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Piotr Małkowski orcid.org/0000-0003-0870-438X
malkgeom@agh.edu.pl
AGH University of Science and Technology

Ievgen Tymoshenko
National Mining University of Ukraine, Dnipro

The quality of coal in Poland, Russia and Ukraine and its effect on dust emission into the atmosphere during combustion

Jakość węgla kamiennego w Polsce, Rosji i na Ukrainie oraz jej wpływ na emisję pyłów do atmosfery podczas spalania

Abstract

This paper presents the characteristics of coal quality in Poland as well in Ukraine and Russia – the two largest import sources. The analysis was carried out on the energy coal market for domestic use in all three countries from the perspective of the supply, demand and current prices. Thereupon was the analysis of the potential dust emission during combustion that results from the natural ash content in the coal, and with consideration to the efficiency of the furnace and the combustion method. The results of the analysis and the computation show that there are no significant differences in the quality of the coal from Poland, Ukraine or Russia. However, the important factor is the calorific value and, closely related to it, the content of non-combustible solids and dust emission. The analysis of dust emission proves that the impact on the environment can be significantly reduced by burning coals with a minimum calorific value of 27,000 kJ/kg.

Keywords: coal quality parameters, steam coal market, coal combustion, dust emission

Streszczenie

W artykule przedstawiono charakterystyki jakościowe węgla kamiennego występującego i wydobywanego w Polsce oraz na Ukrainie i w Rosji – dwóch najbliższych źródeł jego importu. Przeprowadzono analizę rynku węgla energetycznego ww. krajach pod kątem celów komunalno-bytowych, analizując jego dostępność, zapotrzebowanie oraz aktualne ceny. Następnie wykonano analizę potencjalnej emisji pyłu węglowego wynikającego z naturalnej zawartości popiołu w spalanym węglu, uwzględniając możliwą sprawność kotła i metodę spalania. Wyniki analiz i obliczeń pokazują, że nie ma istotnych różnic jakościowych pomiędzy węglem polskim, ukraińskim i rosyjskim. Istotnym szczegółem jest jednak jego kaloryczność, która ściśle przekłada się na zawartość w nim cząstek stałych i emisję pyłu do atmosfery. Wpływ spalania węgla na środowisko naturalne będzie ograniczony, gdy będą spalane węgle o wartości opałowej minimum 27 000 kJ/kg.

Słowa kluczowe: parametry jakościowe węgla, rynek węgla energetycznego, spalanie węgla, emisja pyłu

1. Introduction

The European Union environmental policy is focused on reducing the share of solid fuels (hard coal and lignite) in energy production in the EU. This process is expected to lower the content of particulate matter (PM) in the air (dust PM 2.5 and PM 10), and lower the emission of carbon monoxide and carbon dioxide, especially in mining areas. Parallel to the reduction in the use of hard coal and lignite for electricity and thermal energy production, the quality requirements for solid fuels are becoming increasingly stringent. This situation imposes a need for a new methodology for the evaluation of coal resources the on mining industry – an evaluation not limited to technical and economic aspects of exploitation but broadened to cover coal quality and its impact on the environment during combustion.

The forecasts of experts indicate that coal will continue to be the basic source of energy in Poland in the next few years, and the main energy security factor. The share of hard coal in energy production in the year 2050 is estimated to be as much as 9-45 million tons, depending on the development of nuclear power, clean coal energy technology, changes of other fuels prices and prices for CO_2 emission permits [4].

According to recent changes in the law regarding the environmental protection local governments have the right to decide which fuels are permitted and which are banned, as well as to set the emission standards for furnaces in their areas [10]. In effect, certain low-quality fuels like coal sludge or coal flotation concentrate may be banned in the city or rural communities, as well as furnaces which do not comply with environment protection standards.

The changes in the law were intended to improve the quality of the air in the cities and rural areas of the highest air pollution; among these are areas of deep coal mining. On the basis of the law, anti-smog acts have thus far been introduced in, for example, Małopolskie and Silesia voivodships. The act in the Silesia voivodship can be assumed to be a model regulation for setting the emission limits for heaters, furnaces and fireplaces, as well as procedures for their replacement. This act prohibits also the use of lignite, coal sludge, flotation concentrate and wet wood – this commenced on 1st September 2017. Comparing this regulation with the anti-smog law in the Małopolskie voivodship, where coal and wood burning is entirely banned, the Silesian model better compromises the imperative of environment protection and the expectations of society.

The use of highly calorific and low ash content coals could be an effective solution to the problem. However, this solution necessitates suitable fuel sources. Import of coal may be needed if it is not produced locally up to the required quality and quantity. Russia and Ukraine are the largest producers and potential exporters of hard coal in Europe. The question arises of whether the Russian and Ukrainian coals can compete with coal from Poland in terms of quality and price.

As a result of the above question, the objective of the research presented in this paper was an analysis of the basic quality parameters of hard coals and subsequently providing a comparison which considers the different quality and economic criteria of coal supply from all three countries. A brief analysis was also carried out of the dust emission and environmental impact of coals of various calorific value and ash content burnt in household furnaces of different combustion methods and efficiency levels.

2. Deposits and parameters of coal in Poland

2.1. Deposits

In the national inventory of hard coal resources at the end of 2015 [23], there was a total of 156 coal deposits, including 51 developed deposits, 47 abandoned, and 58 which were documented but yet not developed. Of the last group, the resources of 18 deposits were documented in the initial C_2+D category while 40 deposits were documented in detailed category A + B + C_1 (35 – in the Upper Silesia Coal Basin *GZW*, 4 – in the Lublin Coal Basin *LZW*, and 1 in the Lower Silesia Coal Basin *DZW*).

In total, according to the balance of 31.12.2015, the economic resources within the undeveloped deposits were recorded as 31.20 billion tons comprising 20.21 billion tons in *GZW*, 10.39 billion tons in *LZW*, and 600 million in *DZW* [23].

According to the same national reserves inventory on 31.12.2015, the total economic reserves of hard coal were 56.22 billion tons, including 21.11 billion tons in deposits currently being exploited. The recoverable resources were estimated at 3.56 billion tons, which is comprised of 3.30 billion tons in the exploited deposits and 251 million tons in the mines under construction [23].

Energy coal types 31–33 (steam coals) constitute the largest part of the recoverable reserves [22], and amount to 53.4% of the total recoverable resources and 58.4% of the developed resources (Fig. 1). Of the entire energy production in Poland, 86% is from solid fuels and almost 50% is from hard coal. The remaining 36% is from coking coal (type 34) and ortho-coking coal (type 35). The other coal types (36–38) constitute around 1% of the developed resources.

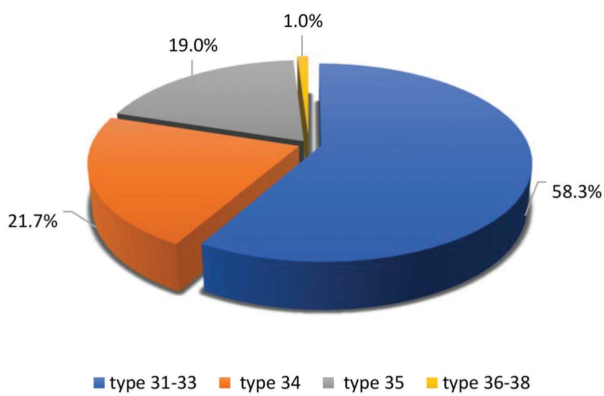

Fig. 1. Distribution of hard coal types in recoverable resources of coal in Poland

2.2. Quality parameters of coal

The quality parameters of coal (calorific value and ash and sulphur content) in recoverable reserves are the main factors considered in the design of the mine (deposit) development. These factors have the strongest effect on the economic effectiveness of the mine determined by the coal price formula [9]. From an energy production point of view, the calorific value parameter is crucial. The developed mines hold recoverable reserves of high calorific value coals. More than 92% of the reserves are in levels that are either already developed or are being developed show calorific values higher than 22,000 kJ/kg (Fig. 2), compared to the 15,000 kJ/kg criterion for the category of economic reserves [22].

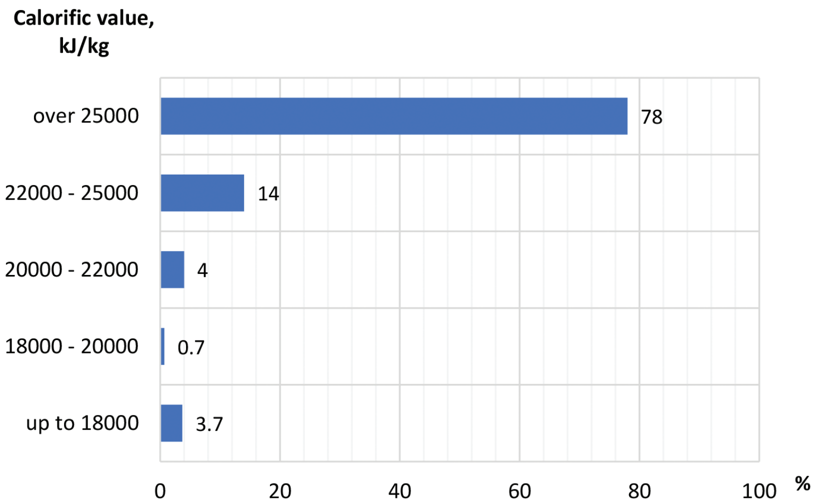

Fig. 2. Distribution of hard coal resources in Poland vs. calorific value

Another quality parameter (ash content) is closely related to calorific value. The lower this index, the higher the calorific value of hard coal. The majority of the resources (81.2%) show an ash content of below 15% (Fig. 3). More than half of the total recoverable resources fall into the low ash category defined as containing less than 10% of non-combustible matter. This amounts to 3.01 billion tons, of which number 2.15 billion tons is in developed levels, or levels that are being developed. The percentage of coals with an ash content higher than 20% in the total recoverable reserves is steadily decreasing. According to the inventory of 01.01.2015, this kind of resource constituted 5.5% of the total recoverable resources [22].

As a result of the above figures, it can be concluded that the hard coal reserve in Poland is ample and the coal is generally of a high calorific value and low ash content. However, the natural ash content in coal – a contamination created during coalbed formation processes, may not be representative of the ash content of the excavated bulk material. The excavated coal may show a higher ash content due to the presence of waste rock intercalations in the coal bed (mainly mudstone); especially if it is more than 5 cm thick. Moreover, excavation of coal beds of a thickness less than 1.5 m, due to the technology of excavation, imposes over-excavation into the roof or floor of the bed, hence the addition of waste rock to the coal that needs to be separated later through processing. Unfortunately, practice shows that the separation process is not fully effective and that in these circumstances, the ash content significantly increases.

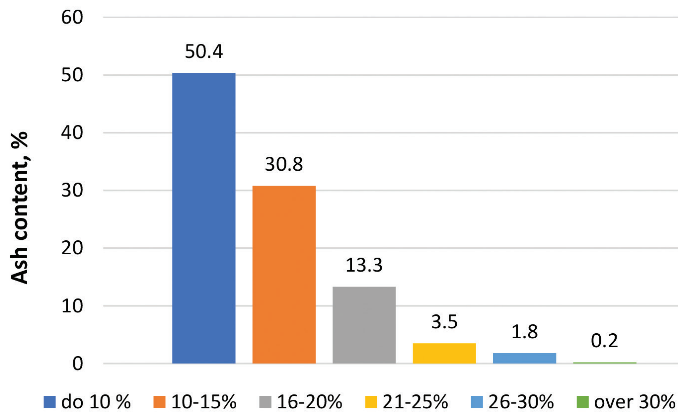

Fig. 3. Distribution of hard coal resources in Poland vs. ash content

Figure 4 displays the distribution of recoverable hard coal reserves versus the coal bed thickness. Its analysis shows up to 20% share of coal resources in beds thinner than 1.5 m, hence in a situation where the ash content in coal will increase due to the technology of excavation [22]. Even though this share has halved (from 39.9%) since year 1991 it is still significant, especially considering that the production of coal has also nearly halved since then. Between 2003 and 2013, the average content of waste rock in coal has increased from 26% to 31.5% [5]; therefore, by applying a trend line, it may reach 32.5–33.0% today, i.e. one third of the output. The case of certain mines shows the content of waste rock in daily excavation to be up to 45–48%. The analysis of the share of thin coal beds in the resources planned for development (Fig. 4) allows us to anticipate that it will remain generally unchanged over the next few years.

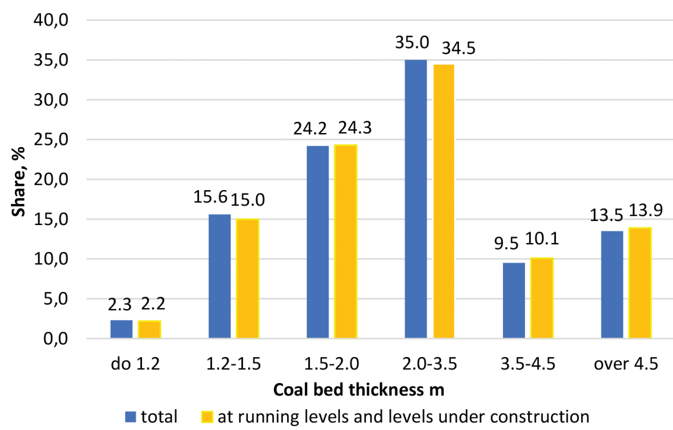

Fig. 4. Distribution of hard coal resources in Poland vs. thickness of beds

Sulphur appears in the hard coal in three forms: as organic compounds, pyrites (FeS_2) and sulphates. Sulphur dioxide (SO_2) – a gaseous product of hard coal combustion – is one of the major pollutants of the environment. Reduction of the high emission of sulphur dioxide is the priority of the European Union environmental protection policy.

Sulphur is found in coal beds at a wide range of levels from traces up to over twelve per cent. However, the average content of sulphur in the hard coals of GZW is low and amounts to about 1.2%, whereas the range of sulphur content is 0.32–2.82%. Most frequently, the sulphur content does not exceed 0.6% [22] (Fig. 5).

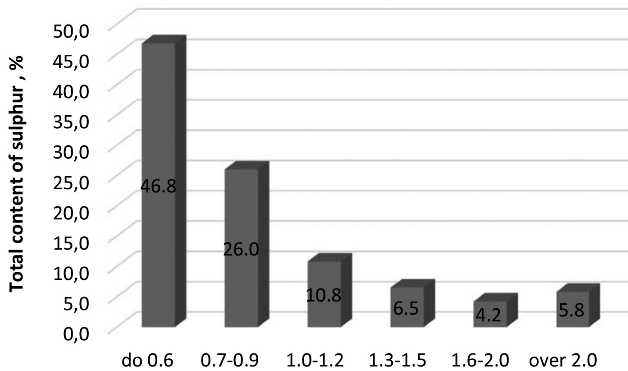

Fig. 5. Distribution of hard coal resources in Poland vs. total sulphur content

3. Deposits and parameters of coal in Ukraine

The recoverable resources in Ukraine, at depths of up to 1,500 m deep, are estimated to be 117.3 billion tons. However, around 80% of these resources are in thin beds (up to 1.2 m) and very thin beds (less than 0.7 m) [2] – Fig. 6.

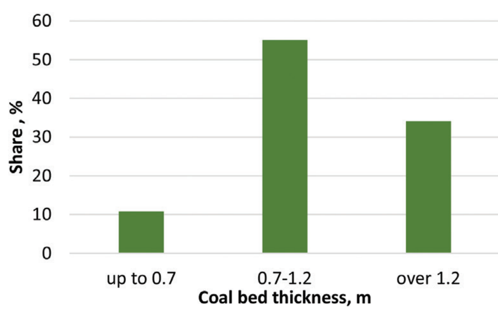

Fig. 6. Distribution of hard coal resources in Ukraine vs. thickness of coal beds

As is the case in Poland, the largest proportion of the recoverable resources in Ukraine are energy (steam) coals of types D, G and GZh, constituting around 60%. The resources of coking coal are estimated to be at around 8% (types K and Zh); 12% – ortho-coking coal (type OC); 20% – anthracite (types A, P) of the total recoverable resources (Fig. 7). Around 40% of energy coal is used for electrical energy production, while around 14% is annually allocated to be used in households.

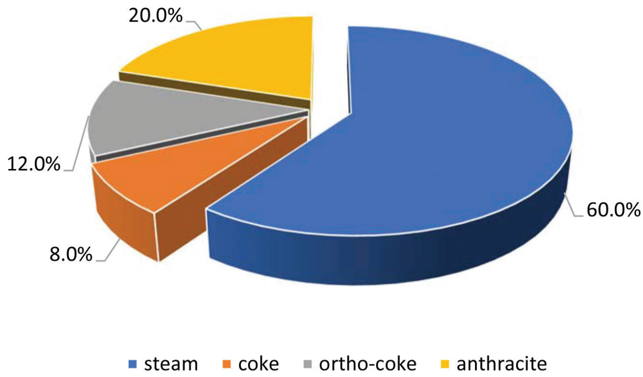

Fig. 7. Distribution of hard coal types in coal resources in Ukraine

The energy coal in Ukraine is characterised by high calorific values of 25,000 kJ/kg and above. However, due to numerous waste rock intercalations in the coal beds and the presence of faults, as well as the applied technology, the coal becomes contaminated and the average calorific value drops to 21,000 kJ/kg or lower.

Coal in Ukraine is also characterised by higher energy coal content of sulphur than in Poland's coal. Within the Ukrainian deposits, the predominant coal categories are sulphur contaminated and highly sulphur contaminated with the sulphur contents of 1.5–5.5% [12]. As a consequence, the coal is subject to intensive processing to achieve energy coal quality criteria, which affects its final price.

4. Deposits and parameters of coal in Russia

To date, around one third of the world's coal resources are geologically documented on Russian Federation territory – this amounts to 193.3 billion tons, of which 101.2 billion tons is hard coal and 85.3 billion tons is lignite [30]. The breakdown of hard coal in the Russia Federation into lithotypes from energy coals to anthracites is presented in Fig. 8. The largest proportion of these resources is found in the Siberia-Kuznieck, Kansk-Aczynsk, Peczorsk, Irkuck and Ulug-Chemsk coal basins, and in the East Donbas-Donieck coal basin. These coal basins are characterised by favourable geological conditions i.e. relatively shallow locations of coal beds (down to 400-500 m, in several cases down to 1000 m), thick coal beds (around 40.6 % of average thickness 1.8–3.5 m, and 38.2 % beds thicker than 3.5 m), and infrequent tectonic disturbances (Fig. 9). Both deep mining and open-pit mining methods are used to develop the coal deposits [3].

The share of hard coal in energy production in 2017 was recorded at 25%. The experts forecast a gradual increase in this value that will reach 35% by the year 2020. This trend is related to the projected demand for electrical energy and the growing export of natural gas to Asian countries. Russian energy coal, like Ukrainian coal, is characterised by calorific value in the range 20,000–25,000 kJ/kg (Fig. 10).

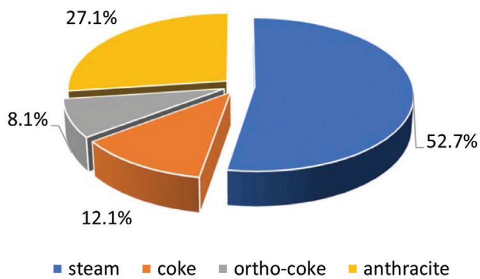

Fig. 8. Distribution of hard coal types in coal resources in Russia (Economy of Russia, 2017)

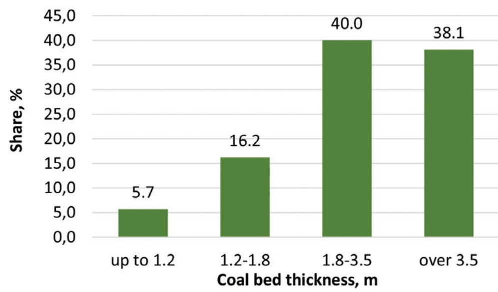

Fig. 9. Distribution of hard coal bed thickness in Russia

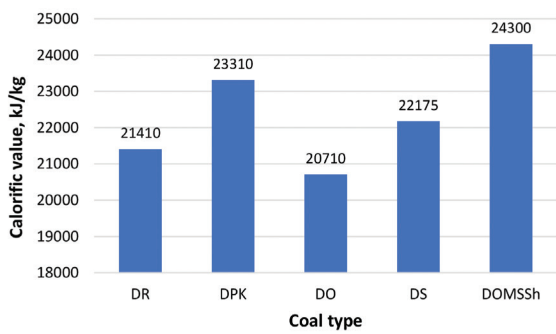

Fig. 10. Calorific value of coal types in Russia

The natural content of ash in Russian coal is estimated to vary between 5% and 38% depending on the source coal basin. For instance, the natural ash content in the Kuznieck Basin is from 5 to 34%, in the Pieczorsk Basin it is 31.4 to 38%, and in Siberia and the Far East it is 9.5 to 38% [7]. Most of the energy coal is processed before entering the market so the ash content is reduced to an estimated range of 3.6–10.1% depending on the coal type and degree of enrichment (Fig. 11).

The content of sulphur in Russian coal is close to that of Ukrainian coal and varies between 0.2% and 3.2%. The sulphur content in the energy coal after processing is estimated to vary between 0.2% to 1%.

The geological conditions indicate the need for changes in the excavation technologies that would result in better coal quality and the reduction of dust and other pollutant emissions.

The technologies need to be modified to reduce the over-excavation of the roof and the floor of the coal beds, thus minimising adding waste rock to the output. Therefore, the mines should plan to limit the excavation of thin beds and beds with high contents of intercalations, as well as excavation within fault zones, and beds with high ash and sulphur contents. This can be achieved by selective excavation with the use of plough systems or by abandoning parts of the coal deposit. However, considering the existing excavation systems, safety aspects and economic factors, it may be expected that the mining plants would have to, and would opt to, improve the processing rather than abandoning lesser quality resources. The cost and time of processing would certainly affect the final market price of the product.

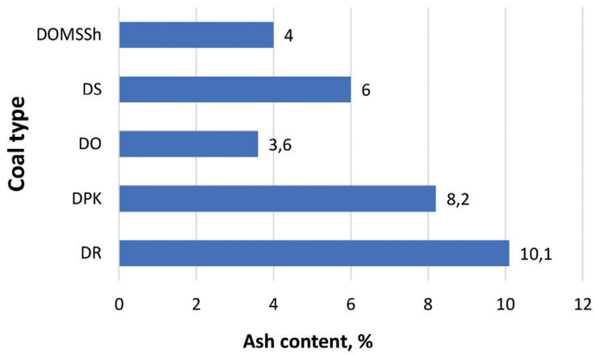

Fig. 11. Distribution of ash content vs. coal type in Russia

5. The situation on the coal market

5.1. Poland

In 2016, Poland consumed around 13.8 million tons of coal for the needs of individual households, of which 5 million tons was supplied from local mines and 8.8 million tons was imported coal mainly from Russia. These values show that individual households use more imported coal. Since the implementation of anti-smog regulation in the Silesia and Małopolska voivodships, the flotation concentrate and coal sludge were eradicated from the market leaving a gap in supplies of around 600,000 tons. In addition, the regulation by the Ministry of Development [21] regarding higher standards for coal furnaces will become binding in the year 2018. From then, the colloquially named 'smokers' ('kopciuchy' in Polish) – a common type of furnace that can burn coarse coal and any combustible waste – will no longer be on sale. New class 5 furnaces are equipped with an automated feeder and designed to only burn highly calorific coal culm with low sulphur and ash contents, or alternatively, a specially prepared coarser sort of coal e.g. a so-called 'eco-bean'. There is a very low availability of this type of coal in Poland [15].

Coal mines, especially those producing high quality energy coal (also used in households) are not able to increase production due to underinvestment. There has been no work carried out to access new resources over the last three years (besides at the LW 'Bogdanka' mine) due to EU anti-coal policy, unstable coal prices on the world markets (relative low in this period), and the reorganisation of coal companies in Poland. Furthermore, the main exporter of energy coal to Poland (the Russian Federation) cannot increase the supply because there is no production surplus that can be allocated for export. Due to this situation, Poland is seeking other sources of coal import from other countries. In 2017, there was the first delivery of coal from the United States, and commercial negotiations are underway regarding the import of coal from Kazakhstan and Columbia [17, 18].

In the abovementioned circumstances, during the peak time for the coal market (i.e. just before the heating season), the individual buyers had to pay 850 PLN for 1 ton of the popular coal type 'nut' [15]. According to the projections made by specialists, the price in December was expected to be 930 PLN, exceeded 1,000 PLN in February, and reaching 1,100 PLN in March (Fig. 12). Until now, due to the relatively gentle winter, the coal prices did not significantly increase comparing to September 2017, yet an increase of around 10% was recorded compared to the previous year. The coal culms of calorific value below 20 MJ/kg show the lowest prices, i.e. the largest producer in Europe – the Polish Mining Group (PGG) – offers the coal culm for 400 PLN per ton [28] (Fig. 13). The price for the 'nut' type is 627–784 PLN/ton, for the 'bean' type it is 615–775 PLN/ton, and for the 'cobble' type it is 701–790 PLN per ton. The most expensive are products branded 'eco', 'eco culm' and 'eco pea', the prices of which reach 900 PLN per ton (Fig. 13). Considering the pro-ecological EU policy, the prices of eco type products will certainly remain at the current level and may even rise.

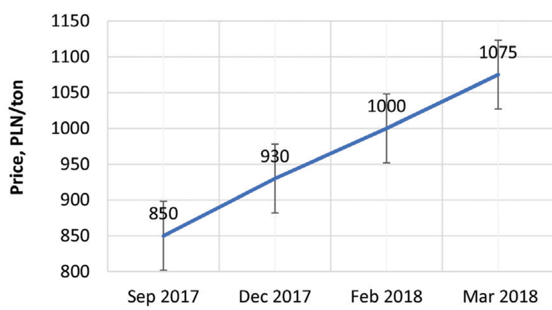

Fig. 12. Predicted rise of prices of 'nut' type hard coal in Autumn 2017

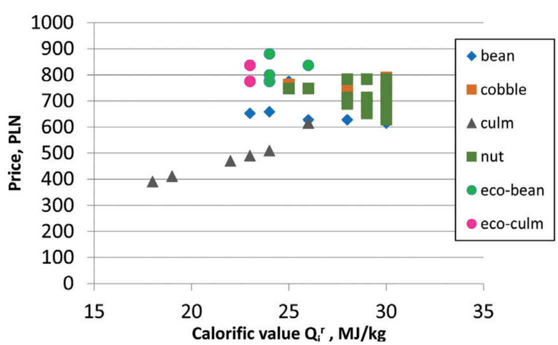

Fig. 13. Prices of coal in PGG – December 2017 [28]

It is important to note that the ash content in the offered coal is usually at a level of 5 to 10%, which also refers to eco-culms and eco-peas (Fig. 14). In the case of ordinary culms, it reaches 20 to 26%. The content of sulphur is most often less than 1% (Fig. 15). There is no apparent relationship between the product type and the sulphur content even though the highest sulphur content is found in coal culm.

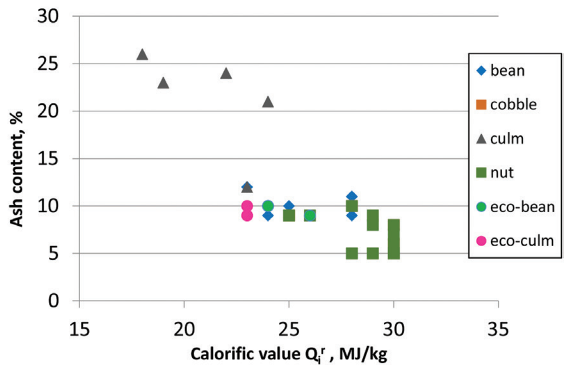

Fig. 14. Content of ash in the coal supplied by PGG – December 2017 [28]

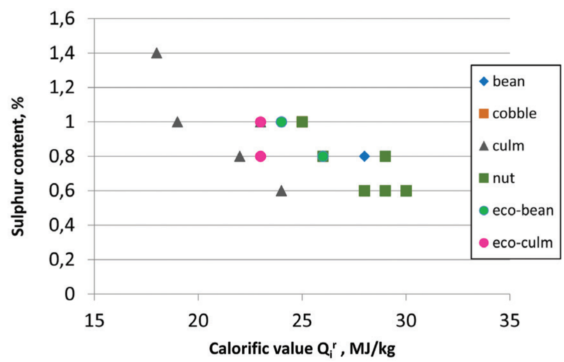

Fig. 15. Content of sulphur in the coal supplied by PGG – December 2017 [28]

5.2. Ukraine

Currently, Ukraine does not have any restrictive regulations with regard to the coal quality and furnace class used in households. Obsolescent types of furnaces and fire places that are used to burn coal and often domestic waste are common. Therefore, coal of low quality is abundant on the Ukrainian market.

The association agreement between the EU and Ukraine obliges Ukraine to adjust its regulations regarding emission to the European law, and in particular, regarding the combustion of solid fuels; this will certainly affect the coal prices. Currently, coal is offered for buyers at 250 PLN/ton (2,000 UAH) [16], this has an average calorific value of 20,500 kJ/kg, ash content 40% and sulphur content 3–5%. The average unit cost of extraction of 1 ton of such coal is 312 PLN (2480 UAH) in state-run mines, and 250 PLN (2000 UAH) in private enterprises.

However, its price strongly depends on the calorific value and is burdened with additional costs of the necessary processing (enrichment). The prices of coal allocated for households (gas-flame coal – type DG) versus the coal calorific value are presented in Fig. 16.

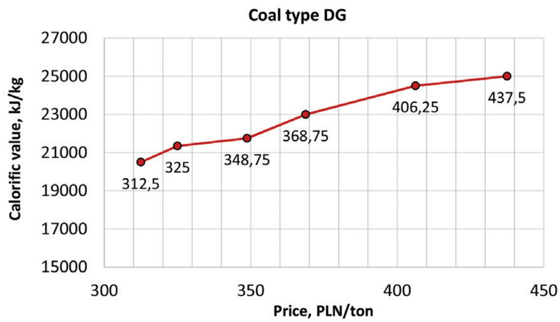

Fig. 16. Price of coal for households in Ukraine vs. calorific value

In the present political situation in Ukraine, the Lwów-Wołyń Coal Basin has become the main coal supplier, yet the quality of its coal is inferior to coal in the Donieck Basin. Today, only a fraction of mines in East Ukraine are on the territory controlled by the Ukrainian authority – 35 state-owned mines and 30 privately owned mines. These mines extracted 40.9 million tons of coal in the year 2016. In the territory controlled by the separatists, there are 97 mines; these are both state owned and privately owned (69 and 28 respectively), which constitutes 57% of the total number of mines. Despite seven of these mines being entirely closed and flooded, the production of coal on the separatist controlled territory was around 17 million tons in the year 2016 (12 million tons in the Donieck district and 5 million tons in the Ługańsk district). This coal is exported to Russia or, via middle agents to the West, mainly to the European Union as so-called 'coal of unknown origin'. This situation and the increasing demand has resulted in a deficiency of energy coal on the market in Ukraine, hence the need for coal imports. Coal imports to Ukraine in 2016 amounted to 15.6 million tons, and 22 million tons in 2017, while the cost of importing it almost doubled due to coal prices increasing on the world markets [27]. Among the countries exporting coal to Ukraine is Poland, who sent about 200,000 tons of this fuel in the previous year.

5.3. Russian Federation

The extraction of coal in Russia in the year 2017 was projected to reach approx. 400 million tons (4% more than in the year 2016), of which 310 mln tons is energy coal. The increase in production of the energy coal in particular is related to the growth in demand from external markets such as Turkey, Asian countries and the European Union [26]. By the end of 2017, the Russian Federation exported approximately 185 million tons of coal [19], and is recording steady yearly growth of exports by 8%.

Mining enterprises in Russia cannot rely on internal market demand from private consumers because the state controls prices for natural gas thus making gas a strong competitor on the energy market. Through this policy, the state encourages household owners to use gas for heating with the effect that less coal is burnt which reduces the emission of pollutants.

The price of energy coal according to KemUgleSbit [29] depends on the coal type and varies from 142 PLN (850 RUB) for 1 ton of fine fraction 0-50 mm coal (DOMSSh – flame culm coal II) to 225 PLN (1,100 RUB) for 25-200 mm fraction coal (DO – flame coal nut II), up to 242 PLN (1,450 RUB) for 1 ton of so-called 'eco-bean' type (DS – flame coal eco-bean I). The current prices of coal in Russia versus coal type are presented in Fig. 17.

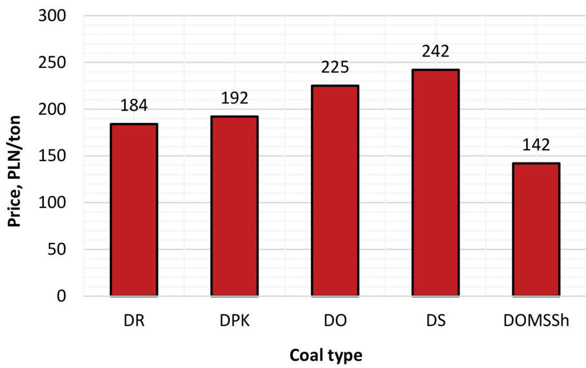

Fig. 17. Prices of energy coal in Russia – breakdown by coal type:
DR –flame coal unsorted; DPK –flame coal cobble II; DO – flame coal nut II;
DS – flame coal bean I; DOMSSh –flame coal fine grained – culm II

Summarising the review, it may be pointed out that the prices of energy coal for household use in Russia and Ukraine are much lower than in Poland, in the region of a half to a third. This situation arises from the fact that in the Ukraine the difference between unit production cost and unit price for 1 ton of coal is compensated for from the state budget. Whereas in Russia, the coal mining industry not only meets the local market demand for energy coal in 100% but provides a surplus that is designated for export. In addition, Russia controls and lowers the price of natural gas which in turn, affects coal demand.

In the case of import of the coal from the Ukraine or Russia, it needs to be considered that the final price is subject to custom duty, cost of transport and the middle agent's margin. The resulting price of the coal imported to Poland is close to the price of locally produced coal. With respect of the main quality parameters of energy coal, such as calorific value, ash content and sulphur content, the local coal is practically of the same quality as Ukrainian or Russian coal. In many cases, Russian or Ukrainian coal may contain slightly more ash or sulphur, yet this is negligible and should not present a barrier to the importation of the coal.

6. Effect of coal quality on dust emission

Coal is still the main source of energy for individual households. Approx. 60% of the households use coal furnaces compared to only 34% of gas burners, according to the statistically representative poll carried out by Czerski and Mirowski [1] in 14 communes in the Małopolska voivodship. Sulphur and nitrogen compounds, then carbon monoxide and dioxide followed by dust are the main contributors to overall emission [8]. The other pollutants are organic compounds, such as polycyclic aromatic hydrocarbons (benzo-(α)-pyrene), dioxins, furan, aliphatic hydrocarbons, aldehydes, ketones, as well as heavy metals [6]. These toxic substances are formed during the combustion of mostly inferior quality coals, e.g. low caloricity coal sludge. It is apparent that the calorific value is closely dependent upon the ash content in the coal. The research conducted in Ukraine shows that the dependency between these two parameters is logarithmic and of very high coefficient of determination (99%) [24] (Fig. 18). The natural ash content in hard coals varies from 10 to 13%; however, as mentioned earlier, due to the geological conditions and applied technology, the ash content in the extracted coal rises to 40–45%. Therefore, the coal needs to be processed before entering the market, which affects the final price.

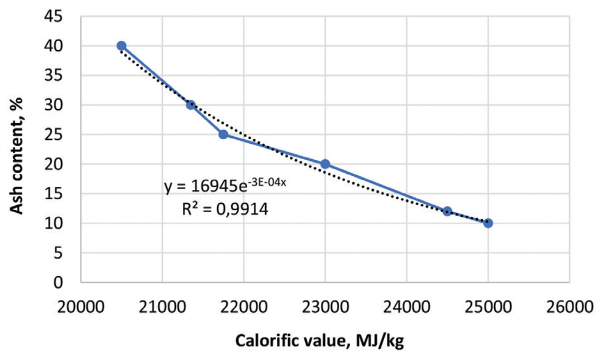

Fig. 18. Relationship between calorific value and ash content in the coal [24]

Dust (particulate matter – abbr. PM) is the air pollutant defined as a mix of particles of solids and liquids, suspended in the air, and consisting of organic and inorganic substances. It may include many chemical substances harmful to man. The chemical composition of dust closely depends on the source of the emission, the season of the year, the meteorological conditions including prevailing wind direction, and characteristics of emissions in the area under consideration [6]. It needs to be highlighted that the dust emission from the burning of coal that is mostly felt and recorded in autumn and winter makes up only a part of the overall dust emission. Coal-related dust emission has also risen due to this fuel being used in low power output, low efficiency furnaces which lack dust filters (domestic heating furnaces, tiled stoves, etc.). The Institute For Chemical Processing Of Coal in Zabrze conducted the research [11], which investigated the effect of the furnace type and the so-called top and bottom coal combustion on dust emission. The authors of the research concluded that the top combustion does not reduce dust emissions in general because it showed a reduction in 40% of the tested cases while in 25% of cases, it significantly increased the emission. A chamber type furnace emits from 279 to 1,322 tons of dust when burning 1 m^3 of 'nut' type of coal, whereas a so-called 'goat' ('koza' in Polish) type of furnace produces 821 to 848 tons of dust from 1 m^3 of coal. Therefore, furnace design alone may reduce the dust emission by around 75%.

The calculus for estimation of the dust emissions during coal combustion in furnaces of known power output is determined in '*Indexes of pollution...*' 2015 [25]. The general equation for estimation of dust emission based on the emission index of the fuel, which is as follows:

$$E = B \times W_o \times W$$

where:

- E – emission of substance, g/ton,
- B – fuel consumption, kg,
- W_o – calorific value of fuel, kJ/kg,
- W – emission index per giga-Joule of chemical energy of the fuel.

In case of coal the W index is defined:

- for fixed grating and natural drought – $1000 \times A^r$,
- for fixed grating and forced drought – $1500 \times A^r$,
- for mechanical grating – $2000 \times A^r$;

where: A^r – content of ash in %.

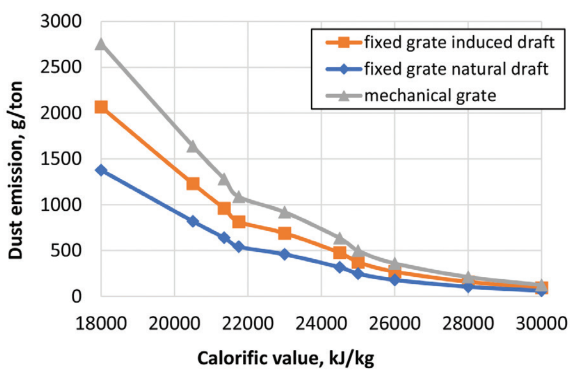

Fig. 19. Relationship between dust emission and calorific value of coal

An analysis was carried out to demonstrate how the calorific value parameter and type of grating affects the dust emission. The analysis included the research on calorific value – ash content relationship presented in Fig. 18. The calculation for theoretically burning 1 ton of coal shows, as expected, that the higher the calorific value of the coal, the lower the emission (Fig. 19) – this drops down to 0.1–0.2 kg at a calorific value of 27,000–28,000 kJ/kg. Moreover, at such high calorific values, the differences of dust emission for different types of gratings are insignificant. Thus, the procurement and use of coal of a calorific value of 27,000 kJ/kg or higher greatly reduces the emission of dust to the atmosphere. It has to be pointed out that the use of coals of a calorific value below 22,000 kJ/kg causes much higher dust emission which even worsens in case of low calorific coal culms. Furthermore, at a calorific value of Q = 19,700 kJ/kg and using the most efficient gratings, the dust emission per 1 ton of coal is higher than 1 kg (Fig. 19), while at calorific value of 18,000 kJ/kg and using a mechanical grating, the emission reaches 2.8 kg.

The best designed furnaces currently available on the market are the furnaces with automated feeders, yet these remain a small fraction of all appliances [1]. They are designed to burn 'eco-bean' ('ekogroszek'), 'eco-culm' ('ekomiał') and regular culm. Efficiently burned culm emits more dust than efficiently burned good quality coals, yet still less than good quality coal burnt in low efficiency furnaces. The Polish Standard PN EN 303–5:2012 [14] imposes the Class 5 rating for new furnaces; this is characterised by high efficiency resulting from the automated supply of air and fuel, and from the use of a top combustion chamber. The new requirements regarding furnaces have been provided by the Minister of Development and Finance in his regulation [21] and they have been valid since 1st July 2018.

The class of furnace is also defined by the type of fuel it is designed for. Figure 20 depicts the relationship between the efficiency of the furnace and its power output (percentage of the nominal power of the furnace). The highest-class furnaces achieve maximum efficiency at just 20% of the nominal power output, Class 4 at 50%, and only Class 3 at 75% power output. The old type furnaces usually have a much lower power output. It needs to be noted that according to the already outdated standard PN-EN 12809 from 2002 [13], the furnaces possible efficiency was not higher than 70–74%, hence there is a systematic rise in quality and efficiency of furnaces.

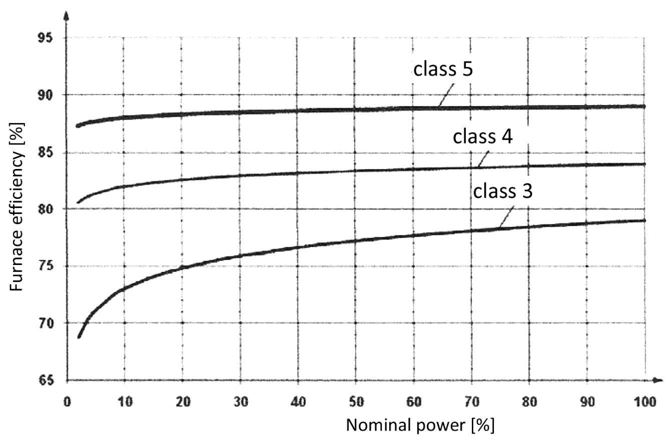

Fig. 20. Efficiency of the highest class furnaces versus power output – in compliance with Polish Standard PN EN 303–5:2012 [14]

In the case where the furnace is equipped with an emission reducing appliance (e.g. an electro-filter), the nominal power is reduced, hence an efficiency less than 100%. Czerski and Mirowski [1], by calling on research by EMEP/EEA Air Pollutant Emission Inventory, demonstrate that just inappropriate use of the furnace or defective installation of a central heating system reduces the efficiency of the furnace to 50–65%. The reduction of efficiency has an immediate impact on coal consumption and the related emission of dust and the volume of ash. The calculations were carried out specifically to demonstrate the effect of the efficiency of the heating appliance with regard to the amount of coal burnt during the heating season. It was assumed for this purpose that the heating season lasts 200 days (i.e. from the middle of September until the end of March – according to the definition by regulation Journal of Law 2007, Item 92 [20] – '…season, when atmospheric condition necessitate continuous generation of heat to warm up premises'), and the heating furnace used is of 20 kW power, which is sufficient to heat an average 170 m^2 house. It was further assumed that the furnace works for ten hours per day at a power output of 70% of the nominal power, and its efficiency is 0.89 – Class 5 furnace, 0.84 – Class 4 furnace, 0.78 – Class 3 furnace, or 0.52 – defectively installed or incorrectly set up furnace. The ash content in the coal was presumed to be 5–26% i.e. the range specified in the selling offer by the Polish Mining Group [28].

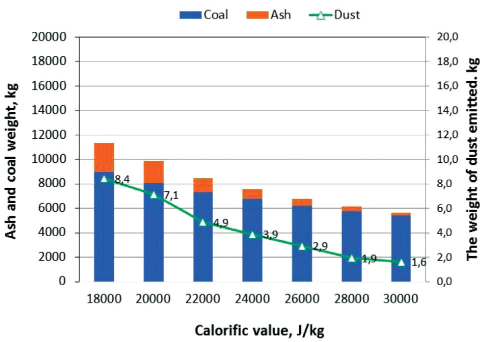

Fig. 21. Coal consumption, amount of ash and dust emission at furnace efficiency η = 0.89

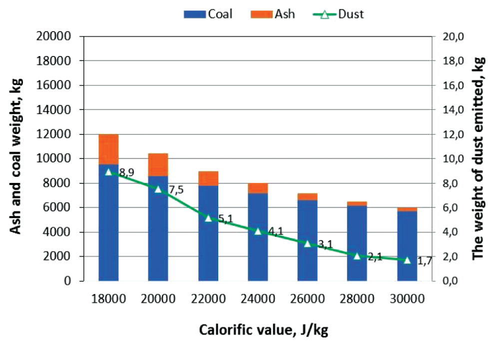

Fig. 22. Coal consumption, amount of ash and dust emission at furnace efficiency η = 0.84

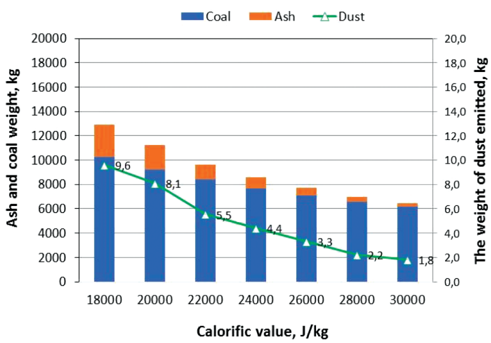

Fig. 23. Coal consumption, amount of ash and dust emission at furnace efficiency η = 0.78

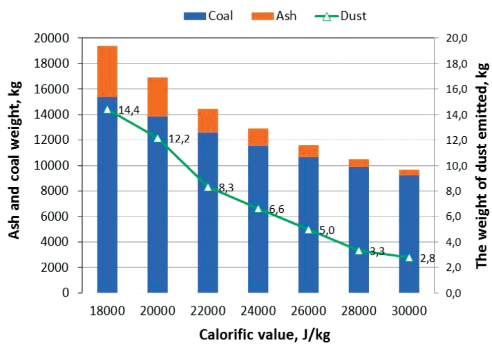

Fig. 24. Coal consumption, amount of ash and dust emission at furnace efficiency η = 0.52

The results of the calculation show an increase of coal consumption at lower furnace efficiency and an increase of dust emission even though coal of highest calorific value is used. The consumption of low calorific coal in the furnaces with an efficiency of η = 0.78-0.89 is estimated as 8,989 kg for the heating season at η = 0.89, and up to 10,256 kg at η = 0.78 (Fig. 21–23). The use of high calorific coal results in a significant drop in coal consumption. The use of coal with a calorific value of 24 MJ/kg reduces the consumption to 6,742 kg (for η = 0.89) and 7,692 kg (for η = 0.78) respectively, whereas the use of 30 MJ/kg caloricity coal reduces the consumption to 5,393 kg and 6,154 kg for η = 0.89 and η = 0.78, respectively. Therefore, the amount of coal needed to heat up the modelled house is reduced by half comparing to low calorific coals. At the same time, the use of high calorific coals reduces the amount of ash by approx. nine times, while the dust emission in case of η = 0.89 furnace will amount to 8.4 kg for culm with a 18 MJ/kg calorific value, yet just 1.6 kg for coal with a calorific value of 30 MJ/kg.

The situation appears entirely different in the case when the efficiency of the furnace in use is $\eta = 0.52$. At such a low efficiency, the consumption of coal increases by more than 50% (Fig. 24) irrespectively of the calorific value of the coal; thus, in the case of coal culm, this will amount to 15,385 kg, and in case of highly calorific coal, it will amount to 9,231 kg. In addition, the coal culm generates 4 tons of ash, while the 30 MJ/kg coal generates almost 0.5 ton of ash. The dust emission increases to 14.4 kg and 2.8 kg for coal culm and 30 MJ/kg coal, respectively.

Generally, assuming that the average user who does not yet possess the modern generation furnace of efficiency $\eta = 0.78$, and applies 'bean' or 'nut' types of coal of 26,000 kJ/kg caloricity, burns approx. 7 tons of coal in the heating season, disposes around 640 kg of ash and emits around 3.3 kg of dust into the atmosphere. Therefore, it consumes half the amount that would be needed in the case of coal culm and emits a quarter of the amount of dust.

Educational and informational programs aimed at the consumers should be delivered to promote use of coal with a calorific value of at least 27,000 kJ/kg.

7. Summary

The article presents an analysis of geological conditions, hard coal quality parameters and the coal market situation in Poland, Ukraine and Russia. The geological condition of coal basins in all three countries are generally similar, yet the thin-bedded deposits are more often found in Ukraine. There are no practical differences in the quality parameters of energy coals in these countries. The only difference between Polish, Ukrainian and Russian coals is usually a higher content of sulphur in the coal from Poland's Eastern neighbours.

One of the imperatives of mining enterprises is minimising impact on the environment during the exploitation process as well as at the coal consumption stage. Therefore, certain measures can be undertaken at the production stage to reduce the content of waste rock and solid particles in the output coal. One such measure, leading to lessening the environmental impact, is the development and implementation of excavation methods for the reduction of the over-excavation of rocks at the roof and floor of the coal bed. These methods are essential for the excavation of thin-bedded deposits. The other measure is the limitation of the exploitation of coal beds with high sulphur and ash content, as well as beds with numerous intercalations and tectonically disturbed beds. It needs to be noted that generally, the Russian and Ukrainian coal deposits are not much different from Polish deposits in the aspect of quality; thus, it is unnecessary to introduce any pro-quality constraints on the import. In particular, the coal offered for sale contains less sulphur and ash due to processing by the producers. However, the cost of the processing adversely affects the final price for the consumers.

Despite comparable quality parameters, the prices of coal for household use in the analysed countries are very much different. While in Russia, the price for coarse coal is 142 PLN (850 RUB) per ton, one needs to pay 420 PLN for the same coal type in Poland. The price of this type of coal in Ukraine is 320 PLN (2,500 UAH) which is significantly lower. The prices of the coal imported to

Poland, after taking into account all costs related to custom fees, transport and the agent's margin, becomes comparable to local coal prices. Nevertheless, Poland imported around 6 million tons from Russia in 2017, of the 9 million tons that was the overall import. It is noteworthy that Russian coal is practically offered for sale only at fuel storage yards, and mainly for household use. Therefore, cutting out the middle agent's margin would substantially reduce the price of the coal.

The key element in this analysis – the calorific value of coal and its relation to ash content – still needs to be addressed. The changes in the law related to limitations of sales of coal sludge and flotation concentrate is a very positive solution that significantly reduces dust emissions into the atmosphere. The computational simulation of dust emission for furnaces of various types of gratings shows that even the best designed furnaces emit large amounts of dust when burning coals of calorific values less than 22,000 kJ/kg, i.e. exceeding 1 kg of dust per one ton of coal. In contrast, burning coal of calorific values of 27,000 kJ/kg, or higher, considerably reduces the dust emission irrespective of the grating type.

The simulation of coal usage in furnaces of various efficiency levels shows that burning bad quality coal in a furnace of efficiency $\eta = 0.89$ has the same environmental impact as burning highly calorific coal in a furnace of $\eta = 0.52$ efficiency. Furthermore, the use of the high calorific coal reduces the generation of ash by approx. nine times, while the emission of dust from an $\eta = 0.89$ furnace in the heating season, for coal culm of 18,000 kJ/kg is 8.4 kg, and just 1.6 kg when using 30,000 kJ/kg coal in the same furnace. The calculation demonstrates that the coal consumption for seasonal heating of 170 m^2 house is approx. 6.5 tons, assuming the calorific value of coal to be 28,000 kJ/kg, and not the best yet well-functioning furnace of 74% efficiency, whereas in the case of the use of 18,000 kJ/kg coal culm, more than 10.5 tons of the fuel is required. In the second case, the burnt fuel leaves almost 3 tons of ash and the dust emission is 10 kg per ton of coal culm. The concern is that to date, the modern, Class 5 furnaces remain rare; the old types and Class 3 and 4 furnaces are more common. Efficiency of the older devices is usually low and slightly above 50%, hence the actual coal consumption per heating season, as well as the amounts of ash and dust, being higher than calculated. However, the analysis proves that the use of coal with a calorific value of at least 27,000 kJ/kg, irrespective of the source, and in various designs and type of furnaces, considerably reduces both the generation of ash and the emission of dust. Therefore, it is strongly recommended that the coal producers should offer more coal types that are environmentally friendly, while the furnace manufacturers should offer models designed for burning coal of the highest quality.

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