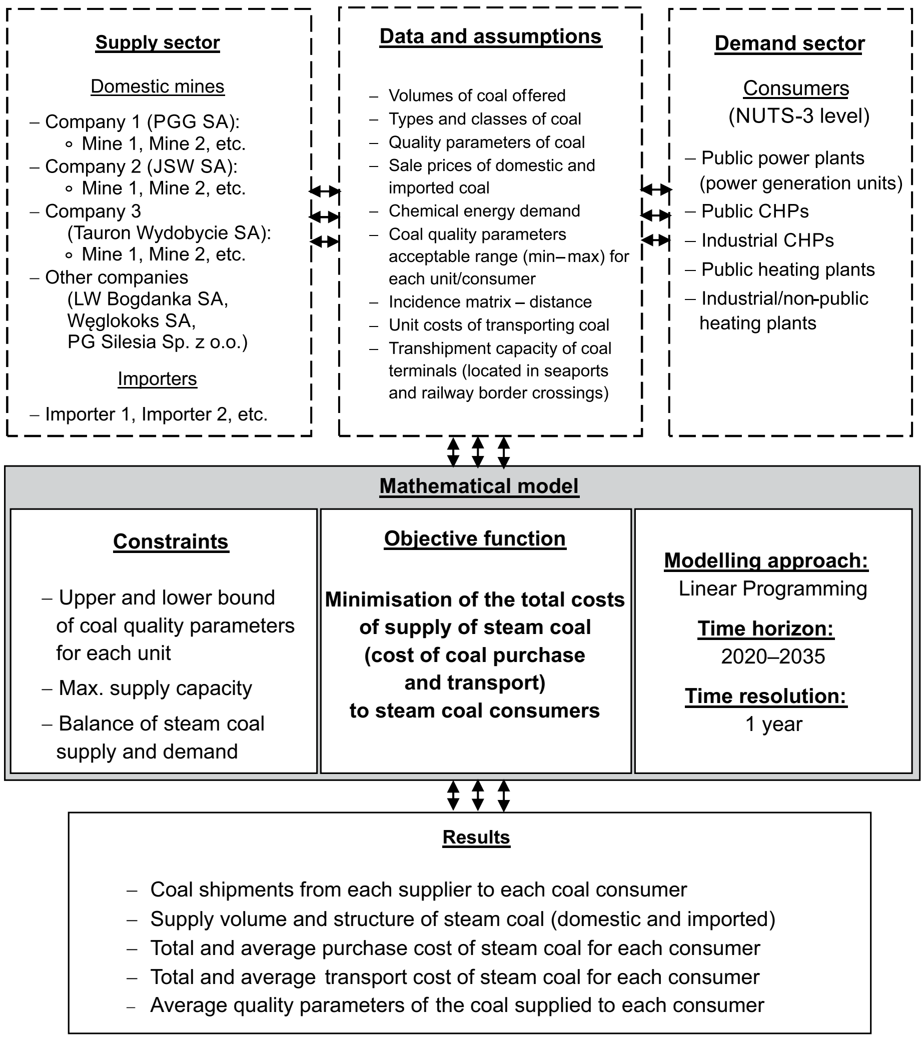

Fig. 2. Concept diagram of the mathematical model

Rys. 2. Schemat koncepcji modelu matematycznego

the NUTS-3 level. It should be noted that the location data of individual power plants and CHPs are also known. Therefore, they can easily be aggregated to the appropriate NUTS-3 region. This enables one to study changes in the volume and structure of coal demand from a regional perspective.

The model incorporates parameters and variables describing both the supply side (suppliers of domestic and imported steam coal) and the demand side (generating units of power plants, individual combined heat and power plants, and other consumers aggregated into

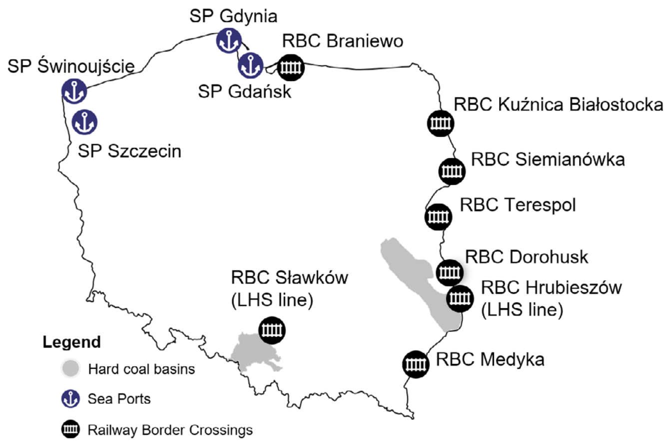

Fig. 3. Main coal transhipment terminals and hard coal basin locations in Poland

Rys. 3. Główne lokalizacje terminalów przeładunkowych węgla oraz zagłębi węglowych w Polsce

homogeneous groups). The maximum volume of coal offered on the market is determined independently for each year of the time horizon of the study. The parameters describing the individual classes and assortments of coal on offer are as follows: calorific value, ash content, sulphur content.

Moreover, quality requirements are also incorporated for each steam coal consumer: minimum and maximum limitations of quality parameters are adopted. There is also an option in the model which enables it to mix coals of various qualities. The results are coal-blends of average fuel quality parameters which meet the assumed consumer requirements.

A railway distance matrix characterizes the relationship between the supply and demand sectors. The matrix reflects the distance between the nearest producer/importer of steam coal (domestic coal mine or importer) and its customers. The unit transport costs are based on the actual price list of the largest carrier in Poland.

The mathematical model is developed using the Linear Programming (LP) approach. The objective function is formulated as the minimization of the total costs of steam coal supplies (the cost of coal purchase and transport) to steam coal consumers, taking account of the quality requirements regarding fuel and other constraints. The limitations adopted mainly apply to the need to meet the demand for coal and to comply with the constraints of coal production capacity (or the capacity of railway border crossings or seaports).

A detailed description of the sets, parameters, variables, and balances/constraints implemented in the model are presented in the following part of this section. Table 1 presents the sets of elements. The following tables present the list and description of model parameters (Table 2), variables (Table 3) and equations/inequalities (Table 4).

Table 1. List of sets used in the model formulae

Tabela 1. Zbiory zdefiniowane w modelu matematycznym

Symbol	Description
s	Coal mines and coal importers (suppliers), $s \in S$
c	Coal types, $c \in C$
d	Coal consumers (public power plants, public CHPs, public and non-public heating plants, and industrial CHPs), $d \in D$
p	Quality parameters of coal: Net Calorific Value (NCV), Ash content and Sulphur content, $p \in P = \{NCV, Ash, Suplhur\}$
i	Import transshipment points – railway border crossings for goods and seaports, $i \in I$
y	Years, $y \in Y$

Table 2. List of parameters used in the model formulae

Tabela 2. Parametry zdefiniowane w modelu matematycznym

Symbol	Unit	Description
$SC_{s,c}$	–	Incidence matrix – assignment of coal *c* offered to mines or importers *s* (1 – if mine/importer offers coal *c,* 0 – otherwise)
$SI_{s,i}$	–	Incidence matrix – assignment of the coal supplier *s* to a railway border crossing or seaport *i* (1 – if coal supplier *s* delivers coal to a railway border crossing or seaport *i*, 0 – otherwise)
$Demand_{d,y}$	GJ	Demand for coal by consumer *d* in year *y*
$CoalQuality_{p,s,c,y}$	GJ/Mg %	The average value of the quality parameter *p* of coal *c* offered by mine/importer *s* in year *y*
$QualityMin_{p,d,y}$	GJ/Mg %	The lower limit of the quality parameter *p* of coal in accordance with the consumer quality requirements *d* in year *y*
$QualityMax_{p,d,y}$	GJ/Mg %	The upper limit of the quality parameter *p* of coal in accordance with the consumer quality requirements *d* in year *y*
$Capacity_{s,c,y}$	Mg	Maximum production or import capacity for coal *c* of mine/importer *s* in year *y*
$Price_{s,c,y}$	PLN/GJ	The price of coal in a specified quality class *c* offered by the mine/importer *s* in year *y*
$Distance_{s,d}$	km	Rail distance of mine/importer *s* from individual consumers *d*
$TransportCost_{s,d,y}$	PLN/km·Mg	The unit cost of coal transport from mine/importer *s* to consumer *d* in year *y*
$TransShipment\ Capacity_{i,y}$	Mg	Maximum reloading capacity (towards import) of terminals at seaports and rail border crossings *i* in year *y*

Table 3. List of variables used in the model formulae

Tabela 3. Zmienne zdefiniowane w modelu matematycznym

Symbol	Unit	Description
Positive variable		
$Supplies_{s,c,d,y}$	Mg	The volume of coal supplies of a specific quality class *c* from supplier (mine/importer) *s* to consumer *d* in year *y*
Free variable		
TotalSuppliesCosts	PLN	The total cost of steam coal supplies (the cost of coal purchase and transport) to steam coal consumers

Table 4. Equations and inequalities of the mathematical model for long-term steam coal production planning

Tabela 4. Równania i nierówności modelu matematycznego do długoterminowego planowania produkcji węgla kamiennego

Symbol	Unit	Description
$EQ\_Demand_{d,y}$	GJ	Balance of coal production/import and demand for consumers *d* in year *y*
$EQ\_QualityMin_{p,d,y}$	GJ/Mg %	Lower bound of quality parameter *p* of coal for consumer *d* in year *y*
$EQ\_QualityMax_{p,d,y}$	GJ/Mg %	Upper bound of quality parameter *p* of coal for consumer *d* in year *y*
$EQ\_Capacity_{s,c,y}$	Mg	Upper bound of coal production capacity *c* for the mine in year
$EQ\_TransShipment\ Capacity_{i,y}$	Mg	Upper bound of the transhipment capacity of import terminals in seaports and rail border crossings *i* in year *y*
EQ_TotalCost	PLN	The objective function of the model – the total cost of steam coal supplies to consumers

The objective function is the minimization of the total cost of steam coal supplies (purchase and transport) to steam coal consumers:

- *EQ_TotalCost*

$$TotalCost = \sum_{s,c,d,y} \left(Supplies_{s,c,d,y} \cdot SC_{s,c} \cdot Price_{s,c,y} \right) +$$

$$+ \sum_{s,c,d,y} \left(Supplies_{s,c,d,y} \cdot Distance_{s,d} \cdot TransportCost_{s,d,y} \right)$$

The remaining constraints read as follows:

- $EQ\_Demand_{d,y}$

$$\underset{d\in D}{\forall}\ \underset{y\in Y}{\forall}\ \sum_{s,c}\left(Supplies_{s,c,d,y}\cdot CoalQuality_{p,s,c,y}\cdot SC_{s,c}\right)\geq Demand_{d,y}$$

- $EQ\_QualityMin_{p,d,y}$

$$\underset{p\in P}{\forall}\ \underset{d\in D}{\forall}\ \underset{y\in Y}{\forall}\ \frac{\sum_{s,c}\left(Supplies_{s,c,d,y}\cdot CoalQuality_{p,s,c,y}\cdot SC_{s,c}\right)}{\sum_{s,c}\left(Supplies_{s,c,d,y}\cdot SC_{s,c}\right)}\geq QualityMin_{p,d,y}$$

- $EQ\_QualityMax_{p,d,y}$

$$\underset{p\in P}{\forall}\ \underset{d\in D}{\forall}\ \underset{y\in Y}{\forall}\ \frac{\sum_{s,c}\left(Supplies_{s,c,d,y}\cdot CoalQuality_{p,s,c,y}\cdot SC_{s,c}\right)}{\sum_{s,c}\left(Supplies_{s,c,d,y}\cdot SC_{s,c}\right)}\leq QualityMax_{p,d,y}$$

- $EQ\_Capacity_{s,c,y}$

$$\underset{s\in S}{\forall}\ \underset{c\in C}{\forall}\ \underset{y\in Y}{\forall}\ \sum_{d}\left(Supplies_{s,c,d,y}\cdot SC_{s,c}\right)\leq Capacity_{s,c,y}$$

- $EQ\_TransShipmentCapacity_{i,y}$

$$\underset{i\in I}{\forall}\ \underset{y\in Y}{\forall}\ \sum_{s,c,d}\left(Supplies_{s,c,d,y}\cdot SC_{s,c}\cdot SI_{s,i}\right)\leq TransShipmentCapacity_{i,y}$$

2. Scenarios and key assumptions

A quantitative assessment of the competitiveness of the Polish hard coal mining sector as a supplier for the heat and power generation system was conducted for 2020–2035. The subject of the research is steam coal consumption in the following units:

- public power plants (implemented in the model at the level of power generation unit),
- public combined heat and power plants (CHPs) (implemented at the level of entire plants),
- public heating plants (implemented at the aggregated NUTS-3 level),
- non-public heating plants (implemented at the aggregated NUTS-3 level),
- industrial CHPs (implemented at the aggregated NUTS-3 level).

The steam coal consumption in these units amounted to 44.9–46.6 million Mg in 2015––2018, which accounted for over 75% of the total hard coal consumption in Poland (ARE SA 2016; 2017a, 2018).

One of the key assumptions in our study is the data on the forecast volume of steam coal consumption in units or groups of units of the Polish heat and power generation system. The forecast was developed using the results of the long-term model of the Polish heat and power generation system, historical data, and consumption trends in the units considered which was published in the Program for the hard coal mining sector in Poland published by the Ministry of Energy (Ministry of Energy 2018). The model of the Polish power generation system was developed with the employment of the Linear Programming (LP) approach. The objective function, which is minimized in the model, is the total discounted system costs of electricity generation in the entire period of the analysis (2020–2035). The results of the long-term model of the Polish power generation system provide the necessary forecast of steam coal consumption in the units considered (Table 5). The complete concept of the model and its mathematical formulae can be found in Kamiński (Kamiński 2018), Kamiński et al. (Kamiński et al. 2015) and Kaszyński (Kaszyński 2019). To meet the objectives of the study, the calculations were conducted for a scenario in which one of the key assumptions was the adoption of a forecast of European CO2 Emission Allowance (EUA) prices. The price of EUA is – apart from fuel costs – the main cost factor in coal-fired power plants and CHPs based on fossil fuels. The assumed prices are based on the forecasts prepared by the International Energy Agency for the New Policy Scenario (NPS) published in World Energy Outlook (IEA 2018). The NPS scenario was selected because its assumptions are similar to those in the current trends of Poland's energy policy.

The demand forecast for the remaining consumer groups (industrial CHPs, public and non-public heating plants) is based on historical data and trends in the consumption of steam coal up to 2030 calculated for the reference scenario in the Program for the hard coal mining sector in Poland (Ministry of Energy 2018). The continuation of this trend is also assumed for further years of analysis (2031–2035) (Table 5).

Table 5. Model assumptions – steam coal demand, thous. Mg

Tabela 5. Założenia do modelu – zapotrzebowanie na węgiel energetyczny, tys. Mg

	2020	2025	2030	2035
Public power plants	21,783.2	24,013.8	22,582.7	15,567.5
Public CHPs	11,401.2	10,624.2	10,074.8	8,837.1
Public and non-public heating plants	4,323.7	4,223.1	3,605.4	3,394.1
Industrial CHPs	2,905.7	2,683.8	2,509.5	2,297.7
Total demand	**40,413.9**	**41,545.0**	**38,772.3**	**30,096.5**

The model adopts the long-term price forecast of imported coal (Figure 4), which was developed based on two sources as follows:

- short-term price forecast for 2020–2024 developed by the Australian Ministry of Industry, Innovation and Science from March 2019 (DIIS 2019a) with an update of part of the value from October 2019 (DIIS 2019b),
- the long-term price forecast for 2025–2035 developed by the International Energy Agency for the New Policy Scenario (IEA 2018).

Additionally, freight and port charges were added to the original values, eventually obtaining total prices at border crossings (seaports and rail border crossings).

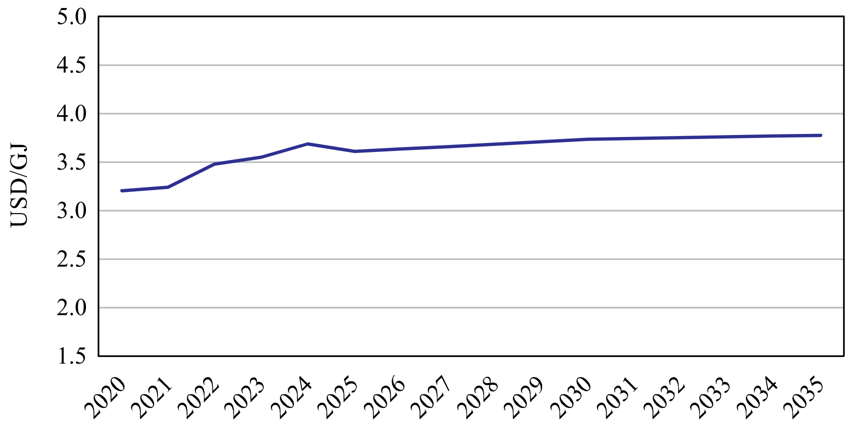

Fig. 4. Model assumption – forecast of imported steam coal
Source: own analysis based on: DIIS 2019a; IEA 2018

Rys. 4. Założenia do modelu – prognozy cen węgla energetycznego z importu

The price forecast presented here was developed for coal imported to Poland with the following specific quality parameters (hereinafter: reference coal):

- calorific value: 25.0 MJ/kg (6,000 kcal/kg),
- ash content: 12.0%,
- sulphur content: 1.0%.

Seventeen scenarios were developed to address the problem in question (Table 6). The reference scenario (scenario 0%) reflects the situation in which the price of domestic coal is equal to the price of imported coal (the price is considered in calculations as a price per unit of chemical energy (GJ)). In the remaining scenarios, the difference between the price of domestic coal and that of imported reference coal ranges from ±5% to ±40%.

Based on the data and assumptions adopted, a set of scenarios and the employment of the mathematical model, calculations were carried out aimed at quantifying the impact of the price relationship of coal (domestic vs imported) on the volume of future demand for

Table 6. Scenario comparison

Tabela 6. Porównanie scenariuszy badawczych

Scenario	Domestic reference coal price in relation to the imported reference coal price
Scenario –40%	40% lower
Scenario –35%	35% lower
Scenario –30%	30% lower
Scenario –25%	25% lower
Scenario –20%	20% lower
Scenario –15%	15% lower
Scenario –10%	10% lower
Scenario –5%	5% lower
Scenario 0% – both reference coal prices are at the same level (in PLN/GJ)	
Scenario +5%	5% higher
Scenario +10%	10% higher
Scenario +15%	15% higher
Scenario +20%	20% higher
Scenario +25%	25% higher
Scenario +30%	30% higher
Scenario +35%	35% higher
Scenario +40%	40% higher

the power generation sector. The methodology applied also allows one to develop the geographical structure of steam coal consumption.

3. Results and discussion

The following results are analyzed to assess the competitiveness of the Polish steam coal mining sector as a supplier for the domestic heat and power generation sector:

- the volume of total domestic fine coal consumption under the scenarios analyzed in 2020, 2025, 2030 and 2035,
- the absolute difference in domestic fine coal consumption under the scenarios analyzed in comparison to scenario 0%,
- the total imported and domestic fine coal consumption in the period analyzed.

Additionally, the results were depicted on cartograms in order to present the distribution of the consumption of domestic and imported coal in the various regions of Poland.

Total domestic fine coal consumption in 2020, 2025, 2030, and 2035 under the scenarios analyzed is presented in Figure 5, and the absolute difference in domestic coal consumption in comparison to scenario 0% is shown in Figure 6.

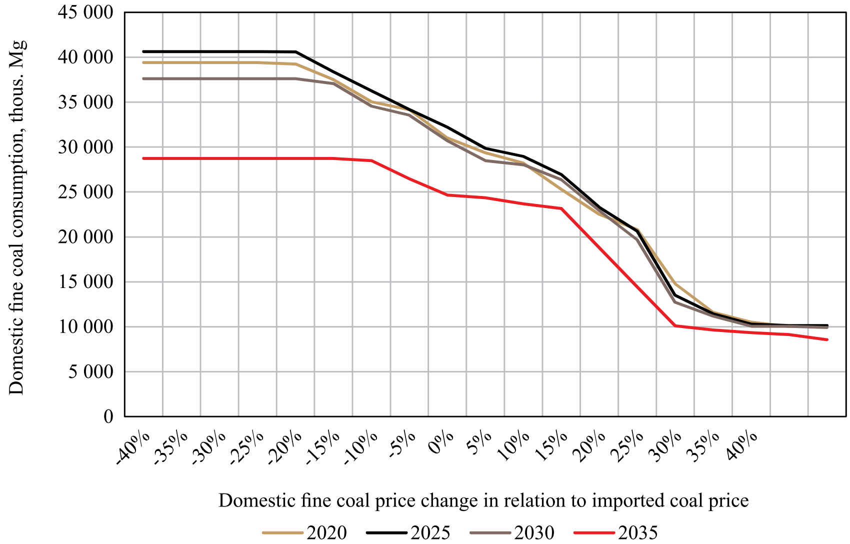

Fig. 5. Total domestic fine coal consumption under model scenarios for 2020, 2025, 2030, and 2035

Rys. 5. Całkowite zapotrzebowanie na miały węglowe dla poszczególnych scenariuszy w latach 2020, 2025, 2030 oraz 2035

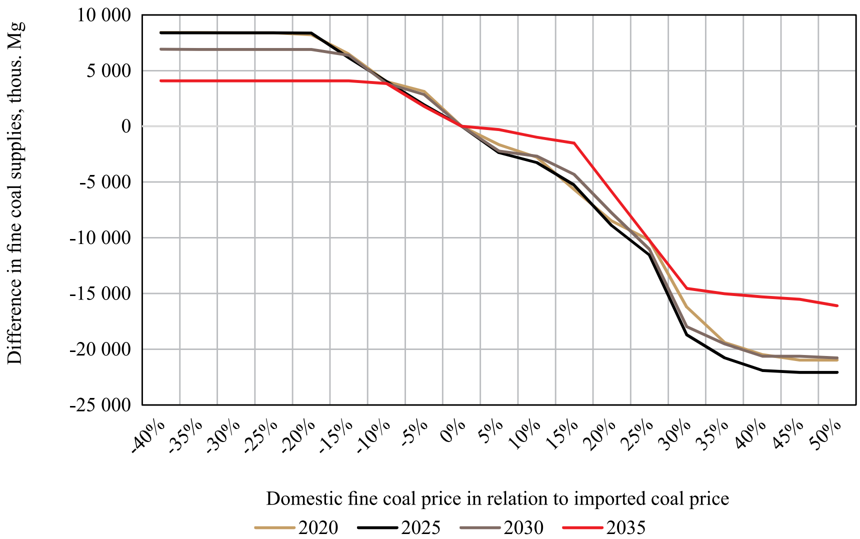

Fig. 6. Domestic fine coal consumption differences under model scenarios for 2020, 2025, 2030 and 2035 in comparison with the scenario for a 0% difference

Rys. 6. Różnice w zapotrzebowaniu na miał węglowy w scenariuszach w porównaniu z różnicami w scenariuszu 0% dla lat 2020, 2025, 2030, 2035

Scenario 0% reflects the same price for domestic and imported coal. It can be observed that in this case the consumption of domestic coal varies in the range of 24.6–32.2 million Mg. The highest value is observed in 2020, and it decreases gradually until 2035. This is a result of a drop in total steam coal consumption in the Polish heat and power generation sector.

If an increase in domestic coal prices in relation to imported coal prices is assumed, a gradual decrease in domestic coal supplies is observed. The decrease is the most dynamic for a price relationship in the range of +15–+30%. Then, the consumption decreases from 23.1–26.9 million Mg to 10.1–14.7 million Mg (depending on the year of analysis). Scenarios showing the largest positive price difference between domestic and imported coal (scenarios +35% and +40%) are characterized by a further decline (2020, 2025 and 2030) or stabilization (2035) of domestic coal consumption. The volume under scenario +40% is between 9.3 million Mg (2035) and 10.5 million Mg (in various years). The numbers depict the minimal level of consumption which stem from the requirements adopted (constraints on quality parameters of coal) in heat and power generation units.

If domestic coal is cheaper than imported coal (scenarios from –5% to –40%), there is a dynamic increase in the consumption of domestic coal as the difference increases. This is particularly the case in 2020 and 2025, in which the demand for fuel is higher. As the price of domestic coal drops below that of imported coal, domestic consumption continues to increase even as far as the scenario of –20%. At this point, the consumption of domestic fine coal is 8.3 million Mg higher than that in the scenario of a 0% difference in price between domestic and imported coal (Figure 6). A further increase in the price difference results in consumption being retained at a similar level because the total demand is being met with steam coal produced in domestic mines. In the remaining years, the difference in consumption between that with cheaper domestic coal and that with import and domestic prices being equal is lower because the demand is also lower. In 2030, the difference in domestic coal consumption between that under the scenario of –15% and that under the scenario of 0% difference in price is 6.3 million Mg at which point domestic coal meets all the demand. However, in 2035, domestic supply had already reached a maximum under the scenario of –10%. At that point, 3.8 million Mg more domestic coal is consumed than under the scenario for a price difference of 0%, (Figures 5 and 6).

The relationship between the total volume of domestic and imported coal consumption in 2020–2035 under the model scenarios, from –40% to +40%, is presented in Figure 7. As previously mentioned, the total demand for coal in heat and power generation units (approx. 585 million Mg) is covered by domestic coal under scenarios from –20% to –40%. Under the remaining scenarios, a gradual increase in the consumption of imported coal occurs, and it reaches its highest value under the scenario +40%. In this scenario, the total consumption of imported coal is almost 400 million Mg, that is 71% of the total demand over the entire period of the model.

The sensitivity analysis was carried out separately for domestic coal, imported coal and total supplies. The results are presented in the form of absolute differences in the total

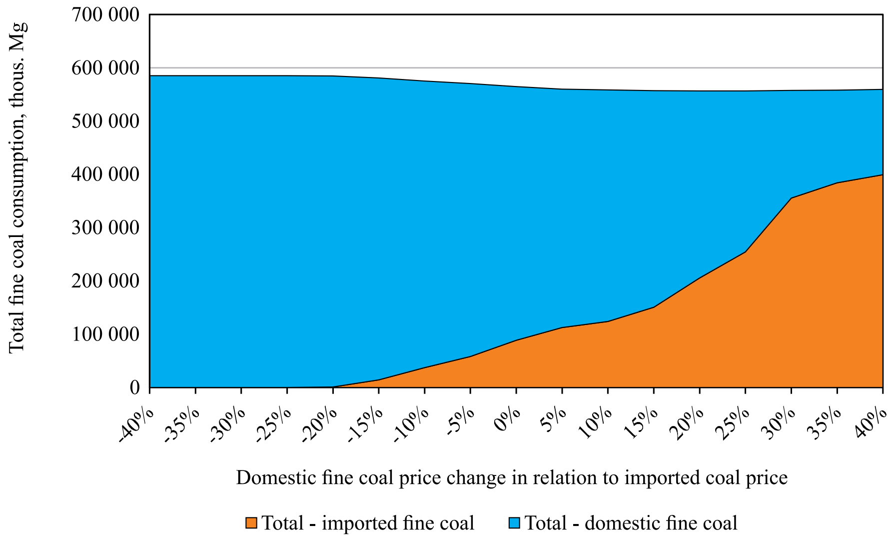

Fig. 7. Total imported and domestic fine coal consumption in the years 2020–2035

Rys. 7. Całkowite zapotrzebowanie na importowane oraz krajowe miały energetyczne w latach 2020–2035

volume of deliveries in 2020–2025 (Figure 8). The differences were determined in relation to the values obtained under a scenario of a 0% difference in price.

The sensitivity analysis was also carried out for individual years (2020, 2025, 2030 and 2035) – the results are presented in Figures 9–12. It can be observed that the volume of coal supplies is more sensitive in the case of domestic coal demanding more favorable prices (higher domestic coal prices than imported ones). The difference in the volume of domestic and imported coal can vary by up to 300 million Mg in either direction depending on the price relationship between domestic and imported coal. The most dynamic change in the proportion of imported coal – an increase in imported coal supplies of 200 million Mg and an inversely proportional decrease in domestic coal supplies of a similar scale – occurs for a change in the price relationship in the range from +15% to 30% (Figure 8).

For the opposite price relationship – lower domestic coal prices – the range of variability of fuel supplies is almost three times lower. When domestic steam coal prices are lower than the prices of imported coal by about 20%, the consumption of domestic coal increases by 109 million Mg compared to the 0% scenario, while imported coal decreases by a similar amount (88 million Mg). An increase of the price difference does not bring further changes in the level of supply as total demand (100%) is covered by coal produced by domestic mines (Figure 8).

It is also worth noting that the total supply of steam coal in the period analyzed changes slightly. In the case of the dominance of imported coal, there is a decline in total volume (by approx. 5–8 million Mg), while in the situation of an increase in the proportion of domestic coal supplies, the total coal supply also increases (by approx. 20 million Mg).

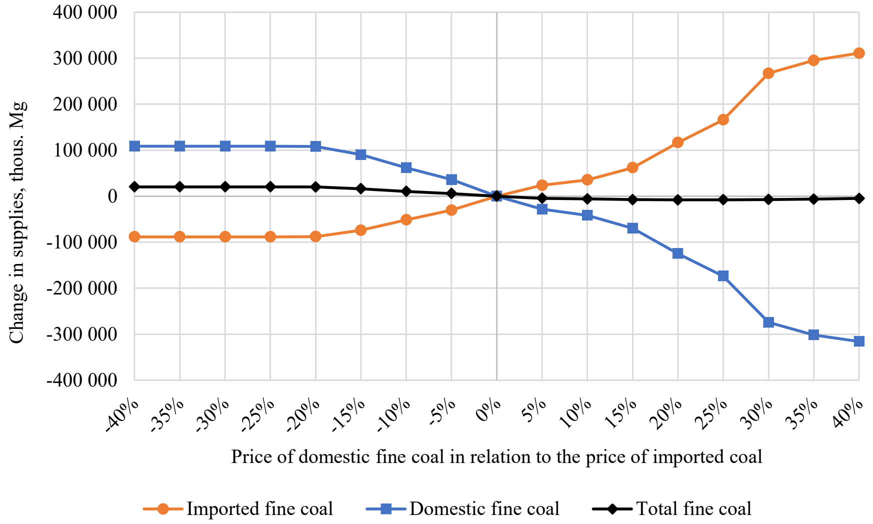

Fig. 8. Change in fine coal consumption with a variation in the coal price relationship (absolute differences in the total volume of deliveries in 2020–2025)

Rys. 8. Zmienność dostaw węgla w zależności od relacji cenowej (bezwzględne różnice w całkowitym wolumenie dostaw w latach 2020–2025)

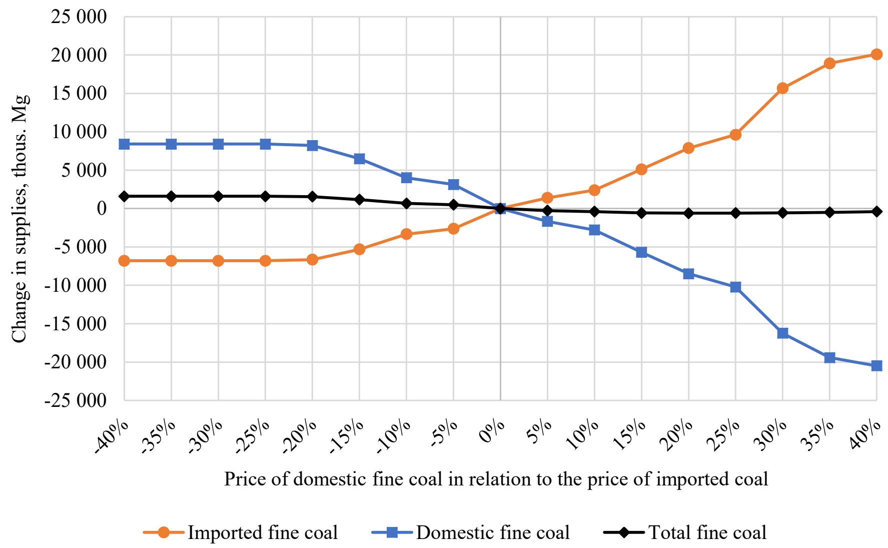

Fig. 9. Change in fine coal consumption in 2020 with a variation in the coal price relationship

Rys. 9. Zmienność zapotrzebowania na węgiel w zależności od relacji cenowej w 2020 roku

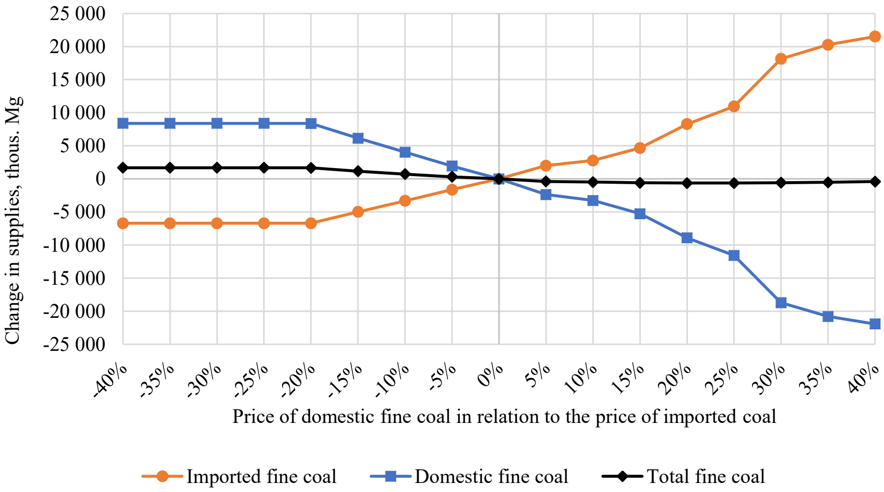

Fig. 10. Change in fine coal consumption in 2025 with a variation in the coal price relationship

Rys. 10. Zmienność zapotrzebowania na węgiel w zależności od relacji cenowej w 2025 roku

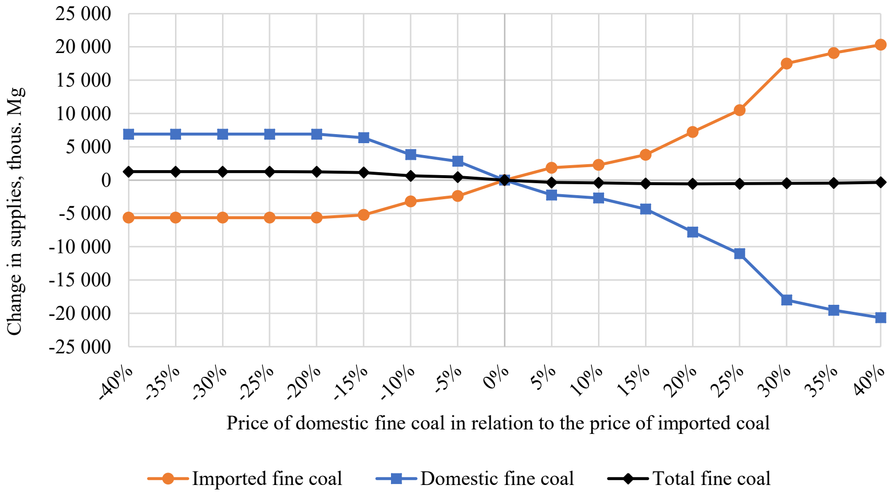

Fig. 11. Change in fine coal consumption in 2030 with a variation in the coal price relationship

Rys. 11. Zmienność zapotrzebowania na węgiel w zależności od relacji cenowej w 2030 roku

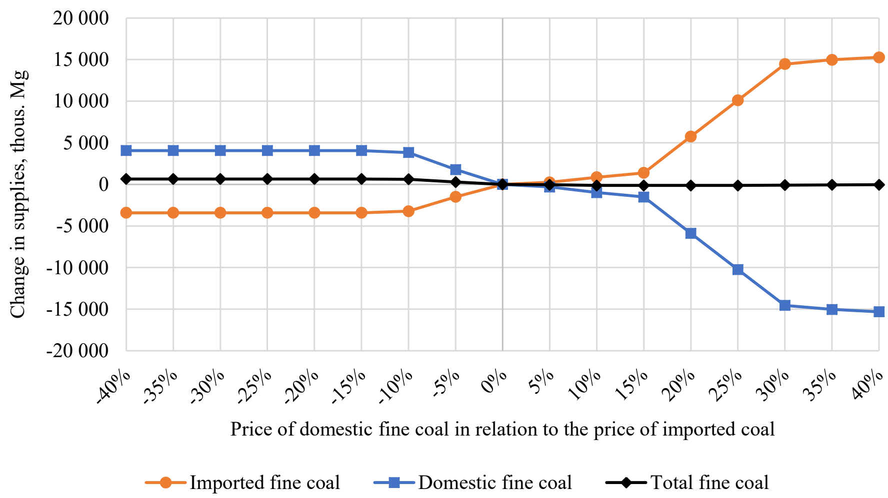

Fig. 12. Change in fine coal consumption in 2035 with a variation in the coal price relationship

Rys. 12. Zmienność zapotrzebowania na węgiel w zależności od relacji cenowej w 2035 roku

The results obtained under the model scenarios were subjected to geographical analysis in terms of the surplus or deficit of coal produced and supplied from domestic mines in relation to imported coal. Figures 13–19 present cartograms of Poland, divided into 73 statistical regions at the NUTS-3 level. For each region, the volume of fine coal consumption was calculated for the entire time horizon of the study (2020–2035) distinguishing the source of fuel supply. Then, the surplus or deficit of supplies in each region is calculated as the difference in the volume of coal supplies from a given source – positive values mean a surplus of domestic coal consumption, and negative values indicate a deficit (imported coal exceeding that from domestic sources).

Calculating the volume of fine coal consumption in each of the NUTS-3 regions required the employment of an appropriate procedure depending on the type of fuel consumer included in the mathematical model. The volume of coal consumption obtained by the model calculations under the research scenarios adopted was assigned to individual regions as follows:

- public power plants and public CHPs – exact location data for generating units was available; their fuel consumption was assigned to the corresponding NUTS-3 region,
- industrial CHPs – coal consumption in individual NUTS-3 regions was estimated using the structure of gross electric capacity available in individual units (for which steam coal was one of the basic fuels) – determined based on ARE SA (ARE SA 2017b),
- public heating plants – coal consumption in individual NUTS-3 regions was estimated using the structure of heat sales for communal and living purposes, determined based on data available in the Local Data Bank in the structure of administrative and statistical units according to NUTS-3 (GUS 2018),

- non-public heating plants – coal consumption in individual NUTS-3 regions was estimated using the structure of the geodetic surface of Poland, determined based on data available in the Local Data Bank in the structure of the administrative and statistical units according to NUTS-3 (GUS 2018).

Figures 13–19 present cartograms for the scenarios identified which enable one to visualize the territorial scope of coal supplies from a specific source (domestic mines or import points) depending on the price relationship. If the prices of reference domestic coal are 40% higher than the prices of imported coal (Figure 13), the supply of imported coal prevails over practically the entire country, except for a few regions located in the south and south-west of Poland. These regions are located at a relatively short distance from domestic hard coal mines and, therefore, far from seaports and railway border crossings. As the coal price relationship changes in scenarios +20%, +10% and 0% (which are depicted in Figures 14–16), supplies of domestic coal gradually increase towards the central part of Poland. A further change in the price relationship in favor of domestic coal (scenario –10%, Figure 17) results in domestic coal prevailing across almost the entire country, with the exclusion of some northern regions located close to seaports and railway border crossings). In the last two scenarios (–20% and –40%) (Figures 18 and 19), domestic coal dominates in all regions.

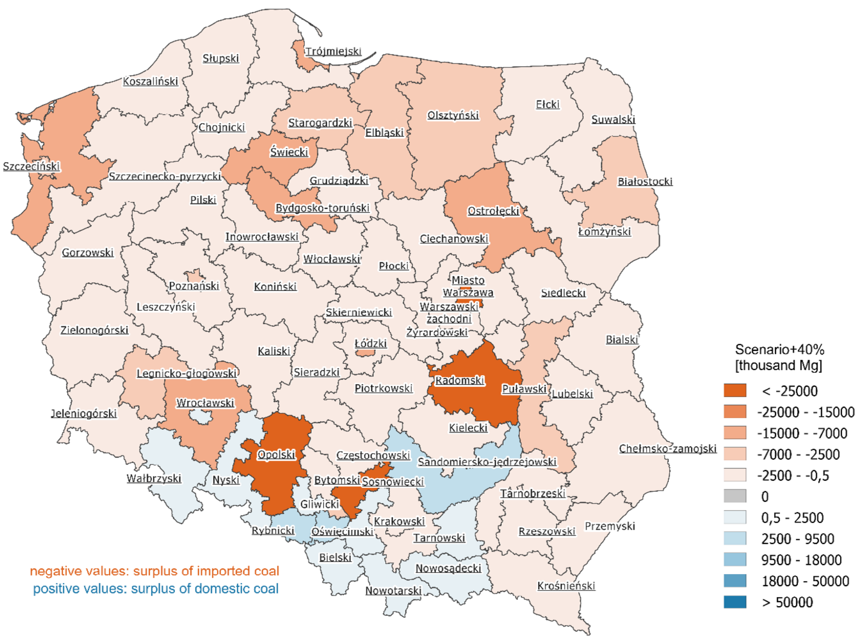

Fig. 13. Total fine coal consumption in 2020–2035 under scenario +40%

Rys. 13. Całkowite zapotrzebowanie na węgiel w latach 2020–2035 dla scenariusza +40%

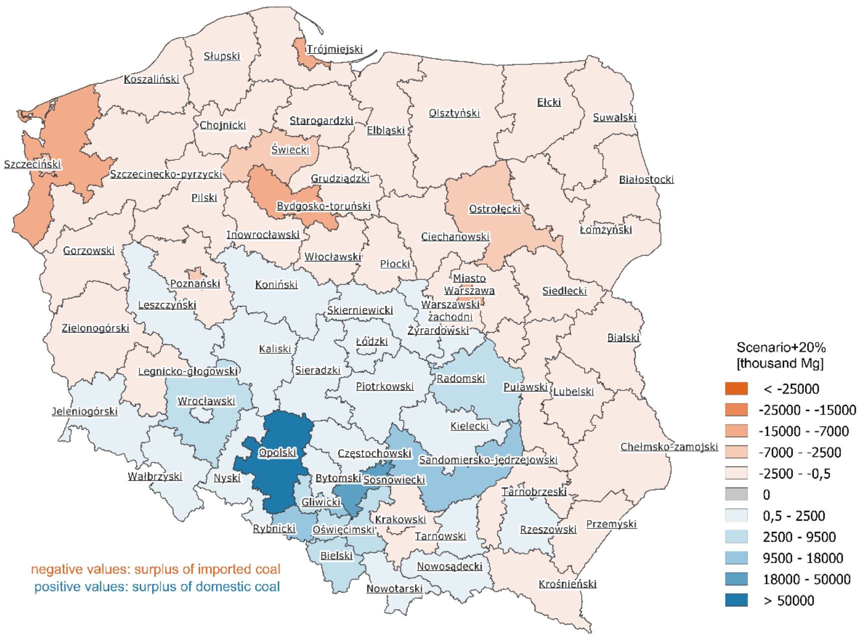

Fig. 14. Total fine coal consumption in 2020–2035 under scenario +20%

Rys. 14. Całkowite zapotrzebowanie na węgiel w latach 2020–2035 dla scenariusza +20%

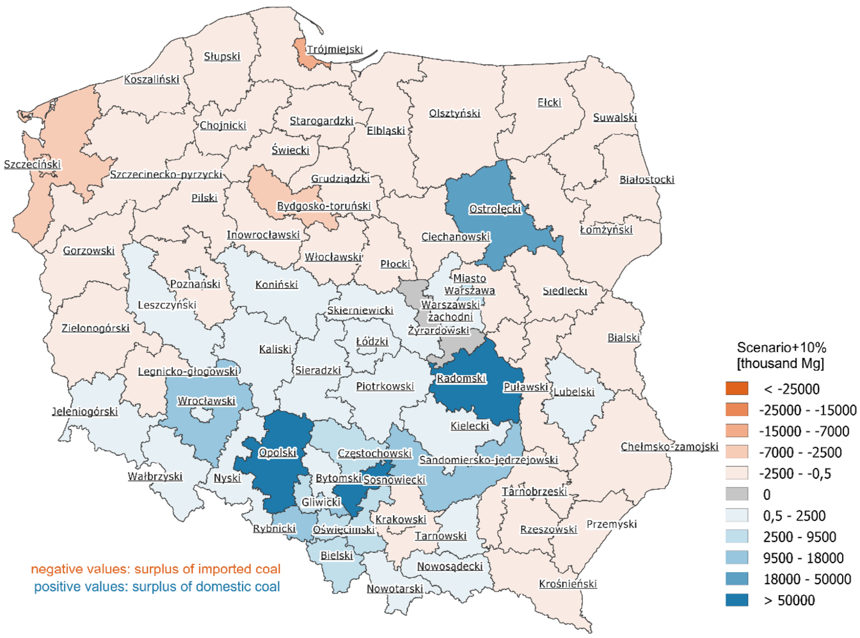

Fig. 15. Total fine coal consumption in 2020–2035 under scenario +10%

Rys. 15. Całkowite zapotrzebowanie na węgiel w latach 2020–2035 dla scenariusza +10%

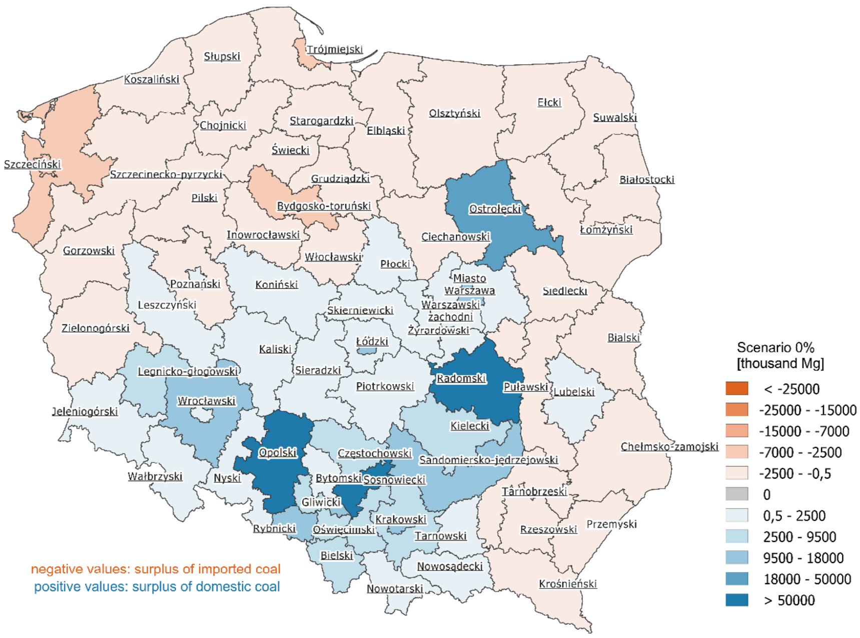

Fig. 16. Total fine coal consumption in 2020–2035 under scenario 0%

Rys. 16. Całkowite zapotrzebowanie na węgiel w latach 2020–2035 dla scenariusza 0%

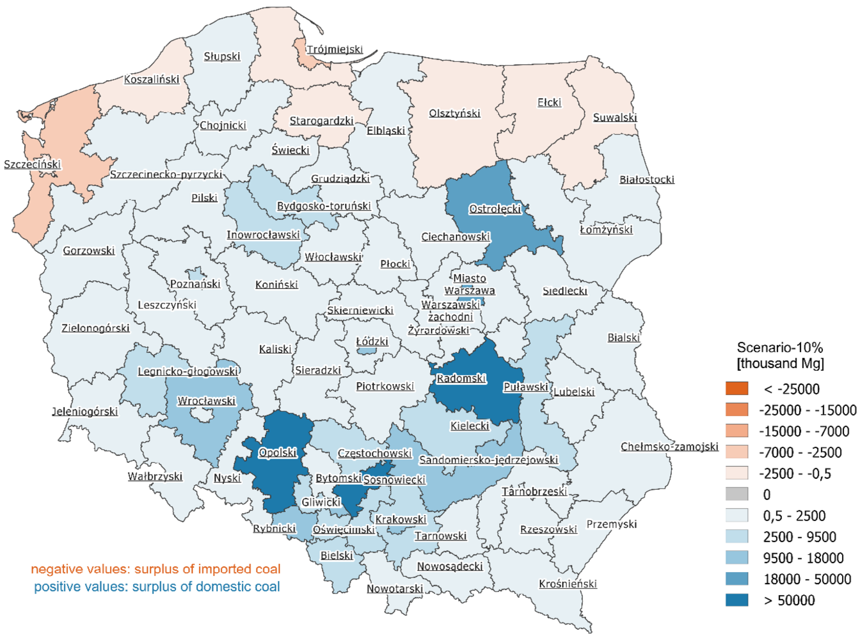

Fig. 17. Total fine coal consumption in 2020–2035 under scenario –10%

Rys. 17. Całkowite zapotrzebowanie na węgiel w latach 2020–2035 dla scenariusza –10%

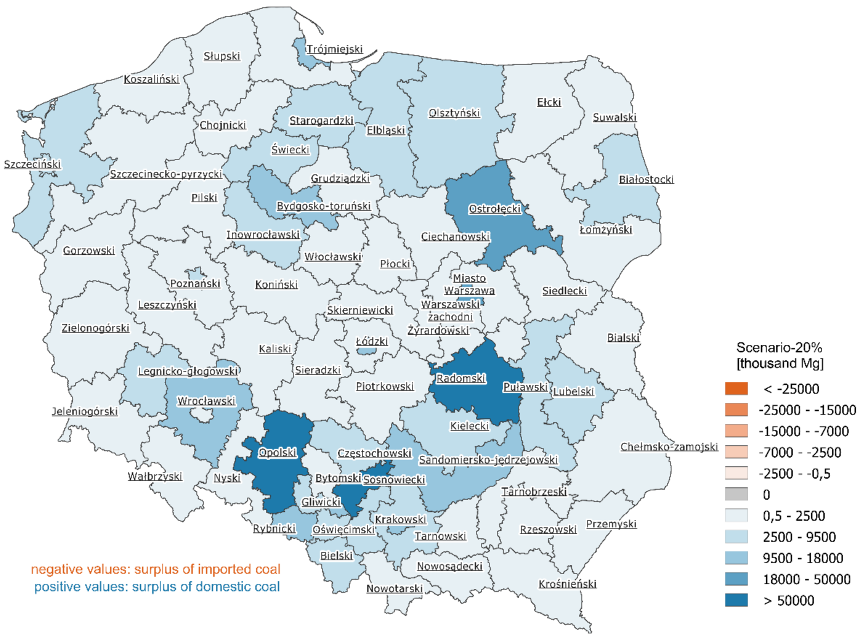

Fig. 18. Total fine coal consumption in 2020–2035 under scenario –20%

Rys. 18. Całkowite zapotrzebowanie na węgiel w latach 2020–2035 dla scenariusza –20%

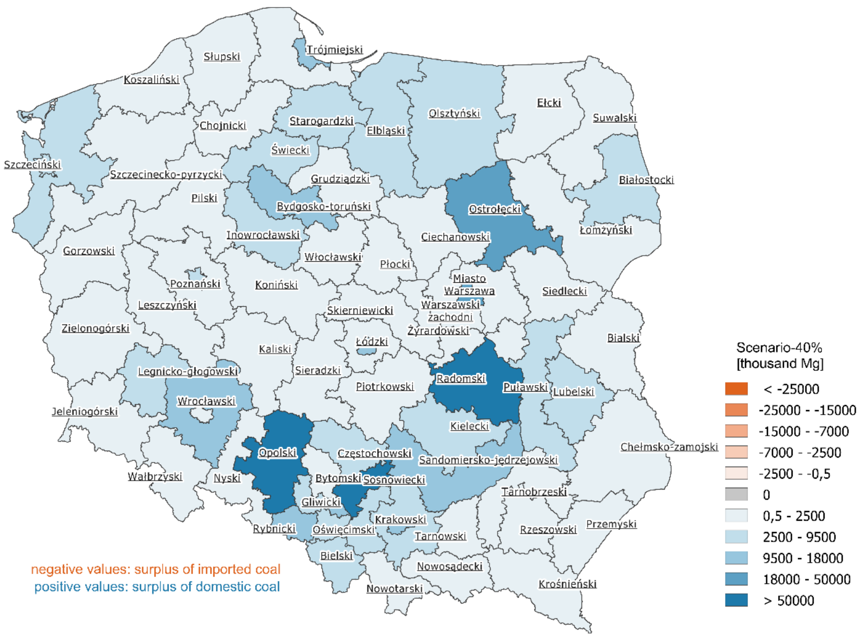

Fig. 19. Total fine coal consumption in 2020–2035 under scenario –40%

Rys. 19. Całkowite zapotrzebowanie na węgiel w latach 2020–2035 dla scenariusza –40%

Conclusions and policy implications

The decarbonization of economies is proceeding in most countries. It is particularly acute in countries that historically base their economy on fossil fuels. Poland is one of them – hard coal and lignite are still the dominant sources of energy, and their exploitation and consumption determine energy security. This paper investigated the impact of the price relationship between domestic and imported coal on the consumption of domestic fine coal in the Polish heat and power generation sector. The research allows coal companies to estimate the upper limit of costs at which the production of steam coal in domestic mines is profitable. The results can support policymakers and mine owners in making efficient decisions on the operation of mines. On that basis, they can determine production plans, the level of short-term production, and estimate region-dependent coal prices.

The analysis conducted and results discussed can also be considered in the context of the costs of hard coal mines operating in Poland, as well as the development by the State of an appropriate long-term development strategy for the entire mining sector. The sensitivity analysis performed as well as the cartograms produced directly indicate at which point in the domestic/imported coal price relationship it is more advantageous to purchase domestic coal (taking transport costs into account).

Based on the empirical analysis, this paper presents several implications for policy-makers, the hard coal mining sector, and the heat and power generation sector. They are summarized below:

1. The findings are important for countries and regions strongly dependent on hard coal; the regional impact of the price relationship between imported and domestic coal enables the better management of domestic exploitation/production.
2. The empirical analysis provides answers for coal companies and policymakers concerning the carrying out of work to ensure the most effective results on the basis of economic efficiency and the management planning of coal mining.
3. Considering the price relationship between domestic and imported steam coals, heat and power generation companies can determine their purchase plans based on their long-term efficiency and sign profitable agreements with hard coal mining companies.

This article aims to expand knowledge on the consequences of coal mining operation and sales policies depending on the forecast development of the international coal market. The conducted research allows us to draw conclusions which are appropriate not only for Poland, but also for other countries where hard coal is exploited.

The methodology applied can be employed in order to derive policy implications in other countries and regions where hard coal mines are located and steam coal is still widely consumed in heat and power generation systems. The methodology presented can also be applied in countries and regions where other fuels, such as biomass, are produced and distributed.

Future research on the impact of the price relationship between domestic and imported coal on the consumption of domestic fine coal in the heat and power generation sector should focus on further expansion of the model. In particular, the model could be reformulated in a way that enables one to introduce stochastic demand for coal. Also, a better representation of coal exporting countries (introduction of coal supplies instead of countries) should be considered.

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COMPETITIVENESS OF THE POLISH HARD COAL MINING SECTOR AS A FUEL SUPPLIER FOR HEAT AND POWER GENERATION

Keywords

competitiveness, steam coal, hard coal mining, fuel and energy sector

Abstract

The paper investigates the competitiveness of the Polish hard coal mining sector as a fuel source for heat and power generation. The main objective of the study is to make a quantitative assessment of the impact of the price relationship between domestic and imported steam coal on the consumption of domestic fine coal in the Polish heat and power generation sector. For this purpose, a long-term mathematical model of the Polish steam coal market is employed and scenarios that mimic the relationship between domestic and imported steam coal prices is developed. The following results are analysed:

- the volume of total domestic steam coal consumption under the scenarios analysed,
- the absolute difference in domestic steam coal consumption under the scenarios analysed in comparison with the scenario 0%,
- the total imported and domestic steam coal consumption in the period analysed.

In addition, the results were depicted in cartograms in order to present the distribution of domestic and imported coal consumption in the various regions of Poland.

The results of the study indicate that the supply of steam coal in Poland can be completely covered by domestic mines when the price of domestic coal is from –40% to –20% lower than that of imported coal. For the remaining scenarios, the consumption of imported coal increases and reaches its highest value in the scenario +40%, in which imported coal covered of 71% of total steam coal consumption in Poland over the period.

The conclusions presented in this paper provide valuable findings and policy insights into the competitiveness of domestic mines and management of domestic production both in Poland and other countries in which power generation systems are mostly dominated by coal.

KONKURENCYJNOŚĆ POLSKIEGO GÓRNICTWA WĘGLA KAMIENNEGO JAKO DOSTAWCY PALIWA DO PRODUKCJI ENERGII ELEKTRYCZNEJ I CIEPŁA

Słowa kluczowe

górnictwo węgla kamiennego, konkurencyjność, węgiel energetyczny, sektor paliwowo-energetyczny

Streszczenie

W artykule przeanalizowano konkurencyjność krajowego węgla energetycznego w porównaniu z węglem importowanym w kontekście jego wykorzystania do produkcji energii elektrycznej i ciepła.

Przeprowadzona została ilościowa ocena wpływu relacji cenowej węgla krajowego do węgla importowanego na stopień wykorzystania poszczególnych źródeł dostaw węgli. W tym celu wykorzystany został długoterminowy model krajowego rynku węgla energetycznego oraz opracowane zostały scenariusze odzwierciedlające różne relacje cenowe pomiędzy surowcem krajowym a importowanym. Analizie poddano następujące wyniki:

- wolumen całkowitego zapotrzebowania na węgiel kamienny energetyczny w krajowym systemie wytwarzania,
- bezwzględną różnicę zapotrzebowania na krajowy węgiel w porównaniu ze scenariuszem referencyjnym,
- sumaryczne zapotrzebowanie na węgiel krajowy i importowany w analizowanym okresie.

Ponadto wyniki zostały zaprezentowane na kartogramach w celu przedstawienia zapotrzebowania na węgiel krajowy i importowany w poszczególnych regionach Polski.

Wyniki przeprowadzonych badań wskazują, że zapotrzebowanie na węgiel energetyczny może być w całości pokryte przez paliwo produkowane w krajowych kopalniach, gdy jego cena jest niższa od węgla importowanego w zakresie od 20 do 40%. W pozostałych przypadkach zapotrzebowanie na surowiec importowany wzrasta i osiąga najwyższą wartość w scenariuszu zakładającym cenę węgla importowanego o 40% niższą w porównaniu z ceną węgla krajowego.

Wyniki przeprowadzonej analizy umożliwiają sformułowanie wniosków dotyczących konkurencyjności krajowych kopalń i zarządzania krajową produkcją nie tylko w Polsce, ale również w innych państwach, w których dominującym paliwem jest węgiel kamienny.