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Review

Changes in the Polish Coal Sector Economic Situation with the Background of the European Union Energy Security and Eco-Efficiency Policy

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Abstract: Poland is a big user of fossil fuels for electricity and heat production. The most important fossil fuel is hard, brown coal and the Polish energy system is based on this source. However, the world has begun to decarbonize the climate and reduce the carbon dioxide and methane which are the main gasses impacting climate change. The main aim of this paper was to recognize changes in Polish coal sector. We focused our attention to the economic situation and employment in coal sector in Poland. The time rage included 1989–2020 and the prognosis 2021–2025. The Polish coal sector faced dramatic changes. The number of hard coal mines decreased from 70 in 1990 to 21 in 2020. In the same timeframe, the prices for hard coal increased from 12.37 PLN/dt to 313.27 PLN/dt. The employment decreased from more than 350 thousand to less than 100 thousand people in hard coal mines. The decrease changes are the effect of strict policies of the European Union. The economic situation of Polish hard coal mines is rather poor. Polish mines achieved negative economic results due to the effect of poor management. We used advanced statistics, including the Augmented Dickey–Fuller test (ADF), to measure the stationarity of analyzed time series. We also used Generalized AutoRegressive Conditional Heteroskedasticity (GARCH) models and conducted a prognosis. Our research proved that the time series describing the hard coal economic situation were not stationary. The Generalized AutoRegressive Conditional Heteroskedasticity (GARCH) models confirmed big changes in Polish coal sector economic results. The elaborated prognosis of variables proved that the price of hard coal will increase in 2021–2025. Moreover, the economic situation will be worse. Our analysis confirmed that global trends of the hard coal sector were influenced by the European Union (EU) energy policy and closing down the mines. The economic situation of Polish hard coal sector worsened.

Keywords: coal sector; electricity production

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1. Introduction

Fossil fuels perform a key role in the production of electricity and heat in Poland, the European Union (EU) and the world. Some countries, including Poland, have big reserves of hard coal to generate most of their electricity. Coal accounted for 80% of electricity production in Poland. However, Poland declared its intent to reduce the use of coal in electricity production to 60% by 2030 [1]. However, coal will remain the most important source of energy until 2050 [2]. Thirty percent of the world's population lives in China, European Union (EU) and the USA, but these regions generate half of the world's energy demand [3]. Fossil fuels have an impact on global heating and cause climate change, hurricanes, floods and affect human health causing serious diseases, such as asthma, malaria and others [4]. Hard coal and lignite deliver the vast majority of electricity production. Lignite, which is not as popular as hard coal, delivers 32–35 of electricity production [5].

Fossil fuels are mainly used for electricity and heat. Coal is used in electricity generation and heat production and oil in transportation and gas in heating [6]. However, coal, oil and gas are responsible for contamination of the environment and are called heating gases. Another problem with fossil fuel use is its waste production. In Poland, the greatest share of waste is produced by Mining and Quarrying (42.3%) and Construction and Demolition (9.5%) [7]. Next to coal, lignite is another source of electric energy that creates environmental contamination [8].

Fossil fuels perform a negative role in serious health problems in people and animals and perform an adverse role as pollutants and drivers of climate change [9]. The utilization of fossil fuels has some problems; for example, coal utilization causes ash forming and environmental pollution [10]. The reduction in CO_2 received great attention as the way to eliminate greenhouse gases [11]. Coal mining is the main source of environmental contamination deteriorating geological conditions and increase natural hazards. That is why innovative mining requires investment in new technologies based on solid technical and economic knowledge [12,13]. Moreover, utilization of hard coal generates smog production in Poland and power plants undergo strict control of gas emissions [14].

China is one of the biggest producers of coal. However, this country undertook reforms to decrease the use of coal by 15% by 2040 compared to 2016. These changes create competition in the Chinese market. Chinese coal enterprises are described as having weak competitiveness, having big resources but with low efficiency compared to modern coal mines in the world [15,16]. China's share in the world coal production rose to nearly 50% making this country a global leader [17]. The utilization of hard coal in China creates many problems for sustainable development. China is producing different kinds of coal, such as anthracite, bituminous coal, and lignite [18]. However, the changes in the world market created by COVID-19 and the war between Russia and Ukraine created addition demand for coal improving the situation for Chinese and world mines.

For many years Poland was self-sufficient in hard coal production guaranteed by national mines. However, in 2011–2018 Poland stopped exporting hard coal and started importing this source of energy [19]. Mining in Poland guaranteed the energy security but recently the sector is facing challenges [20]. Hard coal is a source for eco-pea coal which is more ecological [21]. According to Szpor and Ziółkowska [22] Poland exported in 1990 more than 30 million tons and in 2017 less than 7 million. In 2017, the imports increased to more than 10 million tons. The Polish economy was based on the coal industry, but the sector recorded a decrease in industrial production and drop in demand [23].

Mining delivers hard coal and should be more competitive to be in the market. There are many sources of competitiveness of Polish hard coal mining, for example, production, management, technologic, distributive, external and marketing [24]. The cost of production can be reduced by higher quality production, sales processes and technological possibilities [25]. The COVID-19 pandemic also affected fossil fuels. Moreover, strict European Union energy policies increased blending moving toward the mandate in 2020 [26]. Fossil fuels are not environmentally friendly and are economically unsustainable. Burning fossil fuels delivers greenhouse gas (GHG) to environment [27].

The world energy system is dominated by fossil fuels. However, more attention is now focused on renewable energy sources among which biomass performs a key role. This source of energy is particularly important in countries having large resources of forests. Biomass is mostly used in heating and it delivers more than 15% of the total heating capacity [28]. Renewable energy sources are facing instability due to the COVID-19 pandemic and disruption in the market. The supply chains were broken and many investments in renewable energy sources worldwide were reduced [29].

Another important issue is to evaluate the impact of the COVID-19 pandemic on the energy sector in Poland and the contamination of environment. The world introduced lockdown in many parts of the economy. As the result air pollution levels decreased because of the global confinements [30]. However, the restrictions led to reduced demand for energy and renewable energy leading to a drop in economic growth [31]. Moreover, the

power demand has been reduced due to the COVID-19 pandemic. The lockdown reduced the production and caused disruptions in the energy market [32]. Many jobs were put at risk and many enterprises laid off employees particularly energy companies [33].

The main aim was to recognize the factors influencing the changes in hard coal market conditions. We tried to answer following questions:

1. How did the economic situation in hard coal mines change in Poland after accession to the European Union (EU)?
2. What is the employment situation in the hard coal market in Poland?

The following hypothesis is formulated:

Hypothesis 1 (H1). *The hard coal sector worsened the eco-efficiency because of the lack of investment in technology of manufacturing in production and consumption and strong European Union climate policy.*

The employment in the coal mining in Poland decreased as the result of environmental policies. The paper includes the following parts. Section 1 is the introduction. Section 2 is a review of the literature concerning security and eco-efficiency of the European Union. Section 3 is material and methods. Section 4 describes the results. Section 5 include discussion and conclusion.

2. Energy Security and Eco-Efficiency and Policy of the European Union

Eco-efficiency and energy security policy is an important issue in Polish and European and world energy sector. Socio-environmental conflicts occur in fossil energy and create security threats to Poland, Germany and other states of the European Union (EU) [34]. Moreover, the macro-environmental changes in coal mining in Poland and other countries of the European Union pressed on cost reduction would have an impact on competitiveness in the common European market [23].

Poland is responsible for 8% European Union emissions because its energy system is based on fossil fuels. Coal is the source of the majority of emissions (70%) in Poland which highlights its harmful impact on the environment. Other European Union countries energy systems are less dependent on coal, which places them in a better position [35]. The research on energy efficiency points out that the transformation of energy sector worldwide requires investments in mining technology and changes in energy consumption of the world [17]. Moreover, improvements of energy efficiency can be achieved by coal pre-drying from the power plants and those who have such systems obtain better economic performance [36].

The proper transition of energy sector of the European Union (EU) requires subsidies to make it more competitive and cleaner. The changes in mining sector have dramatic impact on employment reduction which is why the mining sector in countries, such as Poland, requires support. Leaving this sector to free market competition will cause inevitable harmful changes. Moreover, difficult natural geological conditions made the sector non-profitable and cheap exports are preferred [37].

Coal production in Poland should not only include the resources, but also the performance of plants which obtain product based on level of workforce and physical capital [38]. Difficult situations in the world energy sector cause Polish coal enterprises to face decreasing economies of scale as a result of the energy policy of the European Union and war between Russia and Ukraine.

The development of energy and electricity sectors depends on new technologies available for both fossil fuels plants and the renewable energy sector [39]. The share of renewable energy sources is increasing worldwide. The world planned to eliminate the market for coal by 2050, but the current situation requires high investments in other sources other than fossil fuels, such as nuclear energy, natural gas, and renewable energy sources. The investment should be in accordance with the increasing needs for energy.

The development of the energy sector is strongly connected with the sustainable development policy. This sector particularly points out its coherence with agriculture

because this sector is delivering biomass and other renewable energy sources. That is why the expectations about environmental production from agriculture increases. Low price elasticity of demand for agricultural products has an impact on lower incomes from sales [40]. The agriculture in Poland and other countries of the European Union is under the Common Agricultural Policy (CAP), which aims to increase the agricultural production in accordance with the natural environment and nature preservation [41].

Traditional energy sources, such as coal, increase the degradation of the environment and the destruction of eco-systems. This pollution also has a negative impact on human health causing serious diseases. This is why there is strong pressure for a clean production of coal supported by governmental help [42]. Particular roles must fulfill the national and regional governments whose aim should be the promotion of renewable energy sources which reduce the environmental stress and contamination. After mining, the land requires restoration, which is a costly process. It also consists of the draining of mine water. The costs of these activities are not accepted by the majority of people and government [43].

The Polish coal energy system is undergoing dramatic changes and the decrease in production has been observed. It is clear that this sector will be closed in the future and its place will be taken by renewable energy sources. However, these new kinds of energies are very vulnerable to the climate (photovoltaics and wind energy). Moreover, the COVID-19 pandemic created disruptions in supply chain of renewable energy sources [44]. The same opinion is confirmed by Hosseini et al. [45] who claimed that the COVID-19 pandemic caused not only disruption in supply chains, but also in transformation of the coal sector and manufacturing facilities. That is why it is very important to use predicting methods to elaborate the decision and performing for energy sector worldwide [46].

The concept of energy security and eco-efficiency and policy of the European Union helps to develop the sustainability and circular economy. The circular economy is a so-called green economy which enhances the efficient use of resources, helping to achieve the Sustainable Development Goals (SDG) [47]. The circular economy is focused on lowering consumption of natural resources and lower waste return to the environment [48]. The term circular economy is described as regenerative economy enhancing the optimization use of resources [49]. The circular economy has fundamental approaches based on a resource-orientated focused on the reuse of products and recycling materials [49–52]. The second fundamental includes an economically orientated concept focusing on nature conservation. In this approach, technology is important because it can allow the use of different sources of materials, for example, primary and secondary materials [53–56].

3. Materials and Methods

3.1. Data Sources

The main source of information was the literature review and statistics information. First, we gathered data about economic situation of Polish hard coal mines, the employment and the prices of coal (Figure 1).

The main source of information were data from Statistic Poland which included coal sector. We focused particularly on the economic situation of hard coal mines, employment in hard coal mines, prices of coal and the number of active mines in Poland. These data are available within Statistics Poland. The time rage of these data included 1989–2020. Thirty-one years of observations enables us to analyze changes and conduct the prognosis. In the analysis, we used historic data. It was not possible to acquire data from 2021–2022. Normally, statistic data are available after two years.

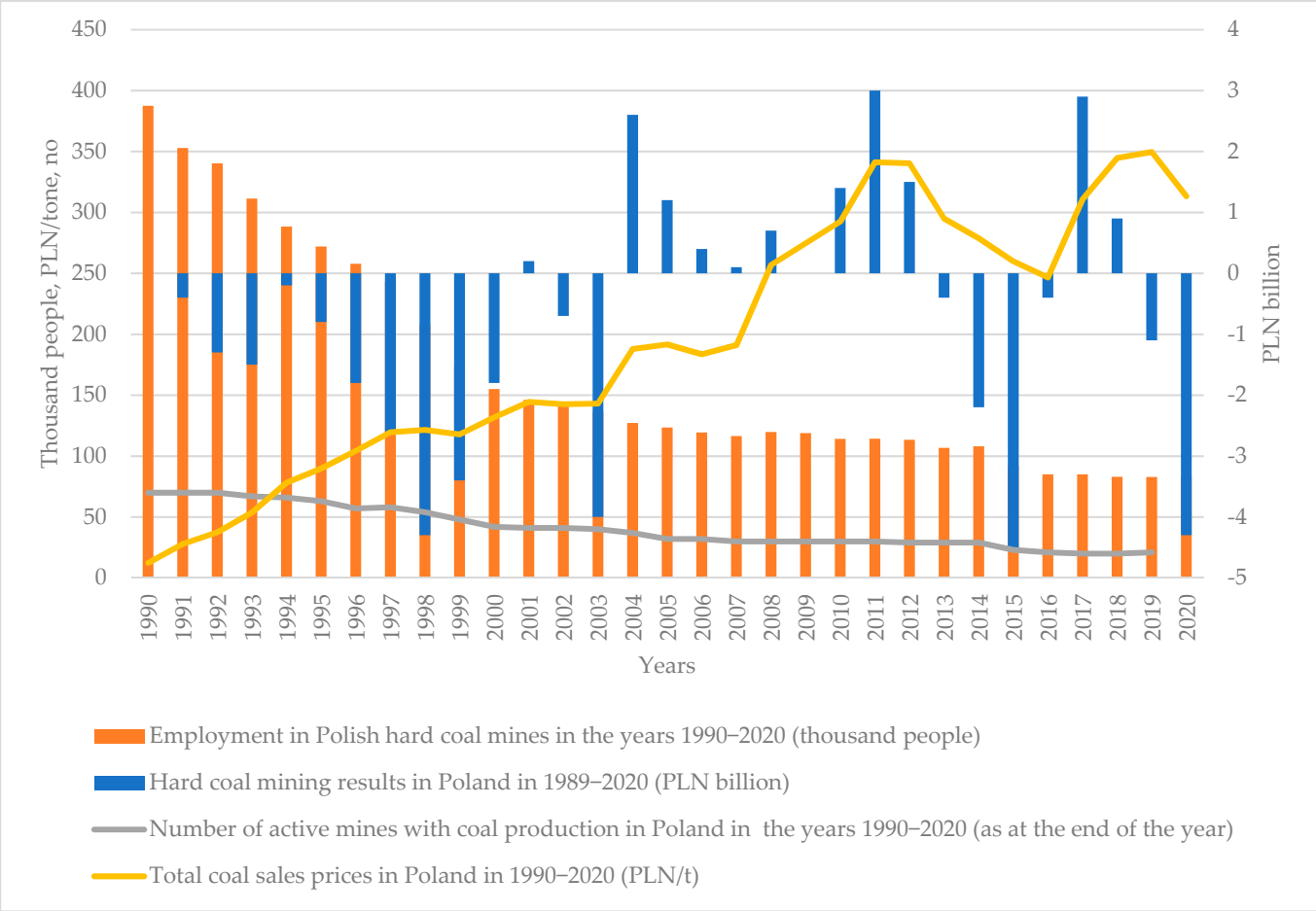

Figure 1. Employment, hard coal mining, number of active mines and total coal sales in Polish coal sector. Source: own analysis based on Statistic Poland.

The COVID-19 pandemic did not have a big impact on the situation in the Polish hard coal sector. Since the beginning of COVID-19, in the year 2019, we could observe the decrease in economic results, decrease in total sale coal prices, decrease in employment and increase in the number of active mines.

3.2. Methods

Different methods were used to check the changes in the Polish hard coal sector. We conducted the analysis using descriptive methods, statistical analysis and prognosis. Such analyses are important not only for scientists, but also policy makers, who make decisions concerning the coal sector [57].

The biggest changes have been observed in total coal sales prices in Poland. It increased the most in 1990–2020. At the beginning of COVID-19, the total coal sales prices decrease. Moreover, the big changes have also been observed in hard coal mining results. The smallest changes have been observed in employment in Polish hard coal mines and number of active mines.

In the first step, we conducted the Augmented Dickey–Fuller (ADF) test to measure the stationarity of the time series [58,59]. This is a popular method in which we test two hypotheses that the time series is stationary (H1) and not stationary (H2).

In our next step, we used the Generalized Autoregressive Conditional Heteroscedasticity (GARCH) models, which were made by Engle [60] and Bollerslev [61]. Nonstationary conditional variance has been checked by GARDCH model [62,63]. The GRCH

models are used to check the changes in dependent variables [64–67] and are presented by the equation:

$$\sigma\ 2\ t = \alpha 0 + \alpha 1 y\ 2\ t - 1 + \beta 1 \sigma\ 2\ t - 1 \quad (1)$$

In our last step, we conducted the prognosis which helped us to foresee changes in 2021–2025. Five years prognosis is very useful for policy makers, politicians and people involved in the hard coal sector in Poland.

It is important to realize that variables, such as the impact of COVID-19, war between Russia and Ukraine, EU energy policy and the rapid development of new energy on fossil energy, were not analyzed in this paper. It was only possible to discuss the literature and policy documents to analyze factors which may increase the realistic prediction results. This is the specificity of GARCH models that rely on the analysis of historical data. These are not regression models where scientists can analyze the influence of the explanatory variables on the explanatory variable. A characteristic feature of GARCH models is the analysis of changes in the time series.

4. Results

The economic situation in Polish hard coal sector has changed in 1989–2020. As we can see from Figure 1 the situation is getting worse. The largest deficit was observed in 2015 (−4.5 PLN billion), 2020 and 1999 (−4.3 PLN billion) and 2003 (−4.0 PLN billion).

Between 1989 and 2020, only in 11 years the positive economic results were observed and the highest was observed in 2011 (3.0 PLN billion), 2017 (2.9 PLN billion) and 2004 (2.6 PLN billion). The negative balance of Polish coal mines was due to various factors. First, the underinvestment was a key factor. Second, the global competition on coal market which changed the prices. Third, the European Union energy policy which forced the government to limit aid to mines. Finally, COVID-19 and war between Russia and Ukraine.

Poland is one of the most important producers of coal globally. However, the European Union elaborated and introduced decarbonization processes, which the aim is to reduce carbon dioxide and other harmful gas production. The process has decreased the competitiveness of Polish hard coal sector [68].

The employment in Polish hard coal mines decreased from nearly 400 thousand people to less than 100 thousand people. Such a decrease was due to the process of closing hard coal mines (Figure 2).This is the direct employment which includes people employed by coal enterprises [69]. However, there is also an indirect employment which includes people employed in companies producing goods and delivering services for coal enterprises and people providing goods to meet the consumption demand [70].

For many years, the most important problem with Polish coal mines was high labor cost which exceeded 50% of all costs. This was the reason to decrease the employment and to introduce mechanization in hard coal mines. The Polish hard coal market was open to the European and world economy, but it was previously protected by so-called geographic rent [23]. These and other factors forced Polish miners to change the profession, look for work in another sector. Other miners found jobs in abroad, particularly in Germany or Czech Republic mines.

Another problem with the employment factor is the hazards of the work, including methane explosions, rock bursts, radioactive substances and others. These factors cause the work to not be attractive for people because of the life and health risks. People resign from such work and look for other, safer occupations [71].

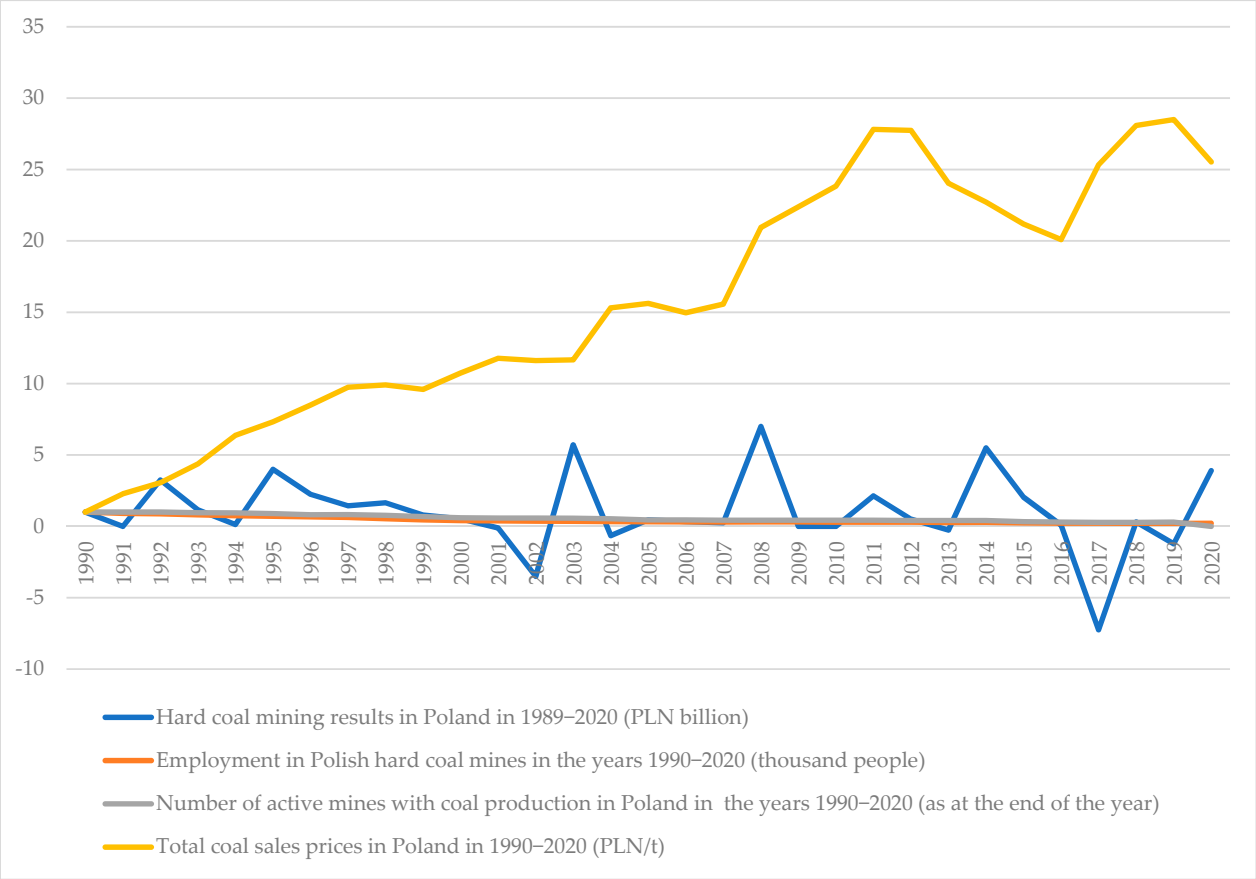

Figure 2. Changes of employment, hard coal mining, number of active mines and total coal sales in Polish coal sector. Source: own analysis based on Statistic Poland.

The number of active coal mines in Poland decreased from 1990. The numbers decreased from 70 to 21 (−70% decrease). There are many reasons for this. First, the layers of hard coal were used. Second, the European Union (EU) policy ordered to close hard coal mines. Third, the processes of consolidations were observed.

Coal production is very important for European Union countries, such as Poland, because those countries want to be secure and independent in case of energy and electricity production. The Upper Silesian Coal Basin located near the border with the Czech Republic is the main place where the coal is extracted [72]. Polish coal mines extract and process coal to the final requirements of consumers. Such complicated procedures require process management which is an important part of management [73].

Coal is a fuel that is possible to extract in many regions of the world. However, the demand for coal changes throughout a year. It increases most in September and October and decreases in April. The seasonality demand for hard coal has been observed determines the production cycle [38]. Poland delivered about 55 mln tons of hard coal in 2020. In 2010, Poland delivered 76 mln tons of hard coal. Such data proved the decrease in hard coal delivery and created a deficit of coal on market. In 2022, approximately 19.4 mln tons should be imported to fulfill the demand for the energy carrier. The problem with imported coal is that it is mainly fine coal with a grain size of 1 to 50 mm, which is 25% coarser coal, which is used as fuel in households.

The prices of coal changed in 1990–2020. The highest prices were observed in 2019 (349.66 PLN/ton) and the lowest in 1990 (12.67 PLN/ton). Such increase in coal sale prices was the effect of increasing demand for heat and electricity. Moreover, Polish electricity system is based on hard coal. The observed decrease in Polish hard coal prices was the result of the decline in sales and the increased importation of cheap coal, mostly from

Russia and other countries. These reasons combined with difficult geological conditions of mining make hard coal mining not profitable. The sector has options to reduce the production or to get more investment support from state budget [37].

Low prices of coal have an impact on low price of electricity from one side, but they also force a reduction of the production capacity. When we compare the price of electricity from coal to price of electricity from other sources, coal is still the cheapest. Low prices forced Poland to close coal mines and to increase import of coal. This situation was typical, not only for Poland, but other European Union countries, such as Great Britain and Germany, as well [72]. This situation led to the dependence on coal imported from Russia and other countries and decreased the energy security of European Union (EU). Such dependence enabled Russia to take advantage and committed blackmail with coal and other energy carriers. To avoid this negative phenomenon, it is necessary in the future to become independent from supplies of coal and other energy carriers from Russia, who spends the money earned in this way on armaments and occupies Ukraine.

In order to analyze the changes in Polish hard coal market, we prepared the descriptive statistics (Table 1). This is a popular method. It provides information about summaries observed in variables [73]. This analysis can be introduction to other statistics.

Table 1. Descriptive statistics for total coal sales prices, number of active mines with coal and employment in Polish hard coal in 1990–2020.

Variable	Average	Median	Minimal	Maximal	Std. Dev.	Coefficient of Variation	Skewedness	Kurtosis
Hard coal sector mining results	−0.671	−0.400	−4.500	3.00	2.057	3.067	−0.226	−0.527
Total coal sales prices [PLN/t]	193.030	187.88	12.670	349.660	104.520	0.541	−0.025	−1.249
Number of active mines with coal [number]	40.645	32.000	20.000	70.000	16.744	0.411	0.595	−1.041
Employment in Polish hard coal [thousand people]	167.670	123.400	82.700	387.500	90.825	0.541	1.091	−0.150

Source: own elaborations based on Skibski et al., 2020 [71].

The hard coal sector achieved negative average mining results. It varied from −4.500 PLN billion to 3.00 PLN billion in the analyzed period. The achieved coefficient of variation of the hard coal sector mining results was very high and achieved the value of 3.067. The skewedness and kurtosis were negative which suggests their left-handed position.

The second variable was average total coal sales price was 193.03 PLN/tone. It increased from 12.7 PLN/tone to 313.27 PLN/tone. Such changes had an impact on the high value of average coal price. The coefficient of variation of total sale coal prices was quite large (0.541). The skewedness and kurtosis of the total coal sale prices was left-handed. This means that during 1990–2020, major changes occurred in the Polish hard coal mines and had a dramatic impact on their conditions.

Another variable is the average number of hard coals was slightly above 40. It decreased from 70 to 32 in 1989–2020. The coefficient of the variation achieved the value of 0.411, which suggests medium changes. The skewedness of the number of coal mines was positive, which suggests a right-handed position in distribution and the kurtosis negative, which suggests a left-handed position in distribution.

The last variable was employment in Polish hard coal mines. It reached the average value of 167 thousand people and decreased from 387.5 to 82.7 thousand people in 1989–2020. The coefficient of variation of employment in Polish hard coal mines was 0.541. The skewedness was positive and kurtosis negative.

We conducted the multivariate analysis, which is an important method in statistics. This method relies on assumption of normality to near normality [74]. Our research was supported by the Augmented Dickey–Fuller-GLS test, which confirmed that the variables describing hard coal sector economic situation in Poland are not stationary and has higher power that Augmented Dickey–Fuller (ADF) test (Table 2). The best result is when the data is stationary. When it is not stationary, we have to first calculate differences [65]. Generally, we test two hypotheses of this test [68]. When we do not confirm the stationarity of time series, we have to first calculate the differences. When we compare the p value, we can conclude that the first differences for test have lower p value, which suggest that they are better for calculating the Generalized AutoRegressive Conditional Heteroskedasticity (GARCH) model. The Augmented Dickey–Fuller (ADF) test with first differences recorded lower p-values. These results suggest that the null hypothesis was not rejected. Our analysis shows that by using the Augmented Dickey–Fuller (ADF) test, we achieved and prepared better data for further analysis [75]. The p value of the test was low in the hard coal sector mining results, total coal prices and number of active mines. The highest p value was observed in employment in the Polish hard coal sector. As we can see, the results of the Augmented Dickey–Fuller-GLS test are better than the ADF test. The autocorrelation of residual from the first raw data achieved better results. This data enabled us to finalize the analysis and elaborate the Generalized AutoRegressive Conditional Heteroskedasticity (GARCH) model and prepare the prognosis.

Table 2. Augmented Dickey–Fuller test (ADF test)-GLS.

Specification	Levels of Dependant Variable				First Differences of Dependant Variable			
	Estimated Value (a-1)	Tau Test Statistics	p Value	Autocorelation of Resuduela	Estimated Value (a-1)	Tau Test Statistics	p Value	Autocorelation of Resuduela of First Raw
Hard coal sector mining results	−0.553	−3.123	0.005	0.140	−1.024	−5.274	0.000	−0.006
Total coal prices	−0.0149	−0.336	0.854	0.366	−0.761	−3.903	0.001	0.084
Number of active mines	−0.014	−0.594	0.769	−0.071	−0.621	−3.508	0.002	0.013
Employment in Polish hard coal	0.006	0.745	0.995	−0.133	−0.012	−0.100	0.925	0.046

Source: own analysis.

A wide use of the Generalized AutoRegressive Conditional Heteroskedasticity (GARCH) model can be observed for both the national and international literature [58]. The use of this model was different for the analysis of longtime series, including financial analysis and others (Table 3). In our second step, we conducted the Generalized AutoRegressive Conditional Heteroskedasticity (GARCH) model, which presents the maximum-likelihood estimates. It is used to model the dynamic nature of volatility by specifying the conditional mean and variance [69]. A Generalized AutoRegressive Conditional Heteroskedasticity (GARCH) models can be fitted to multivariate distribution, and we generally do not re-estimate the model for different weight vectors [76]. The classical model presents theoretical derivations describing stationarity.

As we can see from Table 3, the Generalized AutoRegressive Conditional Heteroskedasticity (GARCH) model achieved positive results. The p value was the lowest for employment in Polish hard coal mines. The standard error was the highest for total coal sale prices pointing out possible mistakes in predicting this variable. The likelihood logarithm was negative and becomes unstable at lower values.

Table 3. GARCH model for analyzed variables.

Specification		Coefficient	Standard Error	z	*p* Value	Arithmetic Mean of the Dependent Variable	Likelihood Logarithm	Critical Bayesian Schwarz Criterion	Standard Deviation of Dependent Variable	Critical Information Akaike Criterion	Critical Hannan–Quinn Criterion	Chi Square
Hard coal sector mining results	Const	−0.446	0.352	−1.265	0.206	0.670	−65.814	145.365	2.057	139.629	141.499	0.0720
	Alpha 0	3.454	0.892	3.873	0.111							
	Alpha 1	0.066	0.259	0.255	0.799							
	Beta 1	0.449	0.174	2.577	0.010							
Total coal sale prices	Const	119.477	6.389	18.70	0.004	193.0268	−178.394	373.957	104.522	366.787	369.124	18.433
	Alpha 0	88.509	205.019	0.432	0.666							
	Alpha 1	0.961	0.707	1.359	0.174							
	Beta 1	0.038	0.554	0.068	0.945							
Number of active mines	Const	30.066	0.889	33.80	0.175	40.645	−110.571	238.312	16.744	231.142	233.479	40.535
	Alpha 0	4.534	3.545	1.279	0.208							
	Alpha 1	0.887	0.469	1.891	0.058							
	Beta 1	1.000	0.325	0.000	1.000							
Employment in Polish hard coal	Const	117.283	1.570	74.69	0.000	167.677	−150.378	317.926	90.825	310.756	313.093	65.755
	Alpha 0	8.203	11.835	0.693	0.488							
	Alpha 1	0.866	0.349	2.481	0.013							
	Beta 1	1.000	0.266	0.375	1.000							

Source: own analysis.

When we compare models with the Bayesian information criterion (BIC), we assume that the model with the lowest BIC is considered the best. In our example, hard coal mining results achieved the smallest critical Bayesian Schwartz criterion.

We also used the Akaike information criterion (AIC), which is a mathematical method for evaluating how well a model fits the data. As we can see from Table 3, the highest value was achieved in total coal sale prices and the smallest in hard coal sector mining results.

Finally, we evaluated the Critical Hannan–Quinn criterion (HQC), which is a measure of the goodness of fit of a statistical mode. It reached the highest value in total coal sale prices model and the lowest in hard coal sector mining results.

The elaborated prognosis confirmed the changes observed in previous years, such as 1989–2020. The hard coal mining results will show a worsening of the economic situation. This situation will be the result of a lack of necessary investment. Moreover, the sector will be closed in Poland and in the European Union (EU) by 2050 (Figure 3). How much the economic situation worsens depends on many factors. First, is undoubtedly the COVID-19 impact. The closing of mines was a process which should have been discussed in wider groups including policy makers, miners, mines managers and the European Union commission. There is no future for coal; however, the process should be undertaken in a stable manner, not because of COVID-19. It is important to find new places of work for the miners who will lose their jobs because of the closing mines.

The total sale coal price will decrease. The demand for coal will be high even though the renewable energy sector will still be developing [76–79]. The price of coal depends on the supply and is the result of consumer demand. As we know, the situation in the world coal market is disrupted not only because of COVID-19, but also because of the war between Russia and Ukraine. Countries supporting Ukrainian defense eliminated the delivery of cheaper hard coal from Russia. As a consequence, the deficit of coal had to be fulfilled by importing from other countries. In 2022, Poland imported about 19.7 million tons of hard coal from all over the world, including North and South American countries, Kazakhstan, Asia, Australia, Indonesia and Africa. The replacement of coal from Russia is more expensive, but politically better to enhance the energy security. The most important factors shaping coal prices are coal compositions, intermediaries and margins. This means that the coal that goes to Polish ports costs PLN 2500, including VAT, and costs PLN 1000 more in a coal deposition. Local governments became involved in the distribution of coal, using municipal companies and various types of enterprises. Due to this, they have the opportunity to buy coal directly from the importer and sell it with a much lower mark-up. The coal is even sold on the internet.

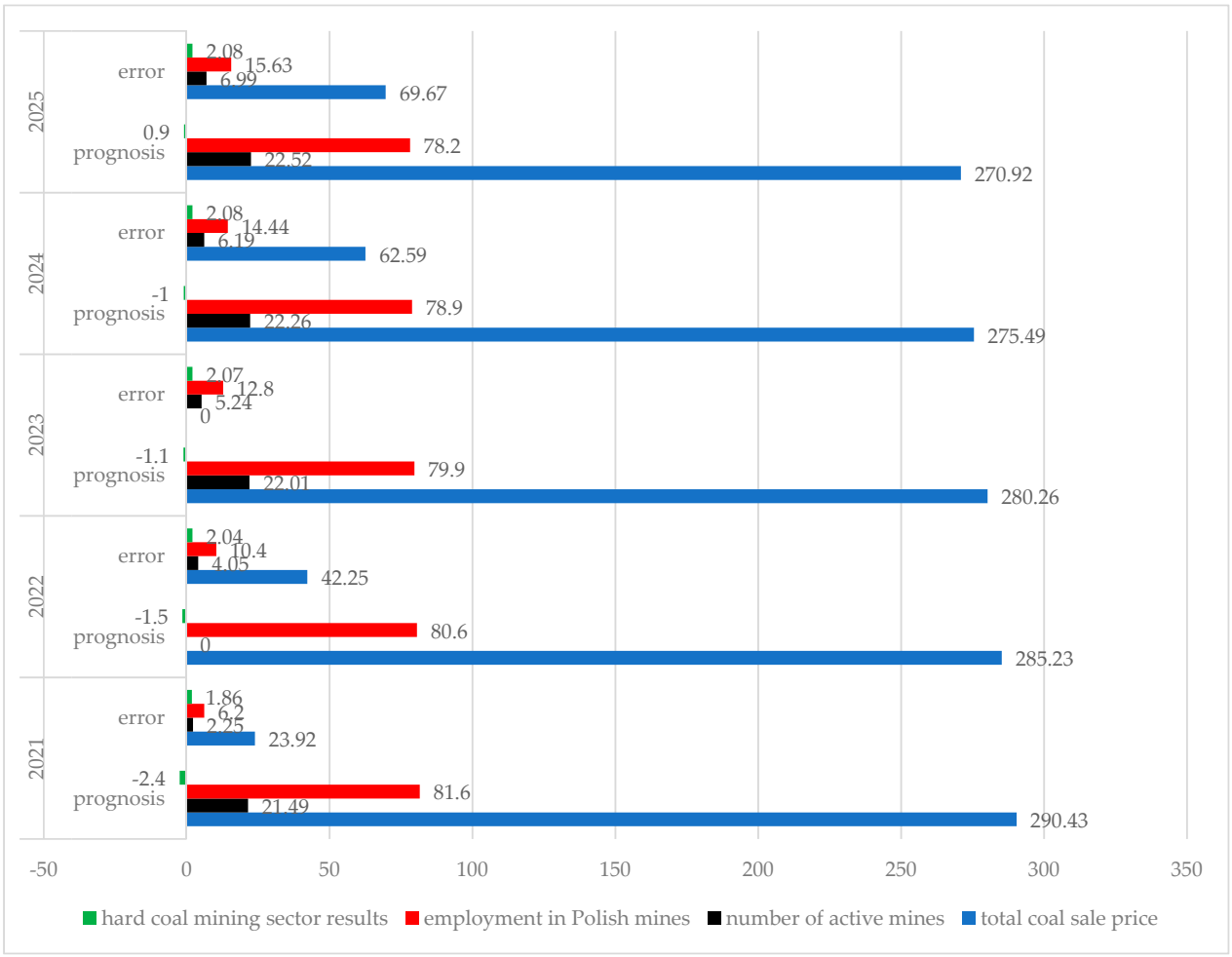

Figure 3. Prognosis and errors of analyzed variables. Source: own analysis.

The number of active coal mines will also slowly decrease as the effect of rationalization of processes. Mining is a very dangerous sector which requires high investment to be competitive. It is worth mentioning that the current situation with coal in Poland is that this country had to import 10 million tons from various places around the world. Before the war between Russia and Ukraine, Poland imported coal from east countries. The world and taxes caused that the deficit to be fulfilled by coal from South America countries.

The employment in Polish hard coal mines will remain unchanged in the nearest future. The current delivery requires the employment of about 80 thousand people. The number of people will fluctuate around this level and will not observe dramatic changes. The employment changes in the Polish energy sector are similar to changes in other countries. Employment in coal mines is decreasing, while employment in the renewable energy sector increasing. For example, according to data from the International Energy Agency (IEA), 7.8 million people are employed in solar and wind energy—the same number as in the oil supply sector—and 13.6 million people are to be employed in the global vehicle manufacturing sector, 10% of which are in the oil sector and others manufacture electric vehicles and their components and batteries [80].

5. Discussion

The hard coal sector is undergoing dramatic changes in Poland in 1989–2020. The biggest problem with Polish hard coal sector is the contamination of environment. It is believed that the EU environmental policy should decrease this problem. The most

important way in decreasing the scope of contamination and decarbonization is the shutting down the mines.

Polish hard coal mining is slowly shutting down. The European Union tendencies and policy is forcing coal mining to close by 2050. This results in the sector not developing and will be a lost sector because of energy policy of the European Union (EU).

To analyze the stationarity, we used ADF test and GARCH model. This model presents variance matrix forecasting accuracy and is a popular model in econometric analysis [69]. Based on the information of our results, we can conclude the importance of having both a short-run and a long-run component of conditional variance. Similar results were achieved by Katsiampa [81], who examined volatility estimation of bitcoin.

Based on our results, we can confirm that the time series including the economic situation of hard coal mines, employment in hard coal mines, prices of coal and the number of active mines in Poland were not stationary with the statistical properties of the analyzed time series changing over time. Moreover, the trend and seasonality had an impact on the mean and variance in the analyzed time range. That is why we had to first calculate differences in order to make the data more suitable for the model. Thus, we can conclude that the behavior of the time series data will depend on different variables, such as policy and current situation in the energy sector, not only in the time series.

The prognosis is rather pessimistic for the Polish hard coal sector. All the variables confirm unprofitable changes for this sector. Polish hard coal mines will achieve negative results. The negative economic results will be decreased; however, they will still be negative. This situation will be due to the effect of global changes in the energy sector. In the future, energy from renewable sources will be the cheapest energy available on the Polish market. Renewables, even considering depreciation costs, remain the most advantageous electricity supply option for both businesses and individual customers. It can even be said that the Polish energy market will be completely dominated by RES. Looking from a broader perspective, it is completely understandable—as a result of international regulations of the energy sector, especially those adopted by EU Member States as part of the common energy and climate policy—that traditional energy sources have become extremely economically unattractive. Burning high-emission fuels (i.e., minerals) in the EU has become illegal and there are high penalties for breaking the ban. At the same time, the pressure from regulators to increase energy efficiency is greater than ever. The Polish government actively supports investments in RES-based energy and local governments are developing programs to subsidize RES micro-installations owned by private individuals [82].

The Polish energy sector will depend on of the drafting of the Polish Energy Policy (PEP) through 2040 [83]. One of the directions set out in this project is the implementation of nuclear energy. Poland has chosen this direction because nuclear power plants guarantee stable energy generation with zero greenhouse gas emissions. In addition, according to experts, nuclear energy will enable the diversification of the Polish energy mix, while strengthening its energy security and competitiveness of the national economy [84]. The main objectives of PEP (Polish Energy Policy) zero-emission energy system and good air quality. Moreover, this policy is focused on the use of Poland's own resources, diversification of suppliers of energy, market development, cogeneration resources, improve efficiency and other factors [85].

6. Conclusions

The development of Polish hard coal sector has been undergoing dramatic changes due to strict policies of the European Union (EU).

The aim of this research was to recognize factors influencing the changes in hard coal market conditions. The changes can be described as constant reduction in hard coal plants. It is believed that the reduction in this sector would decrease the carbon emitted into the atmosphere. However, a better solution would be investment in the hard coal sector. The employment in Polish hard coal sector has also decreased to less than 100 thousand people from about 400 thousand people.

The economic situation of Polish hard coal sector is rather poor. The biggest deficit was observed in 2015 (−4.5 PLN billion), 2020 and 1999 (−4.3 PLN billion) and 2003 (−4.0 PLN billion). Between 1989 and 2020, only in 11 years the positive economic results were observed and the highest was observed in 2011 (3.0 PLN billion), 2017 (2.9 PLN billion) and 2004 (2.6 PLN billion). Poland and other European Union countries, such as Czech Republic, have resources, skilled workers and the possibility to increase coal production. However, the European Union climate policy forced these and other countries to decrease production. It is widely believed that coal will still remain a very important source of energy in Poland.

The main aim of our research was to recognize the factors influencing the changes in hard coal market conditions. We confirmed that the situation was created by the European Union (EU) energy policy and global trends closing the mines. The economic situation of Polish hard coal sector worsened due to this.

We elaborated Hypothesis 1 (H1) assuming that the hard coal sector worsened the eco-efficiency because of the lack of investment in technology of manufacturing in production and consumption. This situation is typical for many countries of the European Union and the world. There is no chance to reactivate the hard coal sector, which will be closed to 2050.

The novelty of the paper is the stationary analysis, Generalized AutoRegressive Conditional Heteroskedasticity (GARCH) models and prognosis. The analysis of Augmented Dickey–Fuller test (ADF) show that the time series, including economic situation of hard coal mines, employment in hard coal mines, prices of coal and number of active mines in Poland, were not stationary. It means that the variables in time were not dependent on each other. That is why we first calculated the differences which enabled us to do the Generalized AutoRegressive Conditional Heteroskedasticity (GARCH) model. The Generalized AutoRegressive Conditional Heteroskedasticity (GARCH) model enabled us to present the maximum-likelihood estimates. In our research, the maximum-likelihood had negative results and our goal was to minimalize the likelihood of the analyzed data. The prediction of our time series confirms the foreseen changes and the discussion in the literature. First, the price of hard coal is going to stabilize as the world will shift more to renewable energy sources. Second, the number of people employed in mines will remain stable or decrease slightly as the results of optimization the situation in energy sector. Third, the number of coal mines will are stable will slightly increase. Fourth, the economic situation of the hard coal mines will stabilize as the effect of government subsidies.

The future research will be based on circular economy and utilization of renewable energy sources. The hard coal sector, which is still important for the world economies, will become less important. The environmental concerns and the European Union (EU) environmental policy will force the government to shut down the coal mines.

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Nomenclature

ADF	Augmented Dickey–Fuller test
AIC	Akaike information criterion
BIC	Bayesian information criterion
EU	European Union
GARCH	Generalized AutoRegressive Conditional Heteroskedasticity
GDP	Gross Domestic Product
GHG	Greenhouse gas
HQC	Hannan–Quinn criterion
IEA	International Energy Agency
MLN	Million
PEP	Polish Energy Policy
RES	Renewable Energy Sources
SDG	Sustainable Development Goals
PLN	Polish currency zloty
T	ton

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