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Coal supply prospects in Poland and Selected European Union Countries

Introduction

Total world coal reserves at the end of 2019 amounted to 1,069,636 million Mg (BP 2020), of which 70% was bituminous coal and anthracite, while the remaining 30% was sub-bituminous coal and lignite. Among the world's coal resources more than 7% are the reserves of the European Union (76 485 million Mg) and 26.9 million Mg is in Poland (BP 2020). It is worth noting that the quoted number of world reserves of the raw material has increased significantly, as the report (BP 2002) states twenty years earlier, in 2001, the total coal reserves were less by over 85 billion Mg.

In 2000, the world's output of hard coal amounted to about 3.64 billion Mg, followed by rapid growth and has remained almost constant at about 7.0 billion Mg per year for several years now (in 2020 it was 6.9 billion Mg) (Tajduś 2021). Thus, the world's crude oil production nearly doubled, with the main contributors countries of South-East Asia, Australia, South America and Russia.

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In contrast, the World Energy Outlook estimates that the global coal consumption will decline by 4.2% per year (WEO 2019). Moreover, the latest report also predicts that coal's share of the global electricity generation balance will fall from 37% in 2019 to 28% in 2030 (calculations prepared for the Stated Policies Scenario – STEPS), and to 15% (in the Sustainable Development Scenario – SDS) over the same period (WEO 2021).

In addition, projected coal demand growth in Asia's developing economies is markedly lower than in previous editions of the World Energy Outlook and is insufficient to offset declines in other countries. Coal use in the electricity sector is strongly affected by the decline in energy demand, (as estimated by the International Energy Agency (IEA 2021) global energy demand in 2020 fell by 4%, the largest decline since World War II and the largest ever absolute decline) occurring during the COVID-19 pandemic, and its use in industry is constrained by lower economic activity. In 2020 the largest declines in coal use for electricity generation were in advanced economies, down 15%, which accounts for more than half of coal's global decline (IEA 2021).

The ever-increasing popularity of the introduction of a coal phase-out policy among countries, mainly European, the development of renewable energy sources and strong competition from gaseous fuel (natural gas) are leading to the phase-out of 275 GW of coal-fired capacity worldwide by 2025 (13% of total capacity in 2019), including 100 GW in the United States and 75 GW in the European Union.

However, we can find a positive note from the coal industry's point of view in the latest editions of the Coal Reports, which reported that in 2021, coal demand has rebounded strongly, reversing all of the declines in 2020, though with major geographic variations. The decline in 2020 was concentrated in the United States and Europe, and demand in advanced economies is expected to recover only by one quarter of its 2020 drop, curtailed by renewables deployment, lower gas prices and phase-out policies. Meanwhile, China is projected to account for 55% of the 2021 increase. Moreover, China is the only major economy where coal demand increased in 2020.

Prices for the most competitive and widely used coal substitute, natural gas, are also expected to rise in 2021, leading to some switching back to coal, notably in the United States and the European Union.

In view of the above information, it can be concluded that coal consumption will, globally, still be significant.

Taking ecological aspects and the pursuit of pro-environmental policy into account, we should remember that the coal combustion process is the main source of sulphur dioxide emissions. It is known that during the energetic use of this raw material, among others, in power plants and combined heat and power plants, particulate matter, nitrogen oxides and sulphur oxides are emitted to the atmosphere, and above all significant amounts of carbon dioxide, which is the main cause of the greenhouse effect. In Poland, the energetic combustion of fuels is responsible for 97% of national sulphur dioxide (SO_2) emissions (KOBiZE 2019). A significant amount of sulphur dioxide is released during coal combustion in households – it is estimated to be about 29%. The intensity of SO_2 emissions from household coal

combustion is about five to eigh times higher than that from power plants (Zhang et al. 2020), which, in an era of increasingly stringent environmental standards, and the move towards zero emissions in European Union countries, will involve taking action to reduce emissions.

1. The Polish Coal Market

The coal mining sector in Poland has been the cornerstone of the country's raw materials economy for many years. Although its existence is currently highly controversial, it is still one of the most important industrial sectors in Poland. For several years, Poland has been one of the leading European Union countries in terms of coal production (Figure 1). Domestic hard coal mining constitutes over 50% of the EU's production, of which it is estimated that 59% is energy coal, while 39% is coking coal (Euracoal 2006–2020).

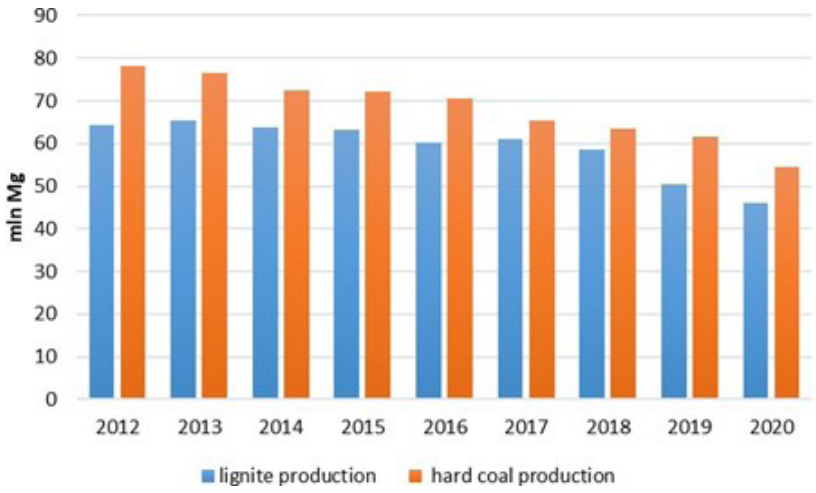

Fig. 1. Coal production in Poland in years 2012–2020, mln Mg
Sources: own study based on (Euracoal Statistics 2012–2020)

Rys. 1. Produkcja węgla w Polsce w latach 2012–2020 [mln Mg]

Based on the PEP 2040 Project and analyzing the case of Poland and the assumptions of the "Energy Policy of Poland until 2040" (project) we can state that the consumption of hard coal in electricity generation in Poland will remain at a level of 60% with a decreasing trend. In the forecast prepared in the document, coal consumption was assumed at the level of 36 million Mg in 2025, 33 million Mg in the years 2030–2035 and 30 million Mg in 2040. A decrease in the use of coal raw material will be compensated by an increase in the consumption of other energy carriers (PEP2040 project). However, according to the current final official version of the document adopted by the Council of Ministers on July 2, 2021

according to the results of a model which reduced the share of coal-fired power stations in electricity production, the consumption of hard coal in power stations and combined heat and power plants is predicted to fall from more than 30 million tons per year in 2020 to around 11 million tons in 2040 (PEP 2040).

Hard coal is in Poland a significant carrier of energy, both electric and thermal. It is a raw material with which the remaining sectors of the national economy are directly or indirectly connected. This raw material is mainly used for the production of electricity and heat in the professional power industry and as fuel in households and local boiler houses. Its use is very widespread in the chemical industry, i.e. in the processes of smelting, hydrogenation and the gasification of coal, which result in various types of fuels and products for other branches of the chemical industry (mainly coke, fuel gases, engine fuels, benzol, coal tar and others).

Significant amounts of coal are used in the metallurgical industry, in this case primarily to fuel steel furnaces. Hard coal is also a raw material widely used in the cosmetics industry, where it is gaining increasing interest and application, serving in the production of cosmetics, as its properties in toothpaste or creams are widely known. Coal is also used in the production of plant protection products, fertilizers, explosives, textile dyes and fragrances. In the medical industry it is used to produce medicines. In the jewelry industry it is used to manufacture jewelry ornaments. Coking coal (after processing into coke) is one of the main raw materials in steel production, the global consumption of which is constantly growing. At the present time there are plans to replace it in steel mills with hydrogen, but for the time being this is not economically viable because of the high costs involved. To do this would result in a significant increase in steel prices. However, the analyses that have been carried out suggest that hydrogen will play a major role in the decarbonization of the coal sector, on the condition that inexpensive renewable energy is available on a large scale. It is significant that the European Commission has included coking coal on its list of twenty-seven critical (strategic) raw materials for the EU. Coking coal is therefore treated as an economically most important raw material, whose supply is highly risky due to the concentration of global production. Access to coking coal is highly concentrated, with Australia alone accounting for 24% of global production. In the European Union, coking coal deposits are already being depleted. On coking coal and its importance can be found in studies (Blaschke and Ozga-Blaschke 2015; Ozga-Blashke 2020). According to Jastrzębska Spółka Węglowa S.A., only 17 million Mg of coke comes from EU countries, of which as much as 68% (11.6 million Mg) comes from Poland, the other directions of supply are Australia, USA, Canada and Mozambique.

In addition, clean coal technologies, i.e. processes aimed at reducing the emission of harmful substances generated during coal processing, are constantly being explored and applied. They are applied already at the stage of extraction of the raw material by implementing methods which help increase the efficiency of obtaining extracted coal. In the course of fuel processing, a number of coal enrichment methods are used, among them grinding and flotation, the removal of solid impurities and non-flammable matter. The development of technology with the highest dynamics is recorded at the stage of coal processing.

Depending on the type of process, there are examples of methods and equipment used. Among clean coal technologies we can distinguish both processes used for flue gas cleaning, such as desulphurization or dedusting, as well as modification of raw material processing methods among clean coal technologies. Among the methods used for coal processing the most widespread are combustion in an oxygen-enriched environment and IGCC (integrated gasification combined cycle), i.e. coal gasification before combustion.

Coal mining in Poland is one of the country's largest and oldest and most entrenched economic sectors. Despite the difficult financial situation that has persisted for some time, coal mining in Poland generated a positive net financial result in 2017 and 2018 (Krawczyk 2020).

Coal mining is also linked to a number of enterprises offering services and products for mining, the so-called peri-mining enterprises. Mining-related enterprises are defined as service companies working for the mining industry, manufacturers of mining machinery and equipment, and research and development institutions with a profile related to mining (Pepłowska et al. 2017). These companies provide materials, as well as research and analysis to advance mining work.

According to Statistics Poland, at the end of Q4 2019, 134.7 thousand people were employed in the "mining and quarrying" subsector, which is almost 5% of the entire "industry" sector in which 2,860.1 thousand people were employed in the same year (Central Statistical Office 2020). Currently, about 23.5 thousand people are employed directly in the lignite industry, and after including jobs in accompanying services, this is up to about 100 thousand people (based on calculations by the Polish Mining Chamber of Industry and Commerce, one job of one miner generates on average four jobs in agriculture and other sectors) (Kasztelewicz et al. 2018).

In view of the fact that the mining industry is both a producer of coal, i.e. a supplier of raw materials to other sectors of the economy, but also a consumer of products from other sectors, it can be said that there is a significant interdependence between the functioning of the mining industry in the Polish market and the functioning of other sectors. This is why the subject of maintaining or closing down domestic coal mining may be such an important issue and constitute an important foundation for the functioning of the Polish economy.

At present, the situation of the domestic coal mining industry is becoming very complicated and the sector is under strong pressure from state authorities and the European Union. In recent years, the European Commission has issued a number of climate laws and regulations that must be translated into targets for individual EU member states. In the documents presented, the European Commission has set targets for the reduction of pollutants, mainly carbon dioxide (CO_2), where the coal mining industry is considered the main emitter in the case of Poland. So far, the goal set for 2030 was to reduce greenhouse gas emissions by at least 40% (compared to 1990 levels) with a plan to achieve a reduction target of 80–95% by 2050, while the documents adopted now "A more ambitious climate target for Europe by 2030. Investing in a climate-neutral future for the benefit of citizens" (European Commission 2020) assume a significant increase in these restrictions, reaching is a reduction of greenhouse gas emissions in the entire EU economy by at least 55% by 2030 compared to

1990, taking emissions and removals with the announcement of the complete elimination of greenhouse gas pollution by 2050 into account, and thus aiming for so-called climate neutrality.

The Polish coal mining industry is facing a number of challenges as a result of dynamic changes in the conditions in which it operates. Given the current conditions, the future of the mining sector will closely depend on the solutions adopted at the international and national level in the area of environmental regulations, affecting the sector directly and indirectly. In particular, this concerns policies aimed at decarbonizing the economy.

Taking the above into account, it should be assumed that the domestic coal mining sector, which has been the main supplier of primary energy for the Polish economy for a number of years, will in the near future be subject to strong pressure resulting from the need to implement the adopted climate strategies. Considering the situation in accordance with conclusions contained in a number of industry analyses and national government documents, this may result in a decrease in the significance of hard coal in the energy balance of Poland, mainly due to environmental conditions. On the other hand, the forecasted high rate of economic growth creates opportunities for an increase in demand for fuels and energy, and thus may reverse or even minimize these unfavorable trends for the national mining industry. An important factor in favor of maintaining the key role of hard coal in Poland and in countries with coal deposits is also its significant role as a fuel ensuring national energy security, particularly in the event of high oil and natural gas prices on world markets. Irrespective of the above conditions, rational and effective management of coal deposits is an essential condition for meeting the needs of customers and maintaining the competitiveness of this sector of the economy.

1.1. Hard coal

Hard coal is one of the fossil coals containing 78–92% of the element carbon (hard coal also includes anthracite, the so-called purest form of coal, containing up to 97% of the element carbon). Coal is characterized by its black color, compactness and brittleness. It undergoes a combustion reaction which releases carbon dioxide. Fossil coals are sedimentary rocks, being a mixture of various organic compounds (containing hydrogen, nitrogen, sulphur, oxygen and carbon), mineral substances (silicates, carbonates) and a small amount of rare elements (e.g. vanadium) (Wasilewski and Kobel-Najzarek 1973).

The need to systematize the properties of coals and assess their suitability for various technological processes has resulted in the need for classification. Due to the complexity of their structure, this issue is complex. There is currently no uniform global classification of hard coal; only countries at their level establish their own classifications. Currently, hard coal classification in Poland is performed according to the amended PN-G-97002: 2018-11 Hard coal – Classification – Types. The basis for the classification of hard coal found in this standard are the natural features characterizing the technological usefulness of hard coal

defined according to the following indices: volatile parts content in coal, vitrinite reflectivity, sinterability index, dilatation and combustion heat.

The standard divides coals into different types:

- flame coal,
- gas-flame coal,
- gaseous coal,
- coking coals (gas-coking coal, ortho-coking coal, metacoking coal, semi-coking coal),
- lean coal,
- anthracite coal,
- anthracites (anthracite, metaanthracite).

The main uses of coal are: combustion, gasification and degassing (coking and extrusion), production of mold coke, smokeless fuels and coal and graphite products, production of liquid fuels (liquefaction), production of Pulverized Coal Injection (PCI), mild coal oxidation, utilization of coal waste and combustion products.

Hard coal is generally used as a fuel. Coal fuel consists of a combustible substance and ballast. The combustible substance consists of hydrocarbons and organic compounds including elements such as carbon, hydrogen, oxygen, sulphur and nitrogen. The ballast consists of moisture and other non-flammable components measured by the ash content. The calorific value of coal fuel ranges from 16.7 to 29.3 MJ/kg and strongly depends on its composition (ash content, sulphur content, moisture content). The calorific value of pure coal is estimated at around 33.2 MJ/kg. Hard coal is a non-renewable source of energy.

Three hard coal basins are located in Poland, i.e.: the Lower Silesian Coal Basin (DLW), Upper Silesian Coal Basin (GZW) and Lublin Coal Basin (LZW). Extraction is currently carried out in two of them, the Upper Silesian Coal Basin and the Lubelskie Coal Basin; in the Lower Silesian Coal Basin, past exploitation of five deposits has been abandoned since 2000.

The Polish classification of mineral resources is based on the possibility of their utilization and divides them into geological resources and industrial resources.

Geological resources of a deposit additionally specify:

- those meeting the limits of the parameters defining the deposit – balance resources,
- those which do not meet the limits of the parameters defining the deposit – off-balance resources.

In the geological documentation of a mineral deposit for solid mineral deposits, the following categories of recognition of a mineral deposit or part thereof shall apply: D, C2, C1, B, A.

The total documented balance resources of hard coal in Poland amount to approximately 64.3 billion Mg (as at 31.12.2019, Table 1.), of which 70.3% are resources of thermal coal (type 31-33), which is used as fuel in the professional power industry. From the balance resources, on the basis of economic criteria, the possibility of technological exploitation and modifying indicators, industrial and non-industrial resources are distinguished. Industrial resources are those balance resources which are intended for extraction.

When considering the supply of domestic coal in the future, we should bear in mind not so much the value of geological reserves, but of industrial reserves, that is, reserves which can be developed and whose exploitation will be justified both technically and economically, while meeting environmental and operational requirements. From the point of view of market demand, individual types of coal are important. Operational resources, i.e. industrial resources less anticipated losses, are dominated by type 31-33 steam coal. The remaining part of the base of operational resources is coking coal, mainly type 34. Hard coal resources by type are presented in Table 1.

Table 1. Hard coal reserves in Poland as at 31.12.2019.

Tabela 1. Zasoby węgla kamiennego w Polsce wg stanu na 31.12.2019 r.

Hard coal reserves, mln Mg	Geological resources						Industrial resources
	Balanced					off--balanced	
	A+B	C1	C2	D	total		
Total national resources							
TOTAL	6 587.87	23 452.12	32 364.56	1 925.29	64 329.84	13 966.19	4 779.20
Type 31-33	4 180.54	15 548.97	24 327.96	1 141.68	45 199.15	10 575.75	2 817.69
Type 34-37	2 399.50	7 857.60	7 933.44	152.71	18 343.25	3 353.60	1 961.40
Other	7.83	45.55	103.16	630.90	787.44	36.84	0.11
of which: in developed deposits							
TOTAL	4 399.80	13 315.27	9 258.05	260.73	27 233.85	3 055.42	4 160.68
Type 31-33	2 567.72	8 548.13	5 078.76	143.16	16 337.77	2 193.02	2 385.06
Type 34-37	1 832.08	4 766.05	4 173.88	117.57	10 889.58	862.40	1 775.62
Other	–	1.09	5.41	–	6.50	–	–
of which: in undeveloped deposits							
TOTAL	486.33	7 742.02	20 972.74	1 664.56	30 865.65	9 301.71	288.46
Typ 31-33	459.77	5 357.37	18 093.51	998.52	24 909.17	7 463.47	242.66
Typ 34-37	26.27	2 378.72	2 877.06	35.14	5 317.19	1 837.96	45.69
Other	0.29	5.93	2.17	630.90	639.29	0.28	0.11
of which: in abandoned deposits							
TOTAL	1 701.75	2 394.82	2 133.78	–	6 230.35	1 609.07	330.06
Type 31-33	1 153.05	1 643.47	1 155.69	–	3 952.21	919.26	189.97
Type 34-37	541.16	712.82	882.51	–	2 136.49	653.25	140.09
Other	7.54	38.53	95.58	–	141.65	36.56	–

Sources: own study based on (PIG-PIB 2020).

In Poland, there are 162 hard coal deposits, of which 46 are developed, 61 undeveloped, and 55 where exploitation has been abandoned. Taking individual coal basins into account, the largest one – Upper Silesian Coal Basin – comprises 145 deposits, including 43 developed, 52 undeveloped and 50 where exploitation has been abandoned. The Lower Silesian Coal Basin (Zagłębie Dolnośląskie) has 7 deposits, including 2 undeveloped and 5 where exploitation has been abandoned. The Lublin Coal Basin has the smallest number of deposits – 10, including 3 developed and 7 undeveloped.

In Poland, hard coal mining, similarly to other minerals, is licensed. At present (according to the List of Exploration, appraisal and mining concessions for solid minerals – as at June 30, 2020), 11 companies hold mining concessions:

- Polska Grupa Górnicza S.A. (concessions Bolesław Śmiały/Łaziska, Chwałowice, Czeczott, Halemba, Halemba II, Imielin-Południe, Jankowice, Marcel 1, Murcki, Mysłowice, Piast, Pokój, Rydułtowy, Sośnica, Staszic, Wesoła, Wieczorek, Wujek, Wujek-Stara Ligota, Zabrze-Bielszowice, Ziemowit, Śmiłowice),
- Tauron Wydobycie S.A. (concessions Brzeszcze, Brzezinka 1, Byczyna, Dziećkowice, Janina, Dąb, Jaworzno, Wisła I, Wisła II),
- Jastrzębska Spółka Węglowa S.A. (concessions Jas-Mos 1, Borynia, Budryk, Bzie-Dębina 2 Zachód, Bzie-Dębina 1 Zachód, Chudów-Paniowy 1, Knurów, Pawłowice, Szczygłowice, Zofiówka, Pniówek),
- Przedsiębiorstwo Górnicze „Silesia" Sp. z o.o. (Silesia concession),
- ZG Siltech Sp. z o.o. (Jadwiga, Bobrek-Miechowice 2 concessions),
- Zakład Górniczy Eko-Plus Sp. z o.o. licence (Bytom I – 1 licence),
- Karbonia S.A. (Dębieńsko concession),
- Węglokoks Kraj Sp. z o.o. (Bobrek-Miechowice 1, Brzeziny, Bytom III, Piekary concessions),
- Spółka Restrukturyzacji Kopalń S.A. (Krupiński and Makoszowy concessions),
- Lubelski Węgiel „Bogdanka" S.A. (Bogdanka, LZW-K-3, Ostrów, LZW – K-6 and K-7 concessions),
- Nexano Minerals Sp. z o.o. (Heddi II concession).

Three of them currently hold concessions for exploration and prospecting of hard coal deposits, i.e:

- Polska Grupa Górnicza S.A. (Piast concession),
- Tauron Wydobycie S.A. (Byczyna 1 concession),
- Jastrzębska Spółka Węglowa S.A. (Ruptawa, Warszowice-Suszec and Rejowiec concessions).

At present, hard coal mining is carried out in 18 mines, including 2 joint mines. Polska Grupa Górnicza Sp. z o.o. mines type 31.2, 32.1, 32.2 and 33 thermal coal, and type 34.1 and 34.2 coking coal: Ruch Marcel, Ruch Rydułtowy, Ruch Jankowice, Ruch Chwałowice, KWK Ruda consisting of three Movements: Movement Bielszowice, Movement Halemba and Movement Pokój, KWK Piast-Ziemowit consisting of two Movements: Ruch Piast and Ruch Ziemowit, as well as the single-shaft mines KWK Bolesław Śmiały, KWK

Sośnica, KWK Wujek, KWK Mysłowice-Wesoła, KWK Murcki-Staszic. The production of power coal at Jastrzębska Spółka Węglowa S.A. takes place at the KWK Budryk and KWK Knurów-Szczygłowice mines, but the domain of JSW S.A. is coking coal, produced (type 34 and 35) at all the Company's mines. The remaining mines extract only steam coal. TAURON Wydobycie S.A. owns three mining plants: ZG Janina, ZG Sobieski and ZG Brzeszcze, while WĘGLOKOKS KRAJ Sp. z o.o. extracts coal in the KWK Bobrek mine. Coal is also produced in the LZW in Lubelski Węgiel Bogdanka S.A. (Bogdanka Mine) and also in three private mines PG Silesia Sp. z o.o., ZG Siltech Sp. z o.o., Eko-Plus Sp. z o.o.

The area of the Upper Silesian Coal Basin within the borders of Poland is estimated at approximately 5,600 km^2, with documented deposits of 3,045 km^2, representing over 81% of the documented balance resources of the country; the total area of the basin is estimated at approximately 7,250 km^2. Hard coal mining from productive Carboniferous formations has been carried out for nearly 250 years.

In Lubelskie Zagłębie Węglowe there is the only one active mine Bogdanka, exploiting the deposit of the same name. Two deposits are currently under preparation for exploitation – Lubelskie Zagłębie Węglowe – area K-3 and Ostrów. This region assumes about 9,100 km^2 as an area with defined deposit prospects. Bogdanka exploits a deposit of approximately

Table 2. Hard coal balance in Poland in 2011–2019, thousand tons

Tabela 2. Bilans węgla kamiennego w Polsce w latach 2011–2019 [tys. ton]

		2011	2012	2013	2014	2015	2016	2017	2018	2019
Extraction		76 402	79 813	77 017	73 245	72 629	70 693	65 885	63 857	62 081
	steam coal	64 966	68 075	64 901	60 956	59 714	57 611	53 504	51 817	50 009
	coking coal	11 436	11 738	12 116	12 288	12 915	13 082	12 380	12 040	12 071
Purchase from abroad		15 031	9 632	10 816	10 303	8 207	8 284	13 347	19 668	16 681
	steam coal	12 466	7 566	7 849	7 899	5 515	6 074	9 717	16 147	13 240
	coking coal	2 566	2 066	2 967	2 404	2 692	2 210	3 630	3 522	3 441
Sales abroad		5 751	7 405	10 555	8 836	9 186	9 067	7 066	4 902	4 390
	steam coal	4 181	5 777	8 358	6 745	6 883	6 629	4 313	1 979	1 815
	coking coal	1 570	1 627	2 197	2 091	2 303	2 438	2 753	2 923	2 575
Con-sumption		85 181	75 400	78 476	73 865	71 719	78 449	74 286	75 882	69 080
	steam coal	72 440	63 130	65 633	60 769	58 306	65 100	61 222	62 709	56 620
	coking coal	12 741	12 269	12 842	13 096	13 412	13 349	13 064	13 173	12 461

77 km^2. In the Lower Silesian Coal Basin (Dolnośląski Zagłębie Węglowe) the exploitation of hard coal was terminated in 2000 with the discontinuation of mining from Nowa Ruda field Słupiec mine. The deposit was characterized by difficult geological-mining conditions, which made mining in this area unprofitable. At present, the geological resources of this deposit are estimated at 423.98 million Mg.

As assumed in the Energy Policy of Poland until 2040, the demand for hard coal will be covered by own resources, and the import-export relation will be supplementary (PEP 2040).

Table 2 presents the balance of hard coal flows in 2011–2019.

In the period in question, a slight decrease has been observed in recent years on both the purchase and sales side of hard coal, similarly in the case of production and consumption of this raw material. However, all parameters are still at a high level.

1.2. Brown coal

The presence of lignite in the country should be considered against the background of the general features of the geological structure of the Tertiary lignite formation. It determines the number of deposits of these minerals, location, geological structure, coal quality and quantity (Ratajczak and Hycnar 2017). Poland has 91 documented lignite deposits. The geological balance resources of lignite at the end of 2019 amounted to approximately 23.26 billion Mg (PIG-PIB 2020) and were 0.23% lower compared to the previous year. The loss of resources was mainly due to mining and related losses. The major part of these resources, i.e. 23 261.19 Mg, are thermal coal (including also bituminous coal and briquette coal), whereas the remaining 0.64 Mg are bituminous coal. From the conducted exploitation the industrial resources were estimated at 994.55 million Mg (0.99 billion Mg) (PIG-PIB 2020). Giving a lower yield than in the previous year, industrial resources decreased by 53.05 million Mg compared to 2018.

Lignite extraction in 2019 amounted to 52,855 thousand Mg (52.86 million Mg) (PIG-PIB 2020) and was lower by over 8 million Mg (or 13.56%) than in the previous year. Almost 70% of domestic extraction came from exploitation carried out by PGE Górnictwo i Energetyka Konwencjonalna S.A. in the Bełchatów-Pole Szczerców deposit, where lignite extraction increased by over 5% compared to the previous year. The Bełchatów-Pole Szczerców deposit is a deposit which mainly meets the needs of the Bełchatów power plant. Less than 10% of domestic extraction was from the Turów deposit and the rest from the Konin deposits. Mining in 2019 was carried out in 8 deposits, no extraction was made from the Sieniawa 1 deposit. The Energy Market Agency, on the other hand, estimates the level of extraction at just over 50 million Mg in 2019, which indicates insufficient coverage of domestic demand. The domestic forecast resources are estimated at over 18 billion Mg. Polish lignite resources are summarized in Table 3.

There are 91 lignite deposits in Poland, of which 9 are developed, 73 are undeveloped, and 9 are abandoned. According to the Draft Energy Policy of Poland until 2040, the Złoczew

Table 3. Lignite resources in Poland as at 31.12.2019.

Tabela 3. Zasoby węgla brunatnego w Polsce wg stanu na 31.12.2019 r.

Lignite resources, mln Mg	Geological resources						Industrial resources
	Balanced					off--balanced	
	A+B	C1	C2	D	total		
Total national resources							
TOTAL	2 297.18	3 514.00	12 645.52	4 805.14	23 261.83	3 517.48	994.55
of which: in developed deposits							
TOTAL	1 039.41	121.01	10.39	–	1 170.81	39.63	994.55
Deposits of active plants	1 039.41	119.89	10.36	–		39.63	993.72
Deposits operated periodically	–	1.12	0.03	–	1.15	–	0.83
of which: in undeveloped deposits							
TOTAL	1 241.00	3 386.80	12 630.62	4 805.14	22 063.55	3 447.62	–
Deposits recognised in detail	1 241.00	3 386.80	1 193.23	–	5 821.03	872.64	–
Deposits initially diagnosed	–	–	11 437.39	4 805.14	16 242.52	2 574.98	–
of which: in abandoned deposits							
Abandoned operation	16.77	6.20	4.51	–	27.47	30.23	–

Sources: own study based on (PIG-PIB 2020).

and Ościsłowo deposits are considered prospective, and the Gubin deposit is considered a reserve deposit.

In literature there are two basic divisions when it comes to regionalization of occurrence of lignite deposits (Kasztelewicz et al. 2018). The first one includes eight regions, dividing them into:

- Western (deposits: Turów, Mosty, Babina-Żarki, Gubin, Cybinka, Sieniawa, Rzepin, Torzym),
- North-Western (deposits: Trzcianka, Więcbork, Nakło),
- Legnicki (deposits: Legnica, Ścinawa, Ruja),
- Wielkopolski (deposits: Mosina, Krzywiń, Czempiń, Szamotuły, Gostyń, Góra, Oczkowice),
- Koniński (deposits: Pątnów, Adamów, Drzewce, Tomisławice, Mąkoszyn-Grochowiska, Dęby Szlacheckie, Piaski, Izbica Kujawska, Grochowy-Siąszyce),

- Bełchatowski (deposits: Bełchatów, Złoczew),
- Łódzki (Rogoźno deposit),
- Radomski (the Głowaczów deposit).

The second one comprises four regions, i.e.:

- Lubuski (with the most important deposits: Gubin, Torzym, Mosty, Babina, Cybinka, Sieniawa, Słubice-Rzepin),
- Wielkopolski (with the most important deposits: Pątnów, Adamów, Lubstów, Drzewce, Tomisławice, Mąkoszyn-Grochowiska, Morzyczyn, Dęby Szlacheckie, Piaski, Izbica Kujawska, Mosina, Krzewino-Czempin, Szamotuły, Gostyń, Góra, Oczkowice, Trzcianka, Więcbork, Nakło),
- Łódzki (with the most important deposits: Bełchatów, Szczerców, Złoczew, Rogoźno),
- Dolnośląski (with the most important deposits: Turów, Legnica, Ścinawa, Ruja).

Lignite in Poland is almost entirely used as a raw material for energy production – mainly electricity, but also heat. Due to its specific nature, this raw material is most often used close to the place of extraction, its transport is unprofitable. During transport by rail, coal is compacted into a mass that is difficult to unload, and in the winter season it additionally freezes.

For this reason, lignite power stations are built close to the deposits and the raw material is often transported to the power station by conveyor belts. However, some power plants (e.g. Konin and Adamów) are supplied by industrial rail from nearby mines. The Adamów power plant was permanently shut down on January 1, 2018.

The use of brown coal for purposes other than energy is marginal. Nevertheless, it can serve as a raw material for the chemical industry, for example to obtain semi-coke, render tar, industrial gases or montan wax. The processing and sorting of lignite produces coal dust, which can be used as a raw material for the production of sorbents, pesticides and herbicides, soil conditioners and soil supplements used to fertilize agricultural soils. Lignite can also be blended with mineral fertilizers. According to the List of Exploration, appraisal and mining concessions for solid minerals (as at 30 June 2020), four enterprises hold concessions for lignite and associated minerals mining, i.e. PAK KWB Adamów S.A. (Adamów concession), PGE GiK S.A. (concessions Bełchatów-Pole Bełchatów, Bełchatów-Pole Szczerców, Turów), PAK KWB Konin S.A. (concessions Drzewce, Pątnów III, Pątnów IV, Tomisławice) and KWB Sieniawa Sp. z o.o. (concessions Sieniawa 1, Sieniawa 2) (SRP 2021). On October 1, 2020, Zespół Elektrowni Pątnów–Adamów–Konin SA (ZE PAK) decided to adopt strategy directions according to which the last electricity produced from lignite will flow at the end of the current decade. Significantly, ZE PAK power plants have already been using the co-firing of coal with biomass. In the coming years more and more energy will be produced from renewable sources in ZE PAK, and after coal extraction is finished only green energy will be produced. An important direction of the new ZE PAK strategy is the production and use of hydrogen.

The lignite mining sector is concentrated in five mining complexes: Brown Coal Mine Bełchatów, Brown Coal Mine Turów, Brown Coal Mine Konin, Brown Coal Mine Adamów,

Brown Coal Mine Sieniawa. Lignite Mine Bełchatów is located in the province of Łódź, south of the city of Bełchatów, and has been operating on the mining market for over 40 years. It is considered to be the largest and most modern opencast mine in Poland. The Turów Lignite Mine is located in the south-western part of the Lower Silesian Province. In terms of both mining output and size, it is the second largest mine in Poland. The Konin Lignite Mine started its operation in 1945. Since then, coal has been extracted from ten open pits. At present, production takes place in three open pits – Jóźwin, Drzewce, Tomisławice. The Adamów Lignite Mine SA is located in central Poland. Formerly a multi-pit mine, it is now a single-pit mine. Lignite is extracted from the Adamów open-pit and delivered by truck to the Pątnów and Konin Power Plants due to the decommissioning of the Adamów Power Plant. The extraction capacity of the mine is 1.0 to 1.5 million Mg per year. A small amount of lignite is also mined in Kopalnia Węgla Brunatnego Sieniawa Sp. z o.o. in Sieniawa Lubuska, which operates in one of the longest known and exploited lignite deposits in Poland, but due to the volume of extraction and its use for heating purposes it has no impact on the Polish energy sector.

Electricity from lignite is produced by four power plants: Konin, Pątnów, Turów and Bełchatów. Both the mines and the power plants belong to two energy concerns, i.e. PGE Górnictwo i Energetyka Konwencjonalna S.A. (PGE GiEK S.A.), which is part of the PGE Group controlled by the State Treasury, and Zespół Elektrowni Pątnów-Adamów-Konin S.A. (ZE PAK S.A.) (Table 4). On August 3, 2020, the Management Board of PAK KWB Adamów S.A. adopted a resolution on dissolution and liquidation of PAK Kopalnia Węgla Brunatnego Adamów S.A. The Bełchatów Power Plant, with an installed electrical capacity of 5298 MWe, generates approximately 32.0 TWh of electricity, which is more than 20% of Poland's annual demand. Polish power plants based on lignite are presented in Table 4.

Power plants based on lignite guarantee stability for energy demand, and because of the low mining costs lignite is a cheap source of energy. Lignite contains more sulphur

Table 4. Polish complexes – lignite mines and power plants

Tabela 4. Polskie kompleksy – kopalnie i elektrownie węgla brunatnego

Ownership	Mine	Power plant	Installed power plant capacity
PGE Górnictwo and Energetyka Konwencjonalna S.A.	KWB Bełchatów	Power plant Bełchatów	5 298.0 MWe
	KWB Turów	Power plant Turów	1 498.8 MWe
ZE PAK S.A. Capital Group	PAK KWB Adamów S.A.	Power plant Konin	193.0 MWe
	PAK KWB Konin S.A.	Power plant Pątnów I	644.0 MWe
		Power plant Pątnów II	474.0 MWe

Sources: own study.

and ash components and has a lower calorific value than hard coal, so its combustion in power stations generates more air pollution per megawatt of power produced. This results in higher costs of purchasing CO_2 emission allowances. It is also risky to assume that units in lignite-fired power plants will meet further requirements to reduce pollutant emissions imposed by EU climate and environmental policies. The above conditions are determinants of economic efficiency and the possibility of generating energy from lignite.

Table 5. Lignite balance in Poland in 2009–2019, thousand tons

Tabela 5. Bilans węgla brunatnego w Polsce w latach 2009–2019 [tys. ton]

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Extraction	57 108	56 510	62 841	64 280	65 849	63 877	63 128	60 246	61 161	58 571	50 329
Purchase from abroad	30	24	60	110	180	159	252	284	311	240	207
Sales abroad	68	115	144	134	218	302	198	212	256	287	147
Consumption	57 075	56 593	62 693	64 115	65 751	63 830	63 019	60 385	61 166	58 548	50 379

Sources: own study based on (ARE 2009–2019).

When analyzing the balance for lignite (Table 5) in the given period, we can see a decrease in both the extraction of domestic raw material and the volume of purchase as well as sales and consumption.

2. European Union Coal Market

In the European Union, coal-fired power generation is disappearing or, in an increasing number of countries, is losing its importance. As already mentioned, the main reason for this is the pursuit of pro-environmental policies, which place renewable energy sources above fossil fuels, and the move towards zero-emission European countries. Coal production in the EU27 has also been decreasing over the years (Figure 2). According to Euracoal in 2019, hard coal production in the European Union fell to 67.2 million Mg (–8.5 Mt or –11.1% compared with 2018), however, taking into account lignite production fell by 16.2% to 307.5 million Mg in 2019 as operators mothballed plants.

The situation is similar for EU coal imports, coal imports were also lower at 133.7 million Mg, a massive 19.3% less than in 2018.

Austria and Sweden closed their last coal plants last year (2020). The situation is similar in Portugal, which is planning its last shutdown for this year Germany, Poland and the Czech

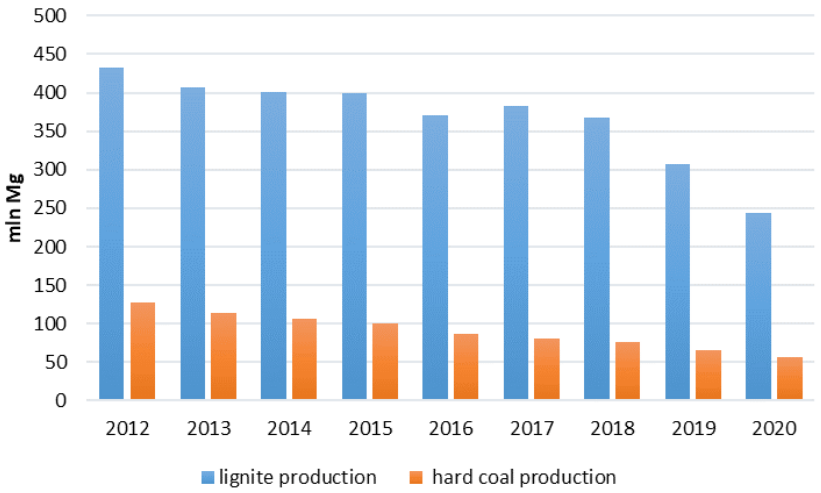

Fig. 2. Coal production in EU-27 in years 2012–2020, million Mg
Sources: own study based on (Euracoal Statistics 2012–2020)

Rys. 2. Produkcja węgla w EU-27 w latach 2012–2020 [mln Mg]

Republic use two-thirds of coal for electricity generation in the EU. Given the uncertainty over the price of energy carriers (IEA 2021) estimates that coal demand in the European Union may only increase by 4% in 2021 mainly due to the recovery of the industrial industry. This growth is far from reversing the 18% decline in demand in 2020.

The limited rebound in coal demand in the European Union in 2021 is mainly due to economic reasons.

2.1. Coal market in Germany

Germany is at the forefront of the countries that have moved away from coal, and its domestic production has been completely stopped. Further capacities of coal-fired power plants were withdrawn from the market. Primary energy consumption in 2019 and 2020 is presented in

The authorities have transformed their policy to introduce and strongly promote the use of renewable energy sources, mainly wind energy and photovoltaic sources. However, this raw material continued to be imported into the country. Currently, the German government estimates that primary energy consumption from coal will continue to decline. It is estimated that there will be a decline of over 16%, resulting in the lowest annual consumption of hard coal in the entire post-war period. This is primarily due to an increase in the price of carbon dioxide emission allowances under the EU Emissions Trading System (EU ETS), the expansion of capacity installed in RES and favorable weather conditions for the pro-

Table 6. Primary Energy Consumption in Germany in 2019 and 2020, Million Tons of Coal Equivalents (Mtce)

Tabela 6. Zużycie energii pierwotnej w Niemczech w 2019 i 2020 r.

Year / Source	2019	2020
Mineral oil	153.9	135.6
Natural gas	109.7	107.0
Hard coal	37.0	30.8
Lignite	39.7	32.6
Nuclear energy	27.9	24.0
Renewable energy	65.0	66.9
Other	7.8	7.6

Sources: own work basis on (AGEB 2021).

duction of electricity from renewable sources. Given the country's energy policy, hard coal was also increasingly replaced by natural gas, which initially benefited from a relatively low price level. There is thus a continuing downward trend in the use of coal in Germany.

On July 3, 2021 the government adopted two laws on the exit from coal-based energy and the restructuring of coal regions. The Coal Exit Act (Kohleausstiegsgesetz), which sets out the rules and timetable for the phasing out of coal-fired power stations and combined heat and power plants, sets the end of the last power station at the end of 2038. The capacity of coal-fired power plants is to be reduced from 39.5 GW to 30 GW in 2022 and to 17 GW in 2030. In addition, an evaluation in 2026, 2029 and 2032 is to examine the possibility of moving away from coal in the power industry in 2035. Another law passed was the Coal Regions Structural Strengthening Act (Strukturstärkungsgesetz Kohleregionen), which provides for a total of EUR 40 billion until 2038 for the restructuring of coal basins.

The timetable for the closure of lignite power plants has been negotiated by the government with the operators. RWE and LEAG are to receive a total of EUR 4.35 billion for the units extinguished by the end of 2029. The dates of power plant shutdowns and the rules for compensation payments are regulated by an agreement between the government and the operators, which is subject to approval by the European Commission. Power plants closing from 2030 onwards will not receive financial compensation.

The most important area of use of hard coal in the country is the steel sector. Compared to 2019, all three sectors where hard coal is used in Germany, namely power plants, the steel industry and district heating, showed a strong downward trend. Hard coal consumption in the form of coking coal and coke in the steel industry, fell by more than 12% to 443 PJ (15.1 Mtce) (AGEB 2021). The decisive factor in this was the reduction in raw iron production, which also fell by 12% to around 22 Mtce in 2020. The use of hard coal in power and

heat generating plants once gain declined and fell by more than 26% to 413 PJ (14.1 Mtce). The aforementioned declines were due to both policy and reduced demand for power generation during the Covid-19 pandemic.

2.2. The coal market in France

France, for example, is a country that is poor in indigenous mineral resources and therefore dependent on imports of these raw materials. Therefore, practically all the coal raw material used is imported. In order to achieve a certain degree of energy independence and thus strengthen the country's energy security, the government has converted the electricity generation system to nuclear fueled power plants. As a result, coal consumption has dropped by almost 60% since 2013 due to power plant shutdowns (France 2021).

The French government entered into an agreement with the state-owned coal company Charbonnages de France and the miners' unions, according to which the industry received state aid as it was being phased out. In May 2001, the European Commission authorized the payment of compensation by the French government in the amount of EUR 991 million – aid to the coal industry in liquidation. Charbonnages de France closed on January 1, 2008 after more than 60 years of operation, and coal mining had already ceased in April 2004 (Mlynarski 2014).

As reported (IEEFA 2020) French power consumption fell by 0.5% in 2019, coal-fired power generation plummeted by 72% to 1.6 terawatt-hours last year. It represented just a fraction of the total electricity output, which fell by 2% to 537.7 terawatt-hours as the state-run Electricite de France SA's atomic plants faced more outages and reduced rainfall curbed hydropower production. The drop in domestic power consumption came as governments across Europe Union introduced policies to fight climate change by encouraging energy savings in a bid to curb pollution from burning fossil fuels. Record low gas prices, occurring in France which have been pressured by mild winter temperatures, have also helped to squeeze coal's share from power mixes across the continent, making gas more competitive.

Summary and conclusion

Coal, both in Poland and Europe, has a wide range of applications. As indicated above, its largest consumer is the power sector, but the possibilities for its use are wider. The main sectors of world economies based on the use of coal are the power industry, as well as the steel industry and the heating sector. Therefore, coal will continue to be a necessary and desirable raw material in these industries to a greater or lesser extent.

Despite a number of forecasts and lack of unambiguous data concerning the shape of world demand, it may be stated with high probability that in the medium term (several years) as well as in the long term, there will not be a sudden collapse in demand for coal and there

may even be an increase in demand for this fossil fuel on a global scale. Many countries do not want to give up coal, but the pressure to move away from coal-fired power generation means that intensive work is being done to find new solutions. It should be noted that 2020 was a year of high economic instability and great fluctuations as a result of the Covid-19 pandemic, which is why the fall in the use of raw materials and the fall in demand for electricity in that year is not an exemplary or representative situation.

In Poland, domestic demand will undoubtedly be strongly correlated with economic development (increase or decrease in Gross Domestic Product – GDP) and the political situation, both in the EU and domestically.

There are a number of possible uses for the fuel and a number of still explored possibilities to use it in a less environmentally harmful, low-emission form. The most promising at the moment seem to be coal gasification and hydrogen production. These technologies require constant fine-tuning and support at both the national and EU level. The necessary financial investments in the development of clean coal technologies may, in the future, result in a breakthrough in conventional energy.

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COAL SUPPLY PROSPECTS IN POLAND AND SELECTED EUROPEAN UNION COUNTRIES

Keywords

coal import, coal supply, coal sector, coal in Poland, coal in Europe

Abstract

The raw material economy determines energy security for individual countries in the world. Coal is one of the most important energy carriers for electricity production and heat generation. World market trends of fossil raw materials such as hard coal and lignite were presented. In the European Union a significant decrease in coal and lignite consumption has been observed in recent years. This situation is primarily related to the accelerating decarbonisation policy and support of renewable energy sources, which are considered to be environmentally friendly. The pandemic occurring in recent years has also played an important role in shaping the raw materials market. The author shows the possibilities and directions in which the coal economy has prospects for development and expansion. The amount of the world's coal resources is presented, as well as the size of the global consumption of the raw material in the 2000–2011 years, specifying in China, India, Asia, the USA and the countries of the European Union. The structure of the coal economy is presented in the light of the policies and laws enacted by the European Union Comission, in particular in Poland, Germany and France. The appearance of the hard coal sector and lignite sector in Poland is described in detail. The size of resources was given in terms of coal classification. The presented data were based on a range of information and reports from world organizations such as the International Energy Agency or British Petroleum.

PERSPEKTYWY PODAŻY SUROWCA WĘGLOWEGO W POLSCE I W WYBRANYCH KRAJACH UNII EUROPEJSKIEJ

Słowa kluczowe

import węgla, podaż węgla, sektor węglowy, węgiel w Polsce, węgiel w Europie

Streszczenie

Gospodarka surowcowa stanowi o bezpieczeństwie energetycznym dla poszczególnych państw świata. Węgiel jest jednym z najważniejszych nośników energii zarówno elektrycznej, jak i cieplnej. W artykule przeanalizowano perspektywy podaży surowca węglowego w Polsce i Europie.

Zaprezentowano światowe trendy rynku surowców kopalnych takich jak węgiel kamienny i brunatny. W Unii Europejskiej obserwuje się znaczące spadki zużycia węgla zarówno kamiennego, jak i brunatnego na przestrzeni ostatnich lat. Sytuacja ta związana jest przede wszystkim z przyspieszającą polityką dekarbonizacyjną i wspieraniem odnawialnych źródeł energii, które uznaje się za źródła proekologiczne. Niemałe znaczenie dla kształtowania się rynku surowcowego miała również występująca w ostatnich latach pandemia. Autorka pokazuje możliwości i kierunki, w których gospodarka

węglowa ma perspektywy rozwoju i rozszerzania. Zaprezentowano ilość światowych zasobów węglowych, a także wielkość światowego zużycia surowca w latach 2000–2011, wyszczególniając Chiny, Indie, Azję, USA oraz kraje Unii Europejskiej. Przedstawiono strukturę gospodarki węglowej w świetle polityki i ustaw stanowionych przez Unię Europejską w szczególności w Polsce, Niemczech i Francji. Szczegółowo opisano wygląd sektora węgla kamiennego i brunatnego w Polsce. Wielkość zasobów podano ze względu na klasyfikację węgla. Przedstawiając dane, bazowano na informacjach i raportach światowych organizacji takich jak International Energy Agency, czy British Petroleum.