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The impact of long-term contracts of the capacity market on the consumption of steam coal in the power system

Introduction

The capacity market is a capacity remuneration mechanism that has been in force in Poland since 2018 (Dz.U. 2018 poz. 9). This mechanism was introduced in order to ensure adequate capacity in the power system in the long term (Milstein and Tishler 2019) in periods of energy transition and the dynamic development of the not-dispatchable renewable power units (Olczak and Surma 2023). The tradable product is capacity (expressed in MW), and companies declare their readiness to meet the demand in system stress events by participating in capacity auctions (Cramton and Ockenfels 2012). Companies submit their offers, including the quantity of capacity they can declare, with consideration to de-rating factors of units and exit prices. The capacity market is regulated by the Capacity Market Law (Dz.U. 2018 poz. 9) and the Capacity Market Rules (PSE 2020). The key executive and administration bodies are the Transmission System Operator (TSO) and the Energy Regulatory Office (ERO).

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Thus far, seven main capacity auctions have been conducted for 2021–2027 delivery years. Table 1 shows the results of these auctions where:

a) the market-clearing price is the price at which the demand announced by the TSO is equal to the supply offered by the participants of the auctions in the last round – the market clearing-price is shown only for capacity market units located in Poland;
b) the price cap is the maximum price of the auction set by the TSO;
c) the capacity obligation is the quantity of the capacity purchased in the auction;
d) the total capacity obligation is a sum of the quantity of the capacity purchased in the auction and the capacity purchases in the previous auctions for the specific delivery year;
e) round is a number of the round in which the auction was cleared;
f) winning bids is the number of bids that won the specific capacity auction for the delivery year.

The capacity auction mechanism and final results are analyzed and discussed in detail by Kaszyński et al. (Kaszyński et al. 2021), Jasiński et al. (Jasiński et al. 2021), and Komorowska et al. (Komorowska et al. 2023). Therefore, the further part of the study is focused on the impact of the capacity market on coal consumption.

Table 1. The results of the main capacity auctions for 2021–2027 delivery years

Tabela 1. Wyniki aukcji mocy głównych na lata dostaw 2021–2027

Parameter	Unit	2021	2022	2023	2024	2025	2026	2027
a) Market-clearing price	zł/kW/year	240.32	198.00	202.99	259.87	172.85	400.39	406.35
b) Price cap	zł/kW/year	327.80	366.00	406.90	404.30	414.70	400.40	406.35
c) Capacity obligation	MW	22,427.1	10,580.1	10,631.2	8,671.2	2,367.3*	7,188.6	5,379.2
d) Total capacity obligation	MW	22,427.1	23,038.9	23,215.0	22,107.6	21.472.8	18,821.9	18,712.4
e) Round	–	5	7	8	5	7	1	1
f) Winning bids	–	160.00	120.00	94.00	103.00	55.00	128.00	95.00

* Of which 275.7 MW are for the period from January 1 to June 30, 2025.
Source: ERO 2018a, ERO 2018b, ERO 2019a, ERO 2019b, ERO 2021, ERO 2022, and ERO 2023.

The mechanism was approved by the European Commission, provided that units that emit more than 550 kg CO_2/MWh will be excluded from the support from July 1, 2025 (European Parliament and Council 2019). As a result, the majority of coal units participated in capacity auctions for delivery periods of January 2021–July 2025 in order to receive remuneration. After this date, only power generation units that fulfil the emissions constraints can participate in the capacity market. In practice, among thermal power units, only natural gas or biomass power plants and combined heat and power plants can be supported by this mechanism.

The auctions in which the coal units were allowed to participate were mostly cleared by the coal power plants and combined and heat power (CHP) plants (Kaszyński et al. 2021). Moreover, the abovementioned regulations of emission constraints ensure that long-term contracts will have been in force throughout their entire duration. For example, if the coal power plants won the auctions in 2018 and the contracts were signed for a period of fifteen years, these units receive remuneration for those fifteen years even if the emission limit is not met.

As a result, despite the introduction of emission limits on coal units, the consequences of their long-term contracts will be observed in the years to come. The results of the previous auctions will have a significant impact on the future hard coal demand, despite the introduction of new regulations. The quantitative analysis performed in this paper facilitates the assessment of hard coal consumption resulting from the contracts signed under the capacity market mechanism.

1. Study objectives and contribution

To the best of the author's knowledge, there is no work in which the assessment of the potential coal consumption in the power generation units that contracted capacity obligation is investigated. As a result, this study is aimed at examining the results of the capacity auctions conducted, investigating the structure of the units that contracted capacity obligations, and analyzing the profiles of electricity production in public thermal hard coal power plants and CHP plants to estimate demand for hard coal due to the capacity market contracts.

This study contributes to the existing body of literature by providing evidence-based findings on scenarios of coal consumption in the years to come. The implementation of European climate policy and energy transition processes requires qualitative analyses to plan and develop strategies for decarbonization, ensuring energy security and the social acceptance of transformation, particularly in regions in which mines and coal power plants have historically played a key role in economic growth.

The paper is structured as follows. Section 2 analyses the main capacity auctions held by 2022 for the 2021–2027 delivery years and presents the methodological approach adopted in the study. Section 3 discusses the result with regard to capacity obligation, electrical capacity in hard coal units with capacity market contracts, and ranges of potential coal consumption. Finally, a summary and conclusions are drawn in Section 4.

2. Materials and methods

The methods applied in the study involve desk research, data collection and data analysis (Figure 1). Firstly, the documents with the official results of capacity auctions held from 2018–2022 were collected. These documents contain the outcomes for the 2021–2027 de-

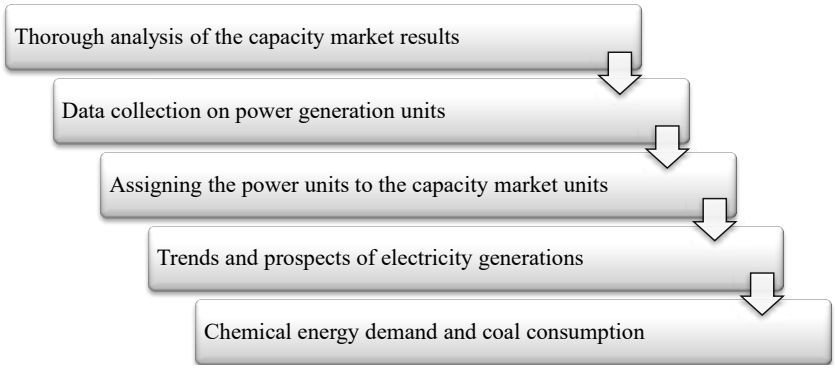

Fig. 1. Scheme of the research procedure

Rys. 1. Schemat procedury badawczej

livery years. In 2018, there were three capacity auctions for the 2021–2023 delivery years (Komorowska and Kamiński 2019). Capacity auctions were then conducted each year for the following delivery years. The official outcomes include information about the total capacity that was contracted, the market-clearing price, the number of rounds in the auction, the types of capacity market units, the capacity contracted by each capacity market unit, the length of contact and the capacity provider (ERO 2018a–2023). The capacity market units are described as existing, refurbishing or new power generation units or demand side response (DSR) units. Please note that the documents do not include any information about individual power generation units, their location and fuels used to produce electricity.

Secondly, based on the official documents, technical parameters of the public thermal power plants and CHPs deployed in the power system, fuel structure, public information presented by generation companies and databases managed by the Mineral and Energy Economy Institute of the Polish Academy of Sciences, the capacity market units are assigned to actual existing or planned power generation units.

Thirdly, the post-processed database is used in the assessment of results of the capacity auctions with regard to the structure of power generation units and fuels used for electricity generation. The structure and length of the contracts facilitated the assessment of the potential capacity factors of existing and planned power generation units.

Finally, the hard coal consumption in public thermal power plants and CHPs is calculated as shown in Equations (1)–(5).

The electricity generation (EG_{cmu}) of each hard coal capacity market unit (*cmu*) is estimated based on the electrical capacity and the historical availability factor (AF_{cmu}) for units above the capacity of 500 MWe or historical capacity factor (CF_{cmu}) for the remaining units (Equations (1)–(2)). Data on availability and capacity factors are sourced from energy statistics published by the Energy Market Agency (ARE 2020–2022). The boundary is set at 500 MWe due to the classification presented in reports describing the Polish power sector.

$$\bigwedge_{cmu>500\text{MWe}} EG_{cmu} = Capacity_{cmu} \cdot 8760 \cdot AF_{cmu} \tag{1}$$

$$\bigwedge_{cmu<500\text{MWe}} EG_{cmu} = Capacity_{cmu} \cdot 8760 \cdot CF_{cmu} \tag{2}$$

The chemical energy demand (CED_{cmu}) required for electricity generation is then calculated as a yearly electricity generation (EG_{cmu}) in each capacity market unit (*cmu*) over the electrical efficiency of this unit (EF_{cmu}) multiplied by the ratio of unit conversion from MWh to GJ (*CR*), which is 3.6 (Equation (3)).

$$\bigwedge_{cmu\in 500\text{MWe}} CED_{cmu} = \frac{EG_{cmu}}{EF_{cmu}} \cdot CR \tag{3}$$

The chemical energy demand is then used to estimate the hard coal consumption in each capacity market unit as shown in Equation (4), where Q_{cmu} stands for the average calorific value of the hard coal in each unit.

$$\bigwedge_{cmu\in CMU} CC_{cmu} = \frac{CED_{cmu}}{Q_{cmu}} \tag{4}$$

To examine the total consumption of hard coal in power generation units related to contracted capacity obligations in the years to come, Equation (5) is used. The total consumption (*CC*) is the sum of coal consumption in each capacity market unit fueled by hard coal.

$$CC = \sum_{cmu} CC_{cmu} \tag{5}$$

The analysis is conducted for three scenarios, reflecting the minimum (MIN), average (AVG) and maximum (MAX) coal consumption in hard coal units in capacity market units by 2035. In the case of new generation units (Kozienice, Opole and Jaworzno), data on the annual availability factors (AF) for units with a capacity of more than 500 MWe operating in the national power system is used as follows (ARE 2020–2022):

- MIN scenario: the average of the lowest AF for the period of three years (2019–2021);
- AVG scenario: the average of the mean AF for the period of three years (2019–2021);
- MAX scenario: the average of the highest AF for the period of three years (2019–2021).

The availability factors are assumed based on the average of minimum, mean, and maximum values observed, giving 0.73, 0.78, and 0.84 in the MIN, AVG and MAX scenarios, respectively.

In the case of other generating units, historical data on capacity factors (CF) adjusted to individual generating units are used instead of availability indicators. The factors are also assumed individually for each scenario, considering the minimum (MIN), average (AVG)

and maximum (MAX) values for the period of three years (2019–2021). Depending on the type of power generation units and their capacity, the capacity factors ranged from 0.12 to 0.48 in the MIN scenario, from 0.28 to 0.51 in the AVG scenario, and from 0.28 to 0.73 in the MAX scenario.

3. Results

The analysis of the results of the main capacity auctions is performed in several stages, which results from the lack of detailed information allowing the direct identification of the generating units that won capacity contracts for a given delivery year. The capacity obligation is determined based on a decision covering the expected level of revenues from the capacity market and the risk resulting from possible failures to meet the capacity contract. As a consequence, the exact identification of generating units, including their primary fuel, that have won auctions requires a comprehensive analysis. Figure 2 presents the result of the analysis performed on the basis of a cross-combination of all published information, publicly available press releases and expert knowledge on the existing and planned generation units of domestic energy companies. The estimated capacity obligations of power units that signed contracts in previous capacity auctions are broken down by the type of fuel/technology.

Hard coal and lignite power generation dominated the first capacity auctions, which covered the 2021–2024 delivery years. Although they mainly obtained one-year contracts, in the auctions for 2021 and 2024 (the first and fourth capacity auctions), five-year capacity contracts were also concluded by the refurbishing units. In addition, during the first capacity auction, new generation units were contracted (for fifteen years), including newly built units in the Kozienice (1,075 MWe), Jaworzno (910 MWe), Opole (2 × 900 MWe) and Turów (496 MWe) power plants. As a consequence, the aggregated estimated volume of capacity obligations of coal units receiving support in the capacity market in 2023–2025 may amount to approximately 14.9–17.5 GW, which is respectively 72.3–78.3% of the total contracted capacity volume during the main auctions.

A significant reduction in coal capacities will take place after 2025 and 2028 to approximately 7.5 GW and 3.6 GW, respectively (41% and 35% of the total volume). This is due to two reasons: (i) the end of the five-year refurbishing contracts in auctions for the 2021 and 2024 delivery years, and (ii) the entry into force of the EU regulation 2019/943 from June 5, 2019, on the internal market for electricity (European Parliament and Council 2019) limiting the support from the capacity remuneration mechanisms to high-emission units. This results in the elimination of support from the mechanism for new coal units, while long-term capacity contracts obtained before that date remain valid. However, it can be observed that some coal units (like the Połaniec power plant) have been contracted for delivery years in 2026 and 2027, which are to be adapted to the co-firing of significant amounts of biomass – around 50% in order to meet the specific emission coefficient.

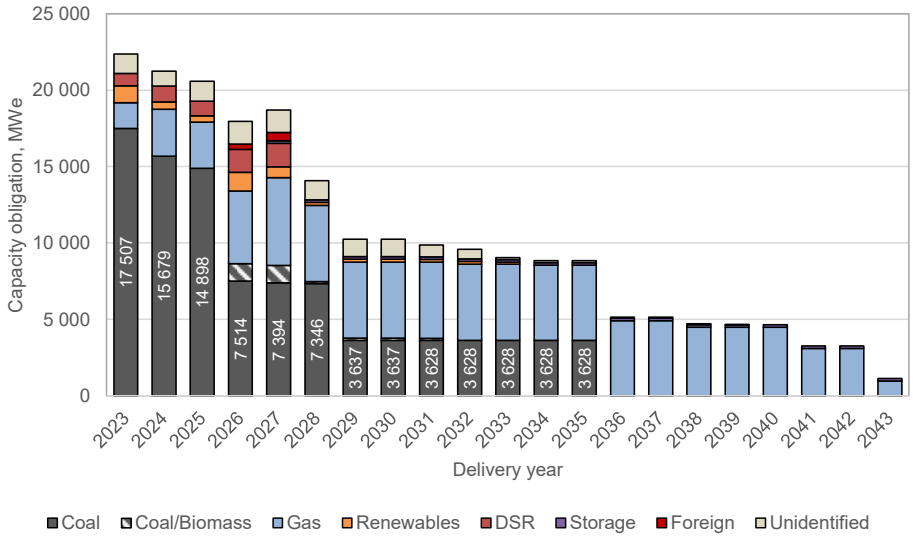

Fig. 2. The estimated capacity obligations of power units that signed contracts in previous capacity auctions, broken down by type of fuel/technology, MWe

Rys. 2. Szacowane zobowiązania mocowe jednostek wytwórczych, które podpisały umowy w poprzednich aukcjach mocy w podziale na rodzaj paliwa/technologię, MWe

In the next stage of the analysis, lignite units are identified and eliminated from the developed database. Then, based on available data (e.g. information on the generation capacity of PSE SA and the catalog of commercial power plants and combined heat and power plants of the ARE), electrical capacity is assigned to the remaining generating units. In some cases, when proper identification of a generating unit is not possible, its electric capacity is determined using the quotient of the contracted capacity obligation and the de-rating factor.

Due to this approach, the value of the generation capacity may be underestimated, but it is certainly not overestimated. This is a direct result of the capacity market regulations, stating that the maximum volume of the capacity obligation that can be submitted in a capacity auction must result from the product of the net capacity of a given unit and the de-rating factor determined for a given power technology (in the case of steam turbines, the de-rating factor was at the level of 91.5–92.9%, depending on the delivery year covered by the capacity auction). The estimated electrical capacity of hard coal units that won capacity contracts in the past auctions is presented in Figure 3. As in the case of a capacity obligation contracted by coal units, the largest reductions are observed after 2025 and 2028.

The next stage of the analysis is focused on the assessment of the demand for chemical energy necessary for the production of electricity in the generating units. For this purpose, the available detailed and averaged data on electrical efficiency are assumed.

As discussed in the material and methods section (Equation (4)), the estimated demand for chemical energy is then divided by the average calorific value of hard coal used in power

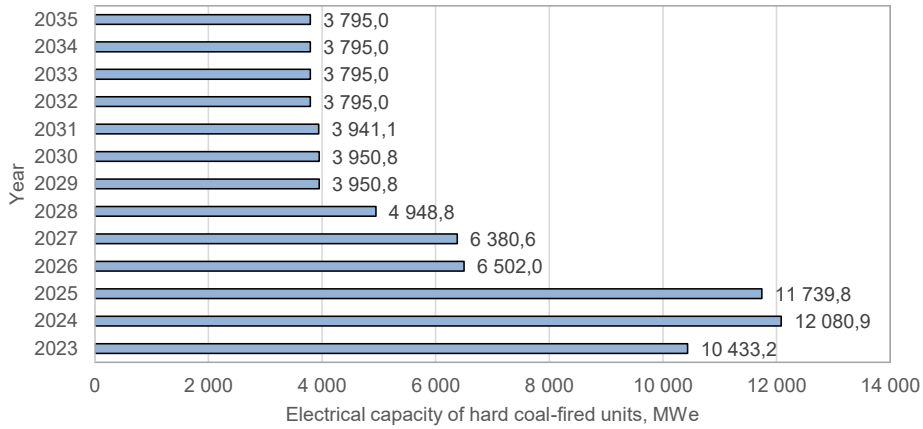

Fig. 3. The estimated electrical capacity of hard coal units that won capacity contracts in the past auctions, MWe

Rys. 3. Szacunkowa moc elektryczna węglowych jednostek wytwórczych, które wygrały kontrakty mocowe w poprzednich aukcjach, MWe

plants and CHPs operating in Poland. Finally, the potential total demand for steam coal used in generation units (for electricity production) that received support under the capacity market is estimated for the years 2023–35 (Figure 4).

The estimated volume of demand for steam coal in the AVG scenario oscillates in the range of 21.3–23.6 million Mg up to 2025 and then decreases to the level of approximately

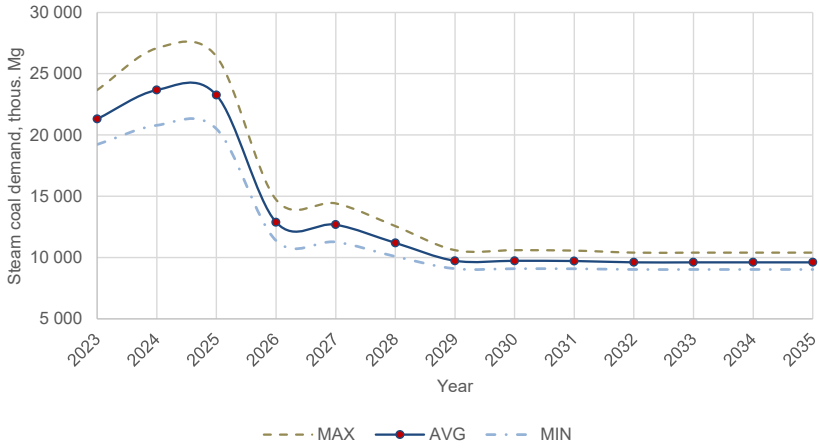

Fig. 4. Forecast of demand for steam coal used for electricity production in power generation units receiving remuneration under the capacity market in Poland in 2023–2035, thousand Mg

Rys. 4. Prognoza zapotrzebowania na węgiel energetyczny wykorzystywany do produkcji energii elektrycznej w jednostkach wytwórczych otrzymujących wynagrodzenie w ramach rynku mocy w Polsce w latach 2023–2035, tys. Mg

11.1–12.9 million Mg for 2026–28. In the subsequent years, when the last of the five-year contracts for the refurbishing units are completed, the demand may stabilize at the level of approximately 9.7 million Mg by the end of the forecast horizon (2035). The entire demand will then come from four new generation units, specifically those in Kozienice, Opole and Jaworzno.

Conclusions

The study has discussed the impact of long-term capacity market contracts on the consumption of steam coal in the power system. Considering the dominant share of hard coal power units in the first capacity auctions, the analysis required a comprehensive examination of the potential ranges of coal consumption in the short- and long-term. For this purpose, the techno-economic method and data describing the Polish power system were applied.

The results have shown that the electrical capacity of hard coal units that won capacity auctions was around 10.4 GWe in 2023. The electrical capacity of hard coal units increased to 12.1 and 11.7 GWe in 2024–2025 and then decreased to around 4.9 GWe by 2028. After this year, the estimated electrical capacity decreased to over 3.8 GWe by 2035. Although the dynamic decrease is observed through the period investigated in the study, the quantity of capacity remains significant and will have an impact upon the consumption of steam coal in the Polish power sector.

The study shows that, depending on the scenario, total coal consumption may range from 19,221 to 23,670 thousand Mg in 2023, achieving an average value of 21,309 thousand Mg. An increase is then observed, with peak consumption being achieved in 2025, from 20,498 thousand Mg in the MIN scenario to 26,406 thousand Mg in the MAX scenario. After this year, a dynamic decrease is observed and the total coal consumption ranges from 11,376 to 14,720 thousand Mg in 2026. Then, a gradual decrease is noticed, with there being a stable coal consumption from 2029 to 2035, ranging from 9 to over 10 thousand Mg, depending on the scenario.

According to the forecast presented in the Polish Energy Policy until 2040, the total consumption of hard coal will decrease from 24,539 Mg thousand Mg in 2025 to 12,527 thousand Mg in 2035 in the minimum scenario and from 28,112 Mg thousand Mg in 2025 to 20,673 thousand Mg in 2035 in the maximum scenario. However, the forecasts include demand in all sectors in which hard coal is consumed, including power and heating systems, households, transport, etc. As a result, the results obtained in the present study are covered by the results presented in the key strategic Polish document.

The results indicate the impact of the capacity market with regard to steam coal in Poland even though European regulations to limit the remuneration for high-emission units have been introduced. The results provide valuable insights into the development of decarbonization strategies, coal phase-out policies and an update of the sectoral forecast of coal consumption in the economy undergoing energy transition.

The outcomes of this study indicate the estimation of potential demand for steam coal for electricity production resulting only from the capacity agreements signed under the capacity remuneration mechanism. Apart from these units, other coal power plants and combined heat and power plants may still operate in the system in the coming years, ensuring the secure operation of the power system during its transition.

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THE IMPACT OF LONG-TERM CONTRACTS OF THE CAPACITY MARKET ON THE CONSUMPTION OF STEAM COAL IN THE POWER SYSTEM

Keywords

capacity market, coal consumption, coal power plants, power system

Abstract

The capacity market is a response to potential capacity scarcity in the system. The missing money problem may occur as a result of the dynamic development of renewable energy sources because their capacity factors are significantly lower in comparison to those of conventional generating units. The capacity market is a response to capacity scarcity in dynamic growth in renewable energy sources with lower capacity factors than thermal power plants. It is a support mechanism that provides additional funds in order for generation companies to be ready to produce electricity in system stress events. So far, seven capacity auctions have been held for 2021–2027 delivery periods. Since the vast majority of capacity market units are coal-fired public thermal power plants and combined heat and power plants, the analysis of capacity auction results provides valuable findings on coal consumption in the years to come. With this in mind, the objective of the study is to investigate the potential of coal consumption resulting from the long-term capacity contracts signed thus far. For this purpose, a comprehensive analysis of the capacity auctions' results is conducted, including the analysis of the duration of the contracts, the structure of ownership, and fuels used in power units. The results show that the figures relating to the consumption of steam coal in units that have won capacity auctions are around 21,306 thousand Mg for 2023 and decreasing to 9,603 thousand Mg for 2035. Although European restrictions were introduced to limit remuneration for high-emission units, the long-term contracts ensure that these will remain in the system and will have an impact on the total consumption of steam coal in the medium- and long-term in the Polish power system.

WPŁYW KONTRAKTÓW DŁUGOTERMINOWYCH RYNKU MOCY NA ZAPOTRZEBOWANIE NA WĘGIEL KAMIENNY ENERGETYCZNY W KRAJOWYM SYSTEMIE ELEKTROENERGETYCZNYM

Słowa kluczowe

system elektroenergetyczny, rynek mocy, zapotrzebowanie na węgiel, jednostki wytwórcze

Streszczenie

Rynek mocy stanowi odpowiedź na potencjalne niedobory mocy zainstalowanej w systemie, które mogą wystąpić na skutek dynamicznego rozwoju odnawialnych źródeł energii, których współczynnik wykorzystania mocy jest znacząco niższy w porównaniu z możliwą dyspozycyjnością konwencjonalnych jednostek wytwórczych. Rynek mocy jest mechanizmem wsparcia zapewniającym dodatkowe wynagrodzenie za pozostanie w dyspozycyjności w systemie oraz dostarczanie mocy w okresach zagrożenia. Dotychczas przeprowadzono siedem głównych aukcji mocy na okres dostaw 2021–2027. Ponieważ zdecydowana większość jednostek, które zawarły umowy mocowe, to elektrownie i elektrociepłownie wykorzystujące węgiel kamienny do produkcji energii elektrycznej, analiza wyników aukcji mocy dostarcza cennych informacji dotyczących potencjalnego zapotrzebowania na węgiel w sektorze energetyki. W świetle zaprezentowanych uwarunkowań, celem artykułu jest przeprowadzenie analizy, która umożliwi oszacowanie potencjalnego wolumenu zapotrzebowania na węgiel kamienny przez jednostki, które są dotychczasowymi beneficjentami rynku mocy. Wyniki wskazują, że zapotrzebowanie na węgiel kamienny energetyczny w jednostkach, które wygrały aukcje, moc wynosi 21 306 tys. Mg w 2023 roku i stopniowo maleje, osiągając poziom 9603 tys. Mg w 2035 r. Należy zwrócić uwagę na fakt, że chociaż w ostatnich latach obowiązują już restrykcje ograniczające wsparcie finansowe dla jednostek wytwórczych przekraczających limity emisji CO_2, to długotrwałe kontrakty zawarte w poprzednich latach przez jednostki węglowe zapewniają pozostanie im w krajowym systemie elektroenergetycznym i w konsekwencji, wpływają na zapotrzebowanie na węgiel energetyczny w Polsce w horyzoncie średnio- i długoterminowym.