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Perspective

The Cost of Using Gas as a Transition Fuel in the Transition to Low-Carbon Energy: The Case Study of Poland and Selected European Countries

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Abstract: The purpose of this article is to answer the question of whether it is economically justified to use natural gas as an interim fuel on the way to creating a low-emission energy sector from the perspective of Poland in comparison to other countries in the European Community. Despite the existence of numerous scientific studies concerning natural gas as a 'bridge' fuel, there is a lack of precise references to the situation of Poland in this respect, especially considering its specific situation in the historical development of energy, as well as the ongoing energy crisis caused by the Russia–Ukraine war. The study suggests that from Poland's point of view, given the changes in natural gas prices resulting from a series of events of an international nature, gas investments are not economically justified in the economic climate (NPV of −891 million EUR) at present and will not be justified in the event of their anticipated changes (NPV of −691 million EUR), having its justification only in the presence of unlikely global changes (NPV of 2.37 billion EUR).

Keywords: transformation; energetic safety; the Green Deal; gas; energy policy; transition fuel

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1. Introduction

The necessity of decarbonizing the energy sector is undoubtedly one of the key elements of the zero-carbon objectives set by several international organizations, such as the United Nations and the European Union [1–3]. The energy sector is particularly important as it is responsible for approximately 73% of greenhouse gas emissions [4], which makes decarbonization necessary to avoid several climate consequences resulting from global warming, such as rising ocean levels, increased risk of extreme weather events, or environmental changes leading to the extinction of animal species [5,6].

Considering the direction of the planned changes, which can be observed, inter alia, in objective 7 of the Sustainable Development Goals, i.e., clean and accessible energy, the target solution is a significant development of widely understood renewable energy sources [7]. However, it should be emphasized that, depending on individual countries, the development of their existing energy infrastructures, their geographical location, or their economic capacity, the implementation of energy based on renewable energy sources will be significantly different. Other actions will be performed, for example, by France, which in 2021 produced approximately 70% of energy in nuclear reactors [8], and by Poland, which in the same year produced approximately 70% of energy using coal (brown and hard coals) [9].

One of the differences in the actions mentioned above is the use of transition fuels in the energy transformation process, particularly the use of natural gas. Due to its international obligations, as well as its undiversified energy mix based predominantly on coal, Poland

has identified gas as a key transition fuel that will enable—from a long-term perspective—the achievement of a zero-carbon energy mix by including it in a way that assumes a significant increase in the use of this fuel for power generation from 14 TWh in 2019 to 54 TWh in 2030 in the Polish Energy Policy until 2040 [10]. Poland's planned actions, given their scale and the state of affairs at present, should be conducted with particular care, bearing in mind not only the broadly understood legitimacy of using natural gas as an interim fuel (in the environmental or energy security dimension), but also taking into account issues that include the country's energy security (especially in view of the ongoing conflict in Ukraine), the short-term effects of carbon emissions, and the economic viability of the changes, which is particularly important given the investment's construction time of approximately 5 years [11] and its cost of approximately 3 billion PLN per MW (approximately 650 million EUR) [12].

The literature on the subject, despite the discussion on the rationale of using natural gas as a transitional fuel, does not focus on the economic dimension of the justification of its use, particularly in reference to individual situations of countries, such as Poland. A consideration of the individual situation is important as far as the actions of the legislator of the European Union is concerned, who makes the decisions in general—for all member states—that are aimed at supporting the idea of using natural gas as a transition fuel, which is evident by the inclusion of this fuel in the taxonomy as an environmentally sustainable activity.

The goal of this paper is to create and present an economic analysis of the profitability of investments in infrastructure supporting the use of natural gas as a transition fuel in the example of Poland. This analysis is performed by considering the occurrence of events, at present, such as the COVID-19 pandemic or the Russia–Ukraine war, which have had a significant impact on the energy market [13,14]. The results of the analysis can provide additional arguments for or against decision-making processes concerning investments in this area.

2. Literature Review

2.1. Environmental Aspect of Gas as a Bridge Fuel

One of the key arguments that justifies the use of natural gas as a transition fuel is undoubtedly the significant difference in carbon dioxide emissions when it is burned compared to other fossil fuels [15–17]. This argument is of particular importance from the perspective of countries, such as Poland or the Czech Republic, which rank second in the European Union in terms of energy production from coal, which is approximately 47% [18]. It should be added that, apart from the emission of carbon dioxide itself, gas as a fuel also has significantly lower emissions of sulfoxides or nitrogen oxides, which is not only related to the emission of the fuel itself, but also to the efficiency of its combustion, which exceeds that of other fossil fuels, particularly coal [19].

The literature also indicates that the use of gas may contribute to the development of renewable energy sources in a broad sense and, thus, reduce greenhouse gas emissions in the long term. The flexible nature of gas makes it possible to rapidly increase or decrease the production of energy, which in turn makes it possible to adapt to fluctuations in the demand for electricity while also regulating fluctuations in the power produced by other sources of electricity [20]. Additionally, the infrastructure required to transport gas, the development of which is a necessary part of gas power development, can be used to transport hydrogen [21,22], which could be one of the key elements of a zero-carbon energy future [23].

It is also worth noting that temporarily replacing fossil fuels, such as coal, with gas can also contribute to improving air quality [24,25], which is crucial for countries struggling with this problem, such as Poland, which is home to 36 of the 50 most polluted cities in the European Union [26].

On the other hand, it is emphasized in the literature that gaseous fuel continues to be a fossil fuel, which means that its use entails similar consequences to the use of other

types of fossil fuels. Despite its significantly lower carbon footprint, it is evident that power generation from gaseous fuels may not significantly reduce greenhouse gas emissions in the long term [27]. In addition, gas production and transportation are associated with emissions of gases, such as ethane [28] or methane, which are crucial in the fight against climate change [29]. In addition, there are other environmental effects that directly affect the environment and humans, including water pollution associated with extraction and power generation [30], increased seismic activity [31], and the impact of chemicals used in gas extraction processes on human health [32].

It should also be highlighted that support for power generation using natural gas, given its carbon intensity, in the long term, may conflict with the overall need and plans to achieve 0% emissions by 2050 [33,34]. The negative environmental effects emphasized in the literature are also highlighted by several NGOs [35,36], especially for international support for the use of this type of fuel, such as the EU taxonomy.

2.2. Energy Security Aspect

Since energy is one of the key sectors of the national economy [37], the context of energy security in the discussion of the energy transition process is essential. The context of energy security can be considered in national and international spheres. However, it should be noted that, according to the literature, energy security at a national level is almost unattainable, which suggests that internationally guaranteed energy security should have a key influence on the factors being considered [38], which is shown, inter alia, by the example of the United States, given its dependence on imported oil [39].

The very concept of energy security, in principle, focuses on anticipating the risks associated with the supply of fuel powering a given energy system and its price [40]. Such an understanding of the definition of energy security means that potential investments in gas and related infrastructures should be considered in light of certain events, such as the Russia–Ukraine war, which has caused a significant increase in the price of this raw material from one of the main suppliers to the entire European continent [41].

At this point, it should be noted that the key aspect in the evaluation of natural gas from the perspective of energy security is its availability [42], which, from the perspective of Poland, in terms of geographical availability (exploitable deposits), is minor [43].

On the other hand, bearing in mind Poland's energy mix, as well as the understanding of the concept of energy security pointing to its dimension of the diversification of energy generation sources, increasing diversification through investments in the natural gas sector should result in increased energy security [44].

In addition, it should be emphasized that, from a broader perspective, taking into account energy security as the constant availability of energy [45], gaseous fuel can be characterized by the role of stabilizing renewable sources, whose uncertainty and instability caused, inter alia, by a dependence on weather conditions (especially in the case of wind or solar energy) can pose a threat to the operation of electricity grids [46,47], which is particularly important because of recent events, such as the COVID-19 pandemic, during which energy consumption was able to decrease by up to 23% [48].

The divergence of opinions in the field of energy security, caused by numerous definitions of this phenomenon [49], makes it impossible to provide a succinct answer to questions concerning the security of investments in a given type of fuel. Nevertheless, this concept is jointly considered with climate change as a problem to solve such issues [50].

2.3. Economic Aspect

In terms of the impact of gas as a transitional fuel on the economy of countries that use it, the authors of the study indicated that the consumption of natural gas [51], as well as its supply [52], results in economic growth, which is caused, among other things, by the price of this fuel. However, it should be noted that the cited studies were conducted in 2019 without considering the significant changes in gas prices caused by the COVID-19

pandemic that occurred in August 2020 [53]. It should be emphasized that there is also no reference to further changes resulting from the conflict in Ukraine.

It should also be stressed that the economic benefits of gas-fired power generation or consumption will depend on the energy intensity of a given country and the availability of gas in the sense of whether it can be obtained from the country's territory or imported [54]. The economic assessment will appear different from the perspective of the United States, which possesses rich deposits of shale gas along with the technology necessary for its extraction [55], compared to a country, such as Poland, which in 2021 imported approximately 84% of the gas fuel consumed [56].

3. Methodology

The authors of the present study selected an experimental method in the form of a thought experiment [57], consisting of simulating the course of financial phenomena related to investment activities in the use of natural gas as a transition fuel through the models presented in the research section of the paper.

The models presented in Section 4 are based on data we obtained from the following sources:

- TGE: energy prices on the wholesale market in Poland [58];
- Stooq: EUR/PLN, USD/PLN exchange rates [59];
- Investing: CO_2 prices, coal prices at ARA ports [60];
- Yahoo Finance: gas prices (Dutch TTF Natural Gas) [61];
- ARP: coal prices in Poland (PSCMI1) [62].

The cost-effectiveness of individual energy sources was estimated by calculating the differences between energy prices and variable costs (Figure 1):

1. In the case of coal, it was the so-called clean dark spread (CDS): energy price—CO_2 cost–coal cost.
2. In the case of gas, it was the so-called clean spark spread (CSS): energy price—CO_2 cost–gas cost.

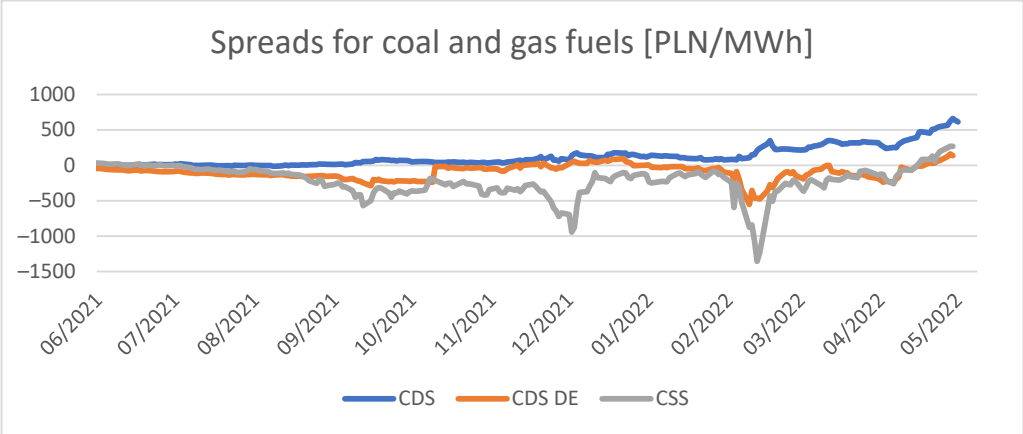

Figure 1. Historical CSS and CDS for Poland and Germany (source: created by authors in 2022).

The only common element in the formulas presented above is the price of energy, which is the same regardless of the source of energy. The cost of CO_2 varies depending on the emission factor of the source:

- For coal, we assumed an emission factor of 0.98;
- For gas, it was 0.35.

As one can observe, this element favors the use of gas fuel, and a further increase in the cost of CO_2 emissions should increase the relative profitability of this energy source. The final component is the price of the fuel itself; in the case of coal, it remains at a constant level (although there are increasingly more frequent ideas to benchmark Polish coal prices

to ARA port prices, which would mean an increase of over 100%), while gas prices at present are five times higher than they were at the start of 2021, which has significantly changed the profitability of this fuel. It is worth mentioning here that in western European countries, which do not have their own hard coal sources and are forced to import this raw material, the profitability of energy production from coal is relatively much lower than in Poland, which is due to prices in ARA ports being two times higher than for Polish coal.

In this article, we prepared three scenarios for the Dolna Odra power plant, which, at present, is under construction, consisting of two gas steam units with a total capacity of 1400 MW. The scenarios differ in the assumed gas and coal prices, while other assumptions are identical for each forecast.

For each scenario, NPV was calculated using the following formula:

$$\mathrm{NPV} = \sum_{t=0}^{n} \frac{\mathrm{CDS}_t - \mathrm{C}_t}{(1 + \mathrm{WACC}_t)^t},$$

where NPV is the sum of cash flows discounted at present, CSS_t is the clean spark spread for a given year, C_t is the sum of expenses in a given year, which consists of CAPEX in the first 2 years of investment and service charges spread over 12 years from the time of the commissioning of the power plant, and WACC is the weighted average cost of capital.

4. Research

The method of calculations proposed by the authors has already been applied in a similar manner in the study of the financial efficiency of coal units [63]; however, considering the purpose of the study, as well as the timeliness of the data used, the authors used a modified version of the calculations.

The authors decided to use the NPV method because it captures all the important factors considered in the proposed model: the assumptions (CAPEX, gas, coal, and CO_2 prices) included in the cash flows and the risks included in the financing structure. Since we can quite accurately estimate how long a gas-fired power plant can operate without a major overhaul, in addition to the chosen forecast period being quite long, the payback period method was not suitable for such an analysis.

The capital expenditures required to construct the units amount to 807 million EUR, of which 437.5 million EUR will be incurred in year zero of the investment, along with 369.5 million EUR in the first year. Additionally, a maintenance agreement for a total amount of 1 billion PLN (217 million EUR) will be in force during the first 12 years of the investment, which means an annual expenditure of 18.1 million EUR. The presented figures are based on PGE's declarations; however, it is worth noting that, in the present reality of high inflation affecting the prices of raw materials, the expenditures for a similar investment could turn out to be much higher.

We assumed that the gas units would operate for 25 years, which seems to be the maximum lifespan for this type of unit (at least without significant upgrades). We assumed a load factor of 40%, which translates into an annual production of approximately 4.91 TWh.

To discount the cash flows, we determined the weighted average cost of the capital (Table 1). We assumed that half of the capital expenditures would be financed by debt, with the other half by equity. As a risk-free rate, we assumed the yield of 10 year Polish treasury bonds at present: the assumed risk premium is 5.5% and the beta coefficient is equal to 1. In addition, we assumed that debt financing would be based on the risk-free rate in addition to a margin of 2 p.p. As a tax rate, we assumed a CIT rate of 19%, applicable in Poland.

For our model gas-fired power plant, we assumed an efficiency of 59%, which translates into a CO_2/kWh emission factor of 0.41. In the case of a hard coal-fired power plant, we distinguished two units—one built under the conditions at present, with an efficiency of 46% and an emission factor of 0.85, and another replicating an old 200 MW unit with an efficiency of 36% and an emission factor of 1.1. In addition, we included an old lignite-fired power plant with an efficiency of 34% and an emission factor of 1.2. We based our energy price forecasts on the merit order functioning in our market, where the energy price is equal

to the marginal variable costs of the most expensive energy producer. In our scenarios, this producer will be a gas- or coal-fired power plant, depending on the prices of both fuels and CO_2 emission allowances.

Table 1. WACC components (source: created by the authors in 2022).

WACC	**9.4%**
Cost of debt	6.9%
Cost of equity	12.0%
Debt share	50%
Equity share	50%
Risk-free rate	6.5%
Debt margin	2.0%
Tax rate	19.0%
Equity risk premium	5.5%
Beta coefficient	1

In our forecast, we assumed an annual growth rate of 2.5% in the price of CO_2 emission allowances.

4.1. Scenario 1: Gas and Coal Prices Remain at Current Levels

In the baseline scenario, the marginal producer in the Polish power system would be a gas-fired power plant, meaning that it would generate zero margins throughout the forecast period; thus, this type of investment would not be able to pay for itself.

The calculation results for Scenario 1 are presented in the Table 2.

Table 2. First scenario (source: created by the authors in 2022).

NPV [mln EUR]	**0**	**1**	**2**	**7**	**12**	**17**	**22**	**23**	**24**	**25**
−891	**2021**	**2022**	**2023**	**2028**	**2033**	**2038**	**2043**	**2044**	**2045**	**2046**
CAPEX [mln EUR]	−437.6	−369.5								
service [mln EUR]			−18.1	−18.1	−18.1					
CDS [mln EUR]			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
cash flow [mln EUR]	−437.6	−369.5	−18.1	−18.1	−18.1	0.0	0.0	0.0	0.0	0.0
discount rate	1.0	0.9	0.8	0.5	0.3	0.2	0.1	0.1	0.1	0.1
discounted cash flow [mln EUR]	−437.6	−337.6	−15.1	−9.6	−6.1	0.0	0.0	0.0	0.0	0.0
load factor			40%	40%	40%	40%	40%	40%	40%	40%
production [TWh]			4.91	4.91	4.91	4.91	4.91	4.91	4.91	4.91
margin [PLN/MWh]			0	0	0	0	0	0	0	0
	2021	2022	2023	2028	2033	2038	2043	2044	2045	2046
energy price [PLN/MWh]	2	368	952	973	998	1025	1057	1063	1070	1077
CO_2 price [EUR/t]	54	85	87	98	111	126	142	146	149	153
	22	22	22	22	22	22	22	22	22	22
hard coal—Poland [PLN/t]	249	290	290	290	290	290	290	290	290	290
hard coal—ARA [USD/t]	121	249	249	249	249	249	249	249	249	249
natural gas—Europe [EUR/MWh]	52	101	101	101	101	101	101	101	101	101
lignite—Poland [PLN/t]		160	160	160	160	160	160	160	160	160
EUR/PLN	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
USD/PLN	3.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
EUR/USD	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Cost per MWh hard coal DE (46%, 0.849) [PLN]	382	680	693	738	788	845	909	923	937	952
Cost per MWh gas DE (59%, 0.41) [PLN]	505	945	952	973	998	1025	1057	1063	1070	1077
Cost per MWh hard coal PL (46%, 0.849) [PLN]	303	431	444	488	539	596	660	674	688	703
Cost per MWh hard coal PL old unit (36%, 1.084) [PLN]	387	550	567	623	688	761	843	861	879	897
Cost per MWh lignite PL old unit (34%, 1.2) [PLN]	385	545	564	628	701	783	875	895	916	937
CDS DE [PLN/MWh]	−13	−48	259	236	210	180	147	140	133	125
CSS [PLN/MWh]	−137	−313	0	0	0	0	0	0	0	0
CDS PL [PLN/MWh]	65	202	508	485	459	430	396	389	382	374
CDS Old Unit PL [PLN/MWh]	−384	−182	385	350	310	265	214	203	191	180
CLS Old Unit PL [PLN/MWh]	−382	−177	388	345	297	243	181	168	154	140

4.2. Scenario 2: Gas and Coal Prices Remain at Current Levels

In the scenario of the return of coal and gas prices by 2019, the relationship between the profitability of power generation from coal and gas would change significantly. A return

of gas prices to several euros per MWh would mean a decrease of over 80% in relation to the prices at present. At the same time, the decrease in coal prices would only be 10%. Moreover, the prices of CO_2 emission allowances in 2019 oscillated around 25 EUR/t, while, at present, their price exceeds 80 EUR/t, which further favors gas over coal power plants. Thus, in our second scenario, the marginal producers are old lignite blocks, whose variable cost is more than twice as high as the variable cost of gas power plants. Moreover, gas-fired units in this scenario also turn out to be significantly more profitable than new-generation coal-fired power plants (with an efficiency of 46%).

The results of the calculations for Scenario 2 are shown in the Table 3.

Table 3. Second scenario (source: created by the authors in 2022).

NPV [mln EUR]	**0**	**1**	**2**	**7**	**12**	**17**	**22**	**23**	**24**	**25**
2370	**2021**	**2022**	**2023**	**2028**	**2033**	**2038**	**2043**	**2044**	**2045**	**2046**
CAPEX [mln EUR]	−437.6	−369.5								
service [mln EUR]			−18.1	−18.1	−18.1					
CDS [mln EUR]			305.6	350.9	402.2	460.2	525.8	539.9	554.3	569.2
cash flow [mln EUR]	−437.6	−369.5	287.5	332.8	384.1	460.2	525.8	539.9	554.3	569.2
discount rate	1.0	0.9	0.8	0.5	0.3	0.2	0.1	0.1	0.1	0.1
discounted cash flow [mln EUR]	−437.6	−337.6	240.0	177.0	130.1	99.3	72.2	67.8	63.6	59.6
load factor			40%	40%	40%	40%	40%	40%	40%	40%
production [TWh]			4.91	4.91	4.91	4.91	4.91	4.91	4.91	4.91
margin [PLN/MWh]			287	329	377	432	493	506	520	534
	2021	2022	2023	2028	2033	2038	2043	2044	2045	2046
energy price [PLN/MWh]	772	368	564	628	701	783	875	895	916	937
CO_2 price [EUR/t]	54	85	87	98	111	126	142	146	149	153
	22	22	24	24	24	24	24	24	24	24
hard coal—Poland [PLN/t]	249	290	290	290	290	290	290	290	290	290
hard coal—ARA [USD/t]	121	249	62	62	62	62	62	62	62	62
natural gas—Europe [EUR/MWh]	52	101	15	15	15	15	15	15	15	15
lignite—Poland [PLN/t]		160	160	160	160	160	160	160	160	160
EUR/PLN	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
USD/PLN	3.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
EUR/USD	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Cost per MWh hard coal DE (46%, 0.849) [PLN]	382	680	428	472	523	580	644	658	672	687
Cost per MWh gas DE (59%, 0.41) [PLN]	505	945	278	299	324	351	382	389	396	403
Cost per MWh hard coal PL (46%, 0.849) [PLN]	303	431	433	477	528	585	649	663	677	692
Cost per MWh hard coal PL old unit (36%, 1.084) [PLN]	387	550	553	610	674	747	829	847	865	884
Cost per MWh lignite PL old unit (34%, 1.2) [PLN]	0	545	564	628	701	783	875	895	916	937
CDS DE [PLN/MWh]	−13	−48	136	156	178	203	231	237	244	250
CSS [PLN/MWh]	−137	−313	287	329	377	432	493	506	520	534
CDS PL [PLN/MWh]	65	202	131	151	173	198	226	232	239	245
CDS Old Unit PL [PLN/MWh]	385	−182	11	19	27	36	46	49	51	53
CLS Old Unit PL [PLN/MWh]	0	−177	0	0	0	0	0	0	0	0

4.3. Scenario 3: Gas Prices Remain at Current Levels, but Polish Coal Prices Are Aligned with ARA Prices

Scenario 3 assumes that Polish coal prices will be equal to ARA prices. In recent years, locally produced coal was more expensive than imported coal, which led mining companies to abandon price formulas based on benchmark prices, i.e., ARA prices; the geopolitical events mentioned in Section 1 have drastically changed the rules, leading to a situation where ARA prices are five times higher than those in Poland. This leads us to wonder whether the price formulas applicable to the Polish market should not be changed again, especially since, in the situation at present, many Polish mines, mainly those associated with PGG, remain unprofitable. We, therefore, decided to include in our forecast an increase in Polish coal prices to ARA levels, which will result in a significant increase in variable costs in coal-fired power plants. Nevertheless, gas-fired power plants will remain a marginal producer in the initial phase. The situation will not begin to turn in their favor until year 11 of the forecast and will become increasingly favorable as time progresses due to rising CO_2 costs, which will place a greater burden on coal-fired generation than on gas-fired generation. However, over the 25 year period of our forecast, the model gas-fired plant will not be able to generate sufficient flows to repay the initial capital expenditure.

The calculation results for Scenario 3 are shown in the Table 4.

Table 4. Third scenario (source: created by the authors in 2022).

NPV [mln EUR]	**0**	**1**	**2**	**7**	**12**	**17**	**22**	**23**	**24**	**25**
−698	**2021**	**2022**	**2023**	**2028**	**2033**	**2038**	**2043**	**2044**	**2045**	**2046**
CAPEX [mln EUR]	−437.6	−369.5								
service [mln EUR]			−18.1	−18.1	−18.1					
CDS [mln EUR]			0.0	0.0	16.9	65.0	119.5	131.3	143.3	155.6
cash flow [mln EUR]	−437.6	−369.5	−18.1	−18.1	−1.2	65.0	119.5	131.3	143.3	155.6
discount rate	1.0	0.9	0.8	0.5	0.3	0.2	0.1	0.1	0.1	0.1
discounted cash flow [mln EUR]	−437.6	−337.6	−15.1	−9.6	−0.4	14.0	16.4	16.5	16.4	16.3
load factor			40%	40%	40%	40%	40%	40%	40%	40%
production [TWh]			4.91	4.91	4.91	4.91	4.91	4.91	4.91	4.91
margin [PLN/MWh]			0	0	16	61	112	123	134	146
	2021	2022	2023	2028	2033	2038	2043	2044	2045	2046
energy price [PLN/MWh]	277	368	952	973	1014	1086	1169	1186	1205	1223
CO_2 price [EUR/t]	54	85	87	98	111	126	142	146	149	153
	22	22	22	22	22	22	22	22	22	22
hard coal—Poland [PLN/t]	249	290	996	996	996	996	996	996	996	996
hard coal—ARA [USD/t]	121	249	249	249	249	249	249	249	249	249
natural gas—Europe [EUR/MWh]	52	101	101	101	101	101	101	101	101	101
lignite—Poland [PLN/t]		160	160	160	160	160	160	160	160	160
EUR/PLN	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
USD/PLN	3.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
EUR/USD	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Cost per MWh hard coal DE (46%, 0.849) [PLN]	382	680	693	738	788	845	909	923	937	952
Cost per MWh gas DE (59%, 0.41) [PLN]	505	945	952	973	998	1025	1057	1063	1070	1077
Cost per MWh hard coal PL (46%, 0.849) [PLN]	303	431	699	743	794	851	915	929	943	958
Cost per MWh hard coal PL old unit (36%, 1.084) [PLN]	387	550	892	949	1014	1086	1169	1186	1205	1223
Cost per MWh lignite PL old unit (34%, 1.2) [PLN]	0	545	564	628	701	783	875	895	916	937
CDS DE [PLN/MWh]	−13	−48	259	236	226	241	259	263	267	271
CSS [PLN/MWh]	−137	−313	0	0	16	61	112	123	134	146
CDS PL [PLN/MWh]	65	202	253	230	220	236	254	257	261	265
CDS Old Unit PL [PLN/MWh]	−110	−182	59	24	0	0	0	0	0	0
CLS Old Unit PL [PLN/MWh]	0	−177	388	345	313	304	293	291	289	286

5. Discussion

The great turmoil occurring in financial markets that the world had to deal with in the last 2 years (2020–2022) had and still has a significant impact on people's daily lives in many countries. Despite the increasing separation of the financial sphere from the real economy, the COVID-19 pandemic and the outbreak of war in Ukraine clearly demonstrated that the relationship between the two spheres remains strong. Supply chain problems associated with lockdowns in China have led to significant price increases for many goods produced in East Asia.

The large government fiscal programs used to bail out temporarily frozen economies present in almost every country in the world led to an increase in demand primarily for durable goods (many service sector industries remained closed at the time). Those circumstances resulted in an even greater mismatch between supply and demand that remained evident even after unblocking most supply chains. This, in turn, encouraged companies to increase production rates, resulting in the increased consumption of many raw materials, both those used in the production process itself and those needed to increase capacities by building new plants or increasing the efficiency of those already in operation.

A significant increase in commodity prices, additionally strengthened by the post-pandemic rebound in the global economy, was already visible in 2021, but it accumulated in early 2022, immediately following the start of the Russia–Ukraine war, which resulted in a real threat of sanctions against Russia, an important exporter not only of oil and gas, but also of many other industrial raw materials, such as coal, copper, aluminum, platinum, gold, silver, and nickel.

The inflationary spiral is particularly visible in Europe, a continent which is heavily dependent on the Russian economy. The first symptoms heralding problems with gas supplies to Europe were visible in 2021, when the price of TTF gas at times exceeded 100 EUR/MW, even though at the beginning of the year prices did not exceed 20 EUR/MW. Some of the largest beneficiaries of this situation were Polish power companies, which generate energy primarily from coal. While in 2020 Poland recorded its highest-ever net

electricity imports (caused by much higher energy prices at home than abroad), in the second half of 2021, it became a net energy exporter for the first time since 2017. In the following months, as the cost of generating energy from gas increased and the cost of energy generating from coal remained relatively stable, the volume of exported energy steadily increased. This allowed Polish power producers to not only increase the amount of energy produced, but to also significantly improve margins, which, in the case of older coal-fired units, were negative until recently (Figure 2).

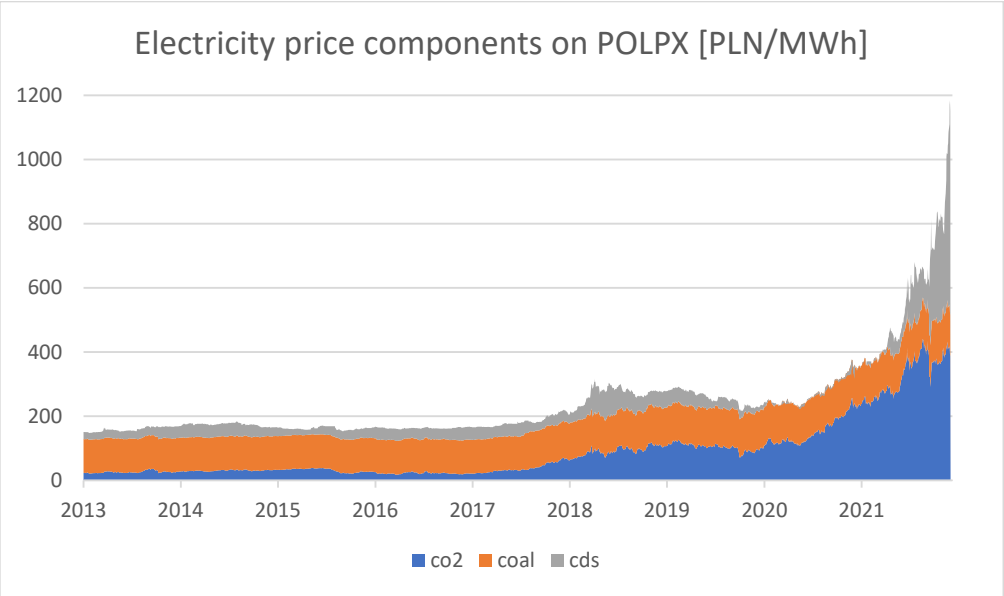

Figure 2. Components of energy prices in Poland (source: created by the authors in 2022).

The favorable situation (from the perspective of power companies) has prevailed. It makes one wonder whether closing coal power plants and replacing them with gas units makes sense in the current geopolitical reality, from both economic and energy security perspectives. While the abandonment of coal for purely financial reasons has been forced in recent years by the EU climate policy and the constantly rising costs of CO_2 emission permits, the issue of energy security has remained marginalized to date.

Considering the abovementioned factors, from the perspective of the situation in which Poland finds itself, the key action is to undertake a wide-ranging discussion of the effects of using gas as a substitute for coal. In addition to the environmental discussion, which unquestionably criticizes the use of gas as a transition fuel, the additional aspects that should be considered are economic and investment aspects. The results of this study mostly indicate that in this field, replacing coal with gas is completely unjustified, as illustrated by the results presented in the next section.

6. Results

Considering the results of the calculations performed in this study, considering certain variables and using the described methodology, one can notice great disparities in the results obtained depending on the scenario adopted.

The first scenario assumes that the macroeconomic and price conditions at present will remain unchanged throughout the forecast period, which means that gas-fired units will be a marginal producer in the Polish merit order; therefore, the investment in a new gas-fired unit will not only be unprofitable, but the ongoing operation of such a unit will also lead to a greater loss than the value of the initial investment (NPV = −891 million EUR vs. the initial investment of 807 million EUR).

The second scenario, which in its assumptions foresees the most optimistic course of events from the point of view of investments in gas fuel as an energy source, i.e., a return

to the conditions at the end of 2019, shows an NPV of approximately 2.37 billion EUR. Throughout the forecast period, the marginal producer is a lignite-fueled unit; at the same time, both new and old coal-fueled units generate lower margins than gas-fueled units. However, it should be noted that this scenario, under the conditions at present, seems unlikely to occur.

The third scenario, which, according to the authors, seems the most likely, assumes that, in the perspective of 2023, Polish coal prices will be equal to ARA prices. In the first 10 years of the forecast, gas-fired power plants are the marginal producer; however, starting from 2032, old hard-coal units become marginal producers. This change is due to steadily increasing CO_2 emission prices, which favor gas over coal. Similar to Scenario 1, Scenario 3 shows a negative NPV of −698 million EUR. It should be emphasized that this value is less than the initial investment, which indicates that positive cash flows will appear in the forecast period, i.e., starting from 2034. If the dynamics of growth of CO_2 emission prices are higher than the value of 2.5% p.a. assumed by the authors, the NPV of this scenario would be appropriately higher. We estimate the breakeven point at 4.94% per year.

7. Conclusions

Many western European countries are, at present, at a very advanced stage of shutting down coal plants (and nuclear plants, in the case of Germany), and they often have no possibility to fire them up again. Therefore, they have condemned the less stable renewable energy sources and gas fuel, which is now historically expensive and may soon need to be imported from even further destinations than at present.

At present, Poland is facing a completely different situation. The coal phase-out process has not even begun, and the plans to close coal mines and coal-fired power plants have been treated very flexibly at this stage. Poland is the largest coal producer in the EU, and domestic coal production can meet the needs of the commercial power sector (although it should be noted the coal used for the heating sector, the industrial sector, and households is largely exported, and it would be difficult to replace with domestic production). From the energy security point of view, it was and is beneficial for Poland to continue to use this fuel. At present, it has also become economically advantageous. However, given a series of geopolitical turbulent events, one can imagine a scenario of a return to the pre-Ukrainian war regime, when Polish coal-fired power plants appeared to be permanently unprofitable.

In this article, we analyzed the factors affecting the profitability of gas-fired power plants compared to the profitability of coal-fired power plants. We answered the question of whether, in the current geopolitical reality, the decommissioning of coal-fired units in favor of building new gas-fired units may prove to be economically viable.

The results of the conducted analyses indicated that, under the macroeconomic and geopolitical conditions at present, the construction of new gas units in CEE seems unprofitable from economic and energy security perspectives, bringing in as much as 84 million EUR in losses, assuming an initial investment of 807 million EUR. The results of the study also indicate certain changes in the situation at present, which the authors believe are the most likely to occur, and investments in gas-fired power generation could result in a negative net present value of −698 million EUR. Only a change in the circumstances to one that corresponds to the situation before the occurrence of numerous and significant international events (2019) can produce a positive NPV of 2.37 billion EUR. It should be recognized that this is an unlikely scenario. Because of the abovementioned factors, as well as the relation of gas fuel to the environment, this places a question mark on the event of a mass transition to gas as a transition fuel for the zero-emission power industry.

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